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Standard Guide for Planning and Conducting Geotechnical Borehole Geophysical Logging[1]

This standard is issued under the fixed designation D5753; 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~~ Scope*

~~1.1 This guide covers the documentation and general procedures necessary to plan and conduct a geophysical log program as commonly applied to geologic, engineering, groundwater, and environmental (hereafter referred to as geotechnical) investigations. It is not intended to describe the specific or standard procedures for running each type of geophysical log and is limited to measurements in a single borehole. It is anticipated that standard guides will be developed for specific methods subsequent to this guide.~~

~~1.2 Surface or shallow-depth nuclear gages for measuring water content or soil density (that is, those typically thought of as construction quality assurance devices), measurements while drilling (MWD), cone penetrometer tests, and logging for petroleum or minerals are excluded.~~

~~1.3 Borehole geophysical techniques yield direct and indirect measurements with depth of the (*1*) physical and chemical properties of the rock matrix and fluid around the borehole, (*2*) fluid contained in the borehole, and (*3*) construction of the borehole.~~

1.1 ~~To obtain detailed information on operating methods, publications (for example, **1**, **2**, **3**, **4**, **5**, **6**, **7**, **8**, and **9**)[2] should be consulted. A limited amount of tutorial information is provided, but other publications listed herein, including a glossary of terms and general texts on the subject, should be consulted for more complete background information.~~ *Purpose and Application:*

1.1.1 This guide covers the documentation and general procedures necessary to plan and conduct a geophysical borehole logging program as commonly applied to geologic, engineering, groundwater, and environmental (hereafter referred to as geotechnical) site characterizations.

1.1.2 This guide applies to commonly used logging methods (see Tables 1 and 2) for geotechnical site characterizations.

1.1.3 This guide provides an overview of the following:

(1) the uses of single borehole geophysical methods,

(2) general logging procedures,

(3) documentation,

(4) calibration, and

(5) factors that can affect the quality of borehole geophysical logs and their subsequent interpretation. Log interpretation is very important, but specific methods are too diverse to be described in this guide.

1.1.4 Logging procedures must be adapted to meet the needs of a wide range of applications and stated in general terms so that flexibility or innovation are not suppressed.

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~~1.5 This guide provides an overview of the following: (*1*) the uses of single borehole geophysical methods, (*2*) general logging procedures, (*3*) documentation, (*4*) calibration, and (*5*) factors that can affect the quality of borehole geophysical logs and their subsequent interpretation. Log interpretation is very important, but specific methods are too diverse to be described in this guide.~~

~~1.6 Logging procedures must be adapted to meet the needs of a wide range of applications and stated in general terms so that flexibility or innovation are not suppressed.~~

[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.

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

*A Summary of Changes section appears at the end of this standard

TABLE 1 Common Geophysical Logs

Type of Log (References)	Varieties and Related Techniques	Properties Measured	Required Hole Conditions	Other Limitations	Typical Measuring Units and Calibration or Standardization	Brief Probe Description
Spontaneous potential **(7, 8, 12)**	differential	electric potential caused by salinity differences in borehole and interstitial fluids, streaming potentials	uncased hole filled with conductive fluid	salinity difference needed between borehole fluid and interstitial fluids; needs correction for other than NaCl fluids	mV; calibrated power supply	records natural voltages between electrode in well and another at surface
Single-point resistance **(7)**	conventional, differential	resistance of rock, saturating fluid, and borehole fluid	uncased hole filled with conductive fluid	not quantitative; hole diameter effects are significant	Ω; V-Ω meter	constant current applied across lead electrode in well and another at surface of well
~~Multi-electrode resistivity **(7, 8, 13)**~~	~~various normal focused, guard, lateral arrays~~	~~resistivity and saturating fluids~~	~~uncased hole filled with conductive fluid~~	~~reverses or provides incorrect values and thickness in thin beds~~	~~Ω-m; resistors across electrodes~~	~~current and potential electrodes in probe and remote current and potential electrodes~~
Multi-electrode resistivity **(7, 8, 13)**	various normal focused, guard, lateral arrays	resistivity and saturating fluids	uncased hole filled with conductive fluid	reverses or provides incorrect values and thickness in thin beds	Ω-m; resistors across electrodes	current and potential electrodes in probe
Induction **(10, 11)**	various coil spacings	conductivity or resistivity of rock and saturating fluids	uncased hole or nonconductive casing; air or fluid filled	not suitable for high resistivities	mS or Ω-m; standard dry air zero check or conductive ring	transmitting coil(s) induce eddy currents in formation; receiving coil(s) measures induced voltage from secondary magnetic field
Gamma **(5, 7, 22)**	gamma spectral **(44)**	gamma radiation from natural or artificial radioisotopes	any hole conditions	may be problem with very large hole, or several strings of casing and cement	pulses per second or API units; gamma source	scintillation crystal and photomultiplier tube measure gamma radiation
Gamma-gamma **(23, 24)**	compensated (dual detector)	electron density	optimum results in uncased hole; can be calibrated for casing	severe hole-diameter effects; difficulty measuring formation density through casing or drill stem	gs/cm^3; Al, Mg, or Lucite blocks	scintillation crystal(s) shielded from radioactive source measure Compton scattered gamma
Neutron **(7, 14, 25)**	epithermal, thermal, compensated sidewall, activation, pulsed	hydrogen content	optimum results in uncased hole; can be calibrated for casing	hole diameter and chemical effects	pulses/s or API units; calibration pit or plastic sleeve	crystal(s) or gas-filled tube(s) shielded from radioactive neutron source
Acoustic velocity **(5, 26, 27)**	compensated, waveform, cement bond	compressional wave velocity or transit time, or compressional wave amplitude	fluid filled, uncased, except cement bond	does not detect secondary porosity; cement bond and wave form require expert analysis	velocity units, for example, ft/s or m/s or μs/ft; steel pipe	1 or more transmitters and 2 or more receivers
~~Acoustic televiewer (28, 7)~~	~~acoustic caliper~~	~~acoustic reflectivity of borehole wall~~	~~fluid filled, 3 to 16-in. diameter; problems in deviated holes~~	~~heavy mud or mud cake attenuate signal; very slow logging speed~~	~~orientated image-magnetometer must be checked~~	~~rotating transducer sends and receives high-frequency pulses~~
Acoustic televiewer **(28, 7)**	acoustic caliper	acoustic reflectivity of borehole wall	fluid filled, 3 to 16-in. diameter; problems in deviated holes	heavy mud or mud cake attenuate signal; slow logging speed	oriented image, 3 axis-magnetometer , 3 axis-accelerometer	rotating transducer sends and receives high-frequency pulses
Optical televiewer **(28, 7)**		optical reflectivity of borehole wall	air or clear water filled, uncased 3 to 16-in. diameter; possible problems in highly deviated holes	cannot use in mud, slow logging speed	oriented image, 3 axis-magnetometer , 3 axis-accelerometer	digital camera with hyperboloidal mirror images unwrapped borehole wall
~~Borehole video~~	~~axial or side view (radial)~~	~~visual image on tape~~	~~air or clean water; clean borehole wall~~	~~may need special cable~~	~~NA[A]~~	~~video camera and light source~~
Borehole video	axial or side view (radial), discontinuities, voids	visual image on tape	air or clean water; clean borehole wall	may need special cable	NA[A]	video camera and light source
~~Caliper (29, 7)~~	~~oriented, 4-arm high-resolution, *x-y* or max-min bow spring~~	~~borehole or casing diameter~~	~~any conditions~~	~~deviated holes limit some types; significant resolution difference between tools~~	~~distance units, for example, in.; jig with holes or rings~~	~~1 to 4 retractable arms contact borehole wall~~
Caliper **(29, 7)**	oriented, 4-arm high-resolution, *x-y* or max-min bow spring	borehole or casing diameter, borehole breakouts	any conditions	deviated holes limit some types; significant resolution difference between tools	distance units, for example, in.; jig with holes or rings	1 to 4 retractable arms contact borehole wall
Temperature **(30, 31, 32)**	differential	temperature of fluid near sensor	fluid filled	large variation in accuracy and resolution of tools	°C or °F; ice bath or constant temperature bath	thermistor or solid-state sensor

Type of Log (References)	Varieties and Related Techniques	Properties Measured	Required Hole Conditions	Other Limitations	Typical Measuring Units and Calibration or Standardization	Brief Probe Description
Fluid conductivity **(7)**	fluid resistivity	most measure resistivity of fluid in hole	fluid filled	accuracy varies, requires temperature correction	μS/cm or Ω-m; conductivity cell	ring electrodes in a tube
Flow **(12, 33, 7)**	impellers, heat pulse	vertical velocity of fluid column	fluid filled	impellers require higher velocities. Needs to be centralized.	velocity units, for example, ft/min; lab flow column or log in casing	rotating impellers; thermistors detect heated water; other sensors measure tagged fluid.
Deviation **(4, 7, 47)**	magnetic, gyroscopic, or mechanical	horizontal and vertical displacement of borehole	any conditions (see limitations)	magnetic methods orientation not valid in steel casing	degrees and depth units; orientation and inclination must be checked	various techniques to measure inclination and bearing of borehole

[A] NA = not applicable.

~~1.7 *This standard does not purport to address all of the safety and liability concerns, if any, (for example, lost or lodged probes and radioactive sources[3]) 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.*~~

1.2 ~~*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 judgment. 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.*~~*Limitations:*

1.2.1 This guide is not meant to describe the specific or standard procedures for running each type of geophysical log, and is limited to measurements in a single borehole.

1.2.2 Surface or shallow-depth nuclear gages for measuring water content or soil density (that is, those typically thought of as construction quality assurance devices), measurements while drilling (MWD), cone penetrometer tests, and logging for petroleum or minerals are excluded.

1.2.3 *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 judgment. 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.*

1.3 *Precautions:*

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

1.5 *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.*

TABLE 2 Log Selection Chart for Geotechnical Applications Using Common Geophysical Borehole Logs[A]

Information Desired	Acoustic: Acoustic Televiewer	Acoustic: Acoustic Velocity, Δt, CBL, VDL, FWS	Electric and Induction: Induced Polarization	Electric and Induction: Multi-electrode Resistivity, Normal, Lateral, Micro Guard Resistivity	Electric and Induction: Single-Point Resistance	Electric and Induction: Spontaneous Potential	Electric and Induction: Induction (Conductivity)	Fluid Logs: Flow Meter	Fluid Logs: Fluid Resistivity	Fluid Logs: Fluid Sampler	Fluid Logs: Temperature, Differential Temperature	Radioactive or Nuclear: Gamma-Gamma Density	Radioactive or Nuclear: Gamma	Radioactive or Nuclear: Neutron	Radioactive or Nuclear: Spectral Gamma	Other Methods: Borehole Video	Other Methods: Caliper	Other Methods: Deviation
Lithology and Correlation																		
Bed/aquifer thickness; correlation, structure	●	●		●	●	●	★					Δ	✓	Δ	✓	◇	✓	
Lithology—depositional environment	?	●		●	●	●	★					Δ	✓	Δ	✓	◇	✓	
Shale or clay content			●	●		●	★					Δ	✓	Δ	✓			
Bulk density												Δ						
Formation resistivity				●			★											
Injection/production profiles				?			?	□	□		□	Δ		Δ				
Permeability estimates		●						□	□		□		✓					
Porosity (amount and type)	●	●		●			★					Δ		Δ				
Mineral identification			●									Δ			✓			
Potassium-uranium thorium content (KUT)															✓			
Rock Mass Parameters																		
Strike and dip of bedding	●															◇		✓
Fracture detection (number of fractures), RQD	●	●		●	●											◇	✓	
Fracture orientation and character	●															◇		✓
Thin bed resolution	●			?	●											◇	✓	
In situ stress data	●	●														◇	◇	
Fluid Parameters																		
Borehole fluid characteristics								?	□	□	□							
Fluid flow						●		□	□		□					◇		
Formation water quality				●		●	★			□								
Moisture content—water saturation				?			?					Δ		Δ				
Temperature		?									□							
Water level and water table	●	●		●	●	●	?		□		□	Δ		Δ		◇		
Borehole Parameters																		
Casing evaluation integrity, leaks, damage, screen location	■	■					?	■			■					◆	✓	
Deviation of borehole																		✓
Diameter of borehole	●																✓	
Examination behind casing		●					★					Δ		Δ				
Location of debris in wells	●															◆	✓	
Well completion evaluation, for example, cement bond, seal location, grout location	?	■					★					Δ	✓	Δ				

[A] Required hole conditions: ■ = cased fluid-filled hole, ✓ = clear fluid or dry cased hole, □ = screened or open fluid-filled hole, ◇ = clear fluid or dry open hole, ◆ = steel casing only, Δ = active nuclear log to be run in stable holes, ★ = open or nonconductive cased holes, dry or fluid filled, ✓ = no restrictions, ● = open fluid-filled hole only, and ? = possible applications.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

[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.

D5088 Practice for Decontamination of Field Equipment Used at Waste Sites
D5608 Practices for Decontamination of Sampling and Non Sample Contacting Equipment Used at Low Level Radioactive Waste Sites

3. Terminology

3.1 *Definitions*—Definitions shall be in accordance with For definitions of common technical terms used in this standard, refer to Terminology D653.

3.2 *Descriptions of Terms Specific to This Standard*—Terms shall be in accordance with Ref (**10**).

4. Summary of Guide

4.1 This guide applies to borehole geophysical techniques that are commonly used in geotechnical investigations. site characterizations. This guide briefly describes the significance and use, apparatus, calibration and standardization, procedures and reports for planning and conducting borehole geophysical logging. These techniques are described briefly in Table 1 and their applications in Table 2.[4]

4.2 Many other logging techniques and applications are described in the textbooks in the reference list. There are a number of logging techniques with potential geotechnical applications that are either still in the developmental stage or have limited commercial availability. Some of these techniques and a reference on each are as follows: buried electrode direct current resistivity (**11**), deeply penetrating electromagnetic techniques (**12**), gravimeter (**13**), magnetic susceptibility (**14**), magnetometer, nuclear activation (**15**), dielectric constant (**16**), radar (**17**), deeply penetrating seismic (**13**), electrical polarizability (**18**), sequential fluid conductivity (**19**), and diameter (**20**). Many of the guidelines described in this guide also apply to the use of these newer techniques that are still in the research phase. Accepted practices should be followed at the present time for these techniques.

5. Significance and Use

5.1 An appropriately developed, documented, and executed guide is essential for the proper collection and application of borehole geophysical logs.

5.2 Borehole geophysical techniques yield direct and indirect measurements with depth of the (*1*) physical, lithologic, mechanical, stresses, hydrologic, discontinuities, and chemical properties of the rock matrix and/or fluid around the borehole, (*2*) fluid contained in the borehole, and (*3*) construction of the borehole.

5.3 An appropriately developed, documented, and executed guide is essential for the proper collection and application of borehole geophysical logs.The benefits of its use include improving the following:

5.3.1 Selection of logging methods and equipment,

5.3.2 Log quality and reliability, and

5.3.3 The benefits of its use include improving the following:Usefulness of the log data for subsequent display and interpretation.

5.1.1.1 Selection of logging methods and equipment,

5.1.1.2 Log quality and reliability, and

5.1.1.3 Usefulness of the log data for subsequent display and interpretation.

5.1.2 This guide applies to commonly used logging methods (see Table 1 and Table 2) for geotechnical investigations.

5.1.3 It is essential that personnel (see 7.3.3) consult up-to-date textbooks and reports on each of the logging techniques, applications, and interpretation methods. A partial list of selected publications is given at the end of this guide.

5.1.4 This guide is not meant to describe the specific or standard procedures for running each type of geophysical log and is limited to measurements in a single borehole.

6. Apparatus

6.1 *Geophysical Logging System,System:* including probes, cable, draw works, depth measurement system, interfaces and surface controls, and digital and analog recording equipment.

6.1.1 Logging probes, also called sondes or tools, enclose the sensors, sources, electronics for transmitting and receiving signals, and power supplies.

6.1.2 Logging cable routinely carries signals to and from the logging probe and supports the weight of the probe.

6.1.3 *Draw Works*—The draw works move Moves the logging cable and probe up and down the borehole and provide the connection with the interfaces and surface controls.

6.1.4 TheA depth measurement system system, which provides probe depth information for the interfaces and surface controls and recording systems.

[4] The references indicated in these tables should be consulted for detailed information on each of these techniques and applications.

6.1.5 ~~The surface~~ Surface interfaces and controls that provide some or all of the following: electrical connection, signal conditioning, power, and data transmission between the recording system and probe.

6.1.6 ~~The recording~~ Recording system includes the digital recorder and an analog display or hard copy device.

6.2 Special cases for probes containing any controlled substances.

6.3 Special badges and/or clothing for working with equipment containing any controlled substances.

7. Calibration and Standardization of Geophysical Logs

7.1 *General:*

7.1.1 National Institute of Standards and Technology (NIST) calibration and operating procedures do not exist for the borehole geophysical logging industry. However, calibration or standardization physical models are available (see Appendix X1).

7.1.2 Geophysical logs can be used in a qualitative (for example, comparative) or quantitative manner, depending on the project objectives. (For example, a gamma-gamma log can be used to indicate that one rock is more or less dense than another, or it can be expressed in density units.)

7.1.3 The calibration and standardization scope and frequency shall be sufficient for project objectives.

7.1.3.1 Calibration or standardization should be performed each time a logging probe is modified or repaired or at periodic intervals.

7.2 *Calibration:*

7.2.1 Calibration is the process of establishing values for log response. It can be accomplished with a representative physical model or laboratory analysis of representative samples. Calibration data values related to the physical properties (for example, porosity) may be recorded in units (for example, pulses/s or µm/ft) that can be converted to apparent porosity units.

7.2.1.1 At least three, and preferably more, values are needed to establish a calibration curve, and the interface or contact between different values in the model should be recorded. Because of the variability in subsurface conditions, many more values are needed if sample analyses are used for calibration.

7.2.1.2 The statistical scatter in regression of core analysis against geophysical log values may be caused by the difference between the sample size and geophysical volume of investigation and may not represent measurement error.

7.2.2 *Physical Models*—A representative model simulates the chemical and physical composition of the rock and fluids to be measured.

7.2.2.1 Physical models include calibration pits, coils, resistors, rings, temperature baths, etc.

7.2.2.2 The calibration of nuclear probes should be performed in a physical model that is nearly infinite with respect to probe response.

7.2.2.3 Some probes have internal devices such as resistors, but this does not substitute for checking the probe response in an environment that simulates borehole conditions, and the use of such devices is considered standardization.

7.2.2.4 *Calibration Facilities*—Commonly used calibration pits or models for use by anyone at the present time are listed in Appendix X1 (**21-4**). The user should inquire concerning the present validity of any ~~facility.~~ facility and identify any new or alternative facilities.

7.2.3 *Sample Analyses:*

7.2.3.1 Representative samples from boreholes in the project area that have been collected carefully and analyzed quantitatively also may be used to calibrate log response.

7.2.3.2 To reduce depth errors, the sample recovery of rock cores in calibration holes needs to approach 100 % for the intervals used for calibration. Log response should be used to select sample depths to span the range of desired log calibration values and to be within thick units to minimize the effects of potential depth errors. Samples need to be analyzed immediately or steps taken to preserve them for later analysis.

7.2.3.3 Samples to be used for log calibration should be analyzed only from depth intervals at which the log response is relatively uniform for a depth interval considerably greater than the vertical dimension of the volume of investigation of the logging probe. Samples near lithologic contacts or fluid interfaces should not be used because of possible boundary effects or depth errors.

7.3 *Standardization:*

7.3.1 Standardization is the process of checking the log response to reveal evidence of repeatability and consistency.

7.3.2 Standardization is needed to establish comparability between logs made with different equipment or at different times and to ensure the accuracy of measurements.

7.3.2.1 Standardization checks should include at least two different measurement values approximating the range of interest (For example, aluminum and magnesium or plastic blocks are used commonly to check the response of gamma-gamma density logging systems in the field.)

7.3.3 Standardization uses some type of a standard that may be used in the field or laboratory and repeat logs.

7.3.3.1 Log response needs to be checked using field standards often enough to satisfy the project objectives. Standardization of the log response provides the basis for correcting for changes (for example, changes in output with time due to system drift or changes of equipment).