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Standard Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations[1]

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1. Scope*

1.1 This guide covers guidance for the selection of soil and rock sampling devices used with drill rigs for the purpose of characterizing in situ physical and hydraulic properties, chemical characteristics, subsurface lithology, stratigraphy and structure, and hydrogeologic units in environmental investigations.

1.2 This guide does not specifically address selection of soil sampling devices for use with direct-push sampling systems, but the information in this guide on thick-wall and thin-wall samplers is generally applicable to direct-push soil sampling.

1.3 This guide should be used in conjunction with referenced ASTM guides, practices, and methods on drilling techniques for geoenvironmental investigations and use of sampling devices referenced in 2.1, and with Guide D5730.

1.4 This guide does not address selection of sampling devices for hand-held soil sampling equipment, and soil sample collection with solid-stem augering devices, or collection of grab samples or hand-carved block samples from accessible excavations. Refer to Appendix X1.2 for guidance on these topics. This guide should be used in conjunction with Guide D4700 when thin-walled, split barrel, ring-lined barrel and piston samplers with solid- and hollow-stem augers are used in the unsaturated zone.

1.5 This guide does not address devices for collecting cores from submerged sediments or sampling devices for solid wastes. Refer to Guide D4823 for guidance on these topics.

1.6 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.7 *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.*

1.8 *This guide offers an organized collection of information or series of options and does not recommend a specific course of action. This document cannot replace education and experience and should be used in conjunction with professional judgment. The word "Standard" in the title of this document means that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D1452 Practice for Soil Exploration and Sampling by Auger Borings
D1586 Test Method for Penetration Test (SPT) and Split-Barrel Sampling of Soils
D1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes
D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration
D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
D3694 Practices for Preparation of Sample Containers and for Preservation of Organic Constituents
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220 Practices for Preserving and Transporting Soil Samples
D4452 Practice for X-Ray Radiography of Soil Samples
D4700 Guide for Soil Sampling from the Vadose Zone
D4823 Guide for Core Sampling Submerged, Unconsolidated Sediments

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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.

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

D5079 Practices for Preserving and Transporting Rock Core Samples
D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter
D5088 Practice for Decontamination of Field Equipment Used at Waste Sites
D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock
D5730 Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Groundwater (Withdrawn 2013)[3]
D5781 Guide for Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5782 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5783 Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5784 Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5872 Guide for Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D5875 Guide for Use of Cable-Tool Drilling and Sampling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D5876 Guide for Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D5911 Practice for Minimum Set of Data Elements to Identify a Soil Sampling Site
D6151 Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling

3. Terminology

3.1 *Definitions*—For definitions of general technical terms used within this guide, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *borehole grab sampler*—a sampling device with a cutting head that advances by rotation and collects a sample by scraping side or bottom rather than coring. (See Section 8.1.)

3.2.2 *chemically intact core sample*—a soil or rock core sample in which the sampling device, collection and handling procedures result in preservation of the chemical properties to a degree that satisfies the purpose for which the sample was taken.

3.2.2.1 *Discussion*—For nonsensitive chemical constituents, representative samples will generally provide chemically intact samples. Nonrepresentative samples may also be chemically intact, but are generally not suitable for analysis because of their uncertain integrity, location or origin. For sensitive chemical constituents, special sample collection and handling procedures are generally required to obtain chemically intact samples as discussed in 6.4 and 6.10. Physically intact samples will generally provide chemically intact samples provided that sampling technique, and materials for sampling devices and containers are selected to avoid chemical alteration.

3.2.3 *clearance ratio (inside)*—the difference between inside diameter of the sampling tube and inside diameter of cutting edge or shoe divided by the inside diameter of the cutting shoe or edge.

3.2.3.1 *Discussion*—Refer to Hvorslev (**1**)[4] and Paikowsky et al. (**2**) for appropriate formulas for calculating wall area ratio.

3.2.4 *core—for the purposes of this guide*, a cylindrical sample of soil or rock obtained by means of a thick-wall, thin-wall, or rotating core sampler.

3.2.5 *direct push sampling system—for the purposes of this guide*, a subsurface sampling system using samplers generally 50 mm [2 in.] in diameter or less that use hand-held percussion driving devices, or mobile hydraulic, vibratory or percussion drive systems that are mounted to a small truck, van, all-terrain vehicle (ATV), trailer, skid, or drill rig.

3.2.6 *drill rig—for the purposes of this guide*, a land-based wheeled, ATV, or skid-mounted assembly or offshore or barge mounted assembly capable of drilling boreholes and collecting soil or rock samples with a diameter generally greater than 50 mm [2 in.] using rotary, drive, push, or vibratory advancement methods.

3.2.7 *drill-rod core sampling*—a sampling process in which a fixed drill rod assembly advances a thick-wall or thin-wall sampler or a rotating drill rod assembly advances a rotating core samplers.

3.2.8 *group A*—samples for which only general visual identification is necessary (see Practices D4220).

3.2.9 *group B*—samples for which only water content and classification tests, optimum dry density or relative density, or profile logging is required and bulk samples that will be remolded or compacted into specimens for swell pressure, percent swell, consolidation, permeability, shear testing, CBR, stabilimeter, etc. (see Practices D4220).

3.2.9.1 *Discussion*—Group B samples are disturbed, remolded samples used primarily for engineering properties tests.

3.2.10 *group C*—intact, natural formed or field fabricated, samples for density determination; or for swell pressure, percent swell, consolidation, permeability testing and shear testing with or without stress-strain and volume change measurements, to include dynamic and cyclic testing (see Practices D4220).

3.2.10.1 *Discussion*—Group C samples are intact samples used primarily for engineering properties tests. Some of these

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

[4] The boldface numbers given in parentheses refer to a list of references at the end of the text.

tests, such as bulk density and permeability are useful for environmental investigations. Additional physical and hydrologic properties that require Group C type samples are identified in Table 1.

3.2.11 *group D*—samples that are fragile or highly sensitive for which tests in Group C are required (see Practices D4220).

3.2.12 *intact sample*—a soil sample that has been obtained by methods in which every precaution has been taken to minimize disturbance to the sample (see Terminology D653). (See also definitions for *chemically intact sample* and *physically intact sample*.)

3.2.13 *liner*—cylindrical tubes or rings made of metal or plastic placed inside a core sampling device to facilitate sample retrieval and handling.

3.2.14 *nonrepresentative sample*—a soil sample that consists of drill cuttings of uncertain integrity, location or origin, or other incomplete or contaminated portions of subsurface materials; generally not suitable for testing or analysis (**3**).

3.2.15 *physically intact core sample*—a soil or rock core sample in which the sampling device, collection and handling procedures result in preservation of the in situ physical and hydraulic properties (such as, structure, density, and moisture content) to a degree that satisfies the purpose for which the sample was taken.

3.2.15.1 *Discussion*—Group C and D core samples are physically intact. Generally collection of intact samples require use of thin-wall or double-tube rotating core sampling devices, but as discussed in 6.2, thick-wall samplers may be satisfactory for some objectives.

3.2.16 *piston core sampler*—a thin-wall or, less commonly, thick-wall sampling device in which the inner piston is held in a fixed position and the cutting head and outer barrel is advanced mechanically or hydraulically into the soil. (See 7.5.)

3.2.17 *representative soil sample*—a soil sample from a known subsurface interval in which some structural features do not survive but other properties, such as moisture content, grain size and gradation and chemical characteristics of the sample interval are preserved; suitable for mechanical and chemical analysis for nonsensitive chemical constituents, and lithologic logging. (See discussion in 6.3.) **Adapted from U.S. Geological Survey, 1980**

3.2.17.1 *Discussion*—This definition follows general usage in the geologic profession, and differs from the definition of representative sample in the statistical sense. The sample is only representative of the subsurface material encountered by the sampler and is not necessarily representative of the formation being sampled. Sample representativeness in the latter sense needs to be addressed in the sample design that defines the specific location of sampling.

3.2.18 *rotating core sampler*—a rotating cylindrical sampler with a coring bit that cuts away soil or rock material from around the core. (See 7.6.)

3.2.19 *sensitive chemical constituents*—chemical species or compounds for which the composition or concentration in soil may change rapidly in soil in response to disturbance, or interaction with sample container materials, due to processes such as volatilization, degassing, microbial action or abiotic oxidation-reduction reactions.

3.2.20 *thick-wall sampler*—a core sampler that does not satisfy the requirements for collection of intact Group C and D samples.

3.2.20.1 *Discussion*—Generally, samplers with a wall area ratio greater than 15 % (see Table 2 for additional specifications). Typical thick wall samplers are found in Test Method D1586 and Practice D3550. (See 7.3.)

3.2.21 *thin-wall sampler*—a sampler that meets the specifications in Practice D1587. (See 7.4.)

3.2.22 *vibratory core sampling*—a sample process in which a thick-wall or thin-wall sampler is advanced using high frequency vibrations rather than hydraulic or percussion forces.

3.2.23 *wall area ratio*—the ratio of gross wall area due to thickness divided by the inside opening of the sampler.

3.2.23.1 *Discussion*—Refer to Hvorslev (**1**) and Paikowsky et al. (**2**) for appropriate formulas for calculating wall area ratio.

TABLE 1 General Sample-Type Requirements for Measurement of Physical and Chemical Properties

Tests to be Performed	Physically Intact	Chemically Intact	Representative
Physical/Hydrologic Properties			
Hydraulic Conductivity	X	. . .	. . .
Specific Yield	X	. . .	. . .
Pressure Head (Matric Potential)	X	. . .	. . .
Moisture Characteristic Functions[A]	X	. . .	X
Water Content	. . .	. . .	X
Particle Size Distribution	. . .	. . .	X
Bulk Density/Porosity	X	. . .	. . .
Strength Properties	X	. . .	. . .
Compressibility	X	. . .	. . .
Mineralogy			
Gross Mineralogy	. . .	. . .	X
Soil Thin Section Micromorphology	X	. . .	. . .
Surface Properties			
Ion Exchange Capacity	. . .	X	. . .
Sorption (Batch Tests)	. . .	X	. . .
Sorption (Flow-Through Tests)	X	. . .	. . .
Sorption Site Density	. . .	X	. . .
Surface Area	. . .	. . .	X
Nonsensitive Chemical Constituents[B]			
Most Total Elemental Concentrations	. . .	. . .	X
Carbonate	. . .	. . .	X
Soil Organic Carbon	. . .	. . .	X
Sensitive Chemical Constituents[C]			
Microbiology	. . .	X	. . .
Volatile and Semivolatile Organics	. . .	X	. . .
Nitrogen- and Sulfur-Containing Species	. . .	X	. . .
Redox-Sensitive Species (As, Cr, Fe, Mn, Se)	. . .	X	. . .
Other Sensitive Inorganics (Hg, cyanides)	. . .	X	. . .

[A] Physically intact sample preferred, but repacked representative sample may be adequate.
[B] Chemical constituents that are sufficiently stable that no special attention need to be given to sample device/container compatibility, or sample handling, transport, and storage if analyzed within a few months.
[C] Special consideration of sample device/container compatibility, sample collection, handling and transport required to obtain chemically intact samples.

TABLE 2 General Sampler Specifications Defining Intact Samples For Group C and D Samples[A]

Sampler Characteristics	Intact (Thin-Wall sampler)[B]	Disturbed[C] (Thick-Wall sampler)	Source
Wall thickness/OD ratio	< 2.5 %	> 2.5 %	Hvorslev **(1)**
Wall area ratio	< 15 %	> 15 %	Hvorslev **(1)** and Paikowsky et al. **(2)**
Clearance ratio (inside)			Shuter and Teasdale **(4)** and Practice D1587. See also Table 7.
Nonplastic soils	0.5 to 1 %	NA	
Intermediate plasticity	1 to 2 %	NA	
Plastic soils (clays)	2 to 3 %	NA	
Length			Practice D1587
Sands	< 10 diameters	> 10 diameters	
Clays	< 15 diameters	> 15 diameters	
Diameter			Shuter and Teasdale **(4)**
Compressible soils	> 76.2 mm [3 in.]	< 76.2 mm [3 in.]	
Less compressible soils	> 50.8 mm[D] [2 in.]	< 50.8 mm[D] [2 in.]	

[A] Group C samples include samples for the following geotechnical tests: density, percent swell, consolidation, permeability testing and shear testing with or without stress-strain and volume change measurements. Group D samples are fragile or highly sensitive for which test in Group C are required. Group C samples collected for environmental testing purposes would include laboratory measurement of hydraulic conductivity, and flow-through core tests for sorption and leachability.
[B] Thin-wall samplers cannot get intact samples of all soil materials. For denser soils, Pitcher (see 7.7.2) or Denison samplers (see 7.7.3) may be required.
[C] Samples collected with thick-wall samplers may qualify as intact samples for the purpose of description of in situ morphologic properties provided that visual indicators discussed 6.2 indicate minimal disturbance (see Table 3), and for the purpose of chemical characterization.
[D] 50.8 mm [2-in.] samples for Group C samples for engineering tests are not recommended.

3.2.24 *wireline core sampling*—a sampling process in which rotating or pushed core samplers are raised and lowered inside drill rods with a wireline and attached for coring or pushing with an overshot latching mechanism.

4. Significance and Use

4.1 Direct observation of the subsurface by the collection of soil and rock samples is an essential part of site characterization for environmental purposes (see 7.1.7 of Guide D5730). This guide provides information on the major types of soil and rock sampling devices used on drill rigs to assist in selection of devices that are suitable for known site geologic conditions, and provide samples that meet project objectives. This guide should not be used as a substitute for consulting with someone experienced in sampling soil or rock in similar formations before determining the best method and type of sampling.

4.2 This guide should be used in conjunction with Guides D2113 and D6151 and drilling method-specific guides (see Guides D5781, D5782, D5783, D5784, D5872, D5875 and D5876) as part of developing a detailed site investigation and sampling plan (see 5.1.5 of Guide D5730) for sites that require mobilization of a drill rig for subsurface investigations. The selection of drilling methods and sampling devices goes hand-in-hand. In some cases soil sample requirements may influence choice of drilling method, or conversely, types of available drill rigs may influence choice of sampling devices.

4.3 This guide should be used in conjunction with Guide D5434 for field logging of soil and rock samples, Practice D5911 for data elements to identify a soil sampling site, and where appropriate, Practice D4220, for preserving and transporting soil samples, Practice D5079 for preserving and transporting rock core samples, Practice D3694 for preparation of sample containers and for preservation of organic constituents, and Practice D5088 for decontamination of field equipment used at waste sites.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

5. Objectives of Sampling Soil and Rock

5.1 Samples of soil and rock can be collected for three major purposes in environmental investigations: measurement of in situ physical and hydraulic properties, measurement of in situ chemical and biological characteristics, and identification of geologic and hydrogeologic characteristics of the subsurface. Table 1 identifies general sample-type requirements for measurement of physical, hydrologic and chemical properties of the subsurface. Most coring devices (see Section 7) provide good to excellent samples for all three purposes. Borehole grab samplers and drill cuttings (see Section 8) are unsuitable for measurement of in situ physical and hydrologic properties. Depending on the specific drilling method, borehole grab samples or cuttings may provide adequate information of geologic and hydrogeologic properties of the subsurface.

5.2 *In Situ Physical and Hydraulic Properties*—Laboratory measurements of physical properties, such as bulk density, porosity, consolidation of clays, and thin-section analysis of sediments, and hydraulic properties, such as specific yield and hydraulic conductivity require intact cores that retain the in situ properties of the sample. Bulk density and porosity are the parameters requiring intact samples that are most significant in environmental investigations because of their significance in vadose zone and groundwater modeling. Hydraulic properties of permeable materials are generally best measured using aquifer tests (see Table A1.1 of Guide D5730, for list of ASTM standards on aquifer tests), but collection of intact samples for laboratory permeameter tests may provide useful information on vertical changes in hydraulic properties. Impermeable materials, such as clays, are generally best measured in the laboratory using intact cores (see Test Method D5084). However, it should be recognized that laboratory measurements generally do not consider preferential flow or secondary porosity effects which can significantly affect the field permeability of a material. Section 6.1 discusses criteria for evaluating degree of sample disturbance. Table 1 lists parameters that require intact samples.

5.3 *Chemical and Biological Characteristics*—Samples for measurement of stable chemical constituents generally do not require physically intact samples, but do require representative samples. Samples for measurement of sensitive chemical constituents, such as volatile organic compounds, require physically intact samples that minimize sample degassing from compression or expansion. Whenever chemical analysis of samples is an objective of the investigation, sampling devices that result in chemical alteration should be avoided. Chemical alteration is most problematic with devices in which drilling fluids come in direct contact with the sample and when sensitive constituents such as volatile organic chemicals and redox sensitive elements (iron, manganese, arsenic, chromium, selenium), or microorganisms below the water table are to be sampled. In contaminated soil and groundwater, casing advancement methods should be used to prevent cross-contamination of samples. Sampling for such constituents requires use of samplers and sampling procedures that avoid or minimize contact with drilling fluids, the atmosphere, other contaminated soil or groundwater, and sample containers made of nonreactive materials (see 6.4 and 6.10). Intact samples are preferred when column leaching or sorption tests are to be performed in the laboratory, although representative disturbed samples can be used in unstructured soil materials if the bulk density is known. Table 1 identifies types of samples required for specific chemical and biological properties.

5.4 *Geologic and Hydrogeologic Properties*—Samples for geologic properties, such as lithology, stratigraphy, and structure should generally be representative, but nonrepresentative samples combined with observations of drilling advancement rates may provide some information on changes in lithology if it is not feasible to collect representative samples (see 8.3). Intact samples are required for adequate characterization of fractures in dense unconsolidated material and rock. The quality of definition of hydrogeologic units will be a function of the quality of lithologic, stratigraphic, and structural interpretations supplemented by water level data and aquifer tests.

6. Specific Criteria for Selection of Sampling Devices

6.1 When the specific objectives of sample collection have been defined (see 4.2), the applicable criteria described below should be identified and the sampling device or devices that will best fulfill the sampling objectives selected for use. When a sampling device has been selected, at least two should be procured, along with appropriate spare parts. Two samplers may be used in alternation if this enhances efficiency of field operations and sample collection, or the second sampler serves as a backup in the event the first one becomes damaged.

6.2 *Sample Physical Disturbance*—The degree of physical disturbance of a soil or rock sample is primarily a concern when in situ physical and hydraulic properties are to be measured. Historically, geotechnical investigators have placed more emphasis on collection of physically intact soil samples than environmental investigators because measurement of many engineering properties requires such samples, whereas alternative methods to permeameter tests (that is, single and multi-well aquifer tests) are available for measuring hydraulic parameters (see 5.2). However, the degree of disturbance also affects the quality of borehole log descriptions and subsequent interpretations. Disturbed soil cores allow logging of primarily textural and density/consistency changes. Intact soil cores allow description of soil morphologic features that are valuable for developing interpretations concerning the potential for contaminant movement in the subsurface (**5**). Collection of oriented intact rock cores allow assessment of fracture location and orientation in the subsurface (see 7.9.4).

6.2.1 *Definition of Physically Intact*—The use of the term "intact" to describe a soil or rock sample always has to be qualified because the sampling process inevitably results in some degree of disturbance as a result of factors such as stress relief or dilation or compression from insertion. Samples collected using a thin-wall sampler provide the least disturbed core samples in soft soils, yet Practice D1587 uses the term "relatively intact" to characterize samples taken with a thin-wall tube sample. The factors that affect physical sample disturbance are numerous and complex enough that professional judgment is still required to determine whether a sample is physically intact. Framing that determination in the context of the objective of the sample (see 3.2.15) makes it easier to make a positive or negative determination using the criteria discussed below, provided that the sampling objectives have been clearly defined prior to collection.

NOTE 2—Reference (**3**) defines intact sample as follows: essentially an in-place specimen in which features such as structure, density, and moisture content are preserved; suitable for most engineering testing and analysis. Rehm et al. (**6**) give a similar definition as samples in which "the physical and chemical properties of the sample have been altered little from the original in situ condition during the collection process." Davis et al. (**7**) define intact samples as "very high quality samples taken under strictly controlled conditions in order to minimize structural disturbance of the sample". The definition of intact sample in this guide (see 3.2.15) adds precision to the above definitions by relating the term to the objective for which the sample is collected.

6.2.2 *Affect of Sampling Device on Degree of Physical Disturbance*—The following three general characteristics of samplers affect the degree of physical disturbance of the sample: increasing wall thickness increases disturbance, increasing tube diameter decreases disturbance, and increasing tube length increases disturbance. The same sampler may cause different degrees of disturbance, depending on the material being sampled, with highly plastic and compressible soils and well sorted noncohesive sands being most susceptible to disturbance. Driving the same sampler can disturb a sample more than pushing the sampler. Thin-wall samplers (see 7.4) generally provide the highest quality cores in terms of minimizing sample disturbance in fine-grained cohesive materials. Piston samplers (see 7.5) may be required for collecting cores in cohesionless materials, with thin-wall types creating less disturbance than thick-wall types). Rotary core samplers, such as the Denison sampler (see 7.6.2), or vibratory/sonic sampling methods (see 7.2.4) may be required to collect intact samples in firm to stiff cohesive soils and dense sands. Depending on the sampler and soil material, thick-wall samplers may also be satisfactory for measurement of in situ physical and hydraulic properties (see 6.2.3). Shuter and Teasdale **(4)** and most of the geotechnical references identified in the appendix provide further discussion of considerations and techniques for collecting intact cores.

6.2.3 *Criteria for Evaluating Degree of Physical Disturbance in Push and Drive Samples*—Table 2 identifies the main sampler characteristics that determine whether a sample is physically intact for Group C and D samples as defined in Practice D4220. Although the definition of these groups has a primarily geotechnical focus, intact samples for hydrogeologic analysis and testing have the same requirements (Refer to Shuter and Teasdale **(4)** for a detailed discussion of requirements for intact soil samples for hydrogeologic analysis and testing). Group C and D samples will also provide high quality samples for visual logging of soil morphologic and sedimentary features that are sensitive to disturbance by thick-wall samplers. Table 3 gives a number of indicators that can be used to evaluate the degree of disturbance in core collected using a thick-wall sampler. X-ray radiography (see Practice D4452) may also be useful for evaluating the quality of Group C and D cores.

6.2.4 *When to Collect Physically Intact Soil Samples*—Intact physical soil samples in cohesionless soils (sands and gravels) are generally more costly in time and money than disturbed samples, and in environmental investigations the decision to obtain intact samples should be based on a judgment that the added information obtained from intact cores outweighs the added costs. Drill cuttings or auger-flight samples are inadequate for most environmental investigations, so the question will generally be framed in terms of whether disturbed core thick-wall samples or thin-wall/rotating core sampling devices should be used. Examples of when high-quality intact samples (Group C and D) in environmental investigations might be appropriate for environmental investigations include: determination of laboratory hydraulic conductivity and porosity for calibration of geophysical logs in an area, thin section examination of sediments for mineralogy and microstructural features, engineering properties for fill/cut slope stability, slurry walls and backfill design for design of waste disposal facilities and remediation of contaminated soil and groundwater, collection of spatially oriented cores to establish strike and dip of formation layering and evaluate potential contaminant pathways in joint and fracture systems (see 7.9.4).

6.3 *Sample Representativeness*—Soil samples from a known subsurface interval that do not preserve in situ structural properties, but for which other physical properties such as water content and particle size distribution or chemistry, or combination thereof, are unaltered, are representative samples. Requirements for obtaining physically and chemically representative samples may differ. For example, Group B soil samples as defined in Practice D4220 are physically representative, but may not be chemically representative if the sampling technique, sampling device or containers result in chemical alteration of the sample. Disturbed samples collected using thin-wall and thick-wall samplers usually give representative samples for physical analysis. However, when drilling methods involve drilling fluids, sample moisture content and chemistry may be altered. Borehole grab samples and drill cuttings may be representative if the sample collection method allows precise determination of the sample interval, measures are taken to prevent mixing of material from other intervals, and the drilling method does not alter sample characteristics (see 8.4).

6.4 *Sample Chemical Integrity*—Soil samples collected for chemical analysis usually do not need to preserve in situ structural characteristics of the sample but must be representative of the sampled interval. Relatively stable chemical properties, such as mineralogy, organic matter content (excluding recent organic residue) and many inorganic constituents can be collected using any device that gives a representative sample. Sensitive chemical constituents, such as redox-sensitive metals, volatile organic chemicals, and other organic chemicals that are subject to biodegradation may require collection of intact or relatively intact samples using stainless

TABLE 3 Indicators of Degree of Core Disturbance in Driven Samples[A]

Indicator	Intact/Less Disturbed	More Disturbed/Disturbed
Advancement Method	Pushed	Driven
Core Recovery	Core length = sample interval	Core length < or > sample interval
Soil morphology/sedimentary structures[A]	No or little observable deformation	Moderate to extensively deformed
Core length (indicator of expansion or compaction)[B]	Length of core equal to sampled interval	Length of core > or < sampled interval
Partings at intervals equal to the distance of each drive impact (driven samples only)	Absent	Weakly to strongly evident
Practice D1586 blow count (N)[C]	N <20	N >20
Core shoe (soil with course fragments)	No visible damage to cutting shoe	Cutting shoe nicked or bent
Gravel fragments or large roots in core	No evidence of grooving along core	Core has been grooved by rock or root fragments inside the core
Borehole condition	Cased or stable borehole with no caving	Unstable, uncased borehole
Drilling fluid	Not used	Drilling fluid coats core top, bottom and sidewalls

[A] Based on visual observation of split cores or X-ray radiography using Test Method D4452.
[B] Also indicator for pushed thin-wall samples.
[C] A standard 50.8-mm [2-in.] thin-wall sampler will often collapse in soils with N values of 30 or greater **(8)**.

steel or brass liners or clear plastic (typically Lexan[5]) liners that are immediately sealed for transport or special coring, paring, or subcoring devices that allow rapid placement or transfer of samples into containers for onsite analysis or preservation and transport to a laboratory. Key considerations in sampling sensitive chemical constituents is that the sampling device and sample handling procedures minimize contact of the sample with the atmosphere and losses or transformation during sample handling, transport, and analysis. Lewis et al. (**9**) and Turriff and Klopp (**10**) describe special sampling devices, preservation and handling procedures for minimizing loss of volatile constituents from soil samples. Chapelle (**11**) and Leach et al. (**12**) describe procedures and equipment for collecting soil samples that preserve anaerobic, reducing conditions. Some sampler materials or linter materials may be incompatible or possibly interfere with analysis of some chemical parameters. For example, stainless steel samplers or liners generally should not be used when chromium is one of the primary analytes of interest. Also, many plastic liners may absorb some of the volatile organic compounds commonly tested for during environmental investigations, resulting in biased data. Selecting the appropriate sample and liner materials before beginning field work is recommended to prevent down time and possibly the need to resample. Also, failure to follow proper equipment decontamination procedures, such as described in Practice D5088, may result in cross contamination of soil samples.

6.5 *Nature of Geologic Materials*—The type of geologic material to be sampled is a primary consideration in selection of sampling devices, and the ease or difficulty in obtaining an intact sample. Table 4 provides some general ratings on suitability of core sampling devices for different geologic materials. In geotechnical investigations soils are often classified as cohesive (clays) and cohesionless (silt, sand and gravel), with the basic types differentiated based on density or consistency (**13**). Table 5 provides criteria used to define density/consistency classes based on *N* values for standard penetration test (see Practice D1586) and unconfined compressive strength. Saturation increases the difficulty in sampling of all unconsolidated materials, but especially sands. Cohesionless well graded sands and sensitive, soft, low plasticity clays and silts pose the greatest difficulties for collection of intact samples. Where only representative samples are required, retainers may improve sample recovery, especially in cohesionless soils. If other methods fail in clean sand, vibratory/sonic or freezing followed by rotary coring may be required to obtain intact samples of cohesionless sediments (see 7.9.3). In very dense unconsolidated materials (stiff to hard clays, glacial tills), specially designed rotary core samplers such as the Denison and Pitcher sampler, or a large-diameter rotary core may be required (see 7.6).

6.6 *Drill Rig Characteristics*—All drill rigs do not have the same capabilities. Site geologic conditions and sampling needs should be well enough defined beforehand that a rig capable of deploying the full range of appropriate sampling and backup tools are selected. Procedures for collecting core samples using some drilling methods such as cable tool and solid stem auger

[5] Lexan is a registered trademark for SABIC Innovative Plastics, Riyadh, Saudi Arabia.

TABLE 4 Suitability of Core Sampling Devices for Different Geologic Materials[A]

NOTE 1—Key: Ratings: E = excellent; G = good; F = fair; P = poor; NA = not applicable. Other: FD = face discharge; RBD = recessed bottom discharge.

Sampler Type	Soil/Unconsolidated Material[B]						Rock[C]	
	Fine-Grained		Coarse, Cohesive		Cohesionless[D]		Soft	Hard
	Soft-Stiff	Stiff-Hard	Sand	Gravel	Loose	Dense		
Drive/Push Samplers								
Thick-Wall	E-G	G-P	E-G	F-P	F-P	G-P	NA	NA
Thin-Wall	E	F-P	G-F	NA	F-P	P	NA	NA
Piston[E]	E	F-P	G-F	NA	E-P	P	NA	NA
Rotating Soil Core Samplers								
Hollow-Stem Auger	G-F	E-G	E-G	F-P	F-P	G-P	NA	NA
Pitcher	G-F	E-G	E-G	G-P	G-P	E-P	NA	NA
Denison[F]	G-F	E-G	E-G	G-P	F-P	G-P	NA	NA
Rotating Rock Core Samplers[G]								
Single Tube, FD	NA	NA	NA	NA	NA	NA	F-P	E-P
Double Tube RBD	P	P	NA	F-P[H]	NA	G-P	E	E
Triple Tube	P	P	NA	P	NA	G-P	E	E

[A] Ratings are for general guidance only. Performance of specific sampling devices can vary depending on the type of drill rig, diameter of the sampler and nature of the geologic material.
[B] Refer to Table 5 to density/consistency terminology.
[C] Soft rock includes shales, siltstone, and weakly cemented sandstone. Hard rock includes limestone, dolomite, and most igneous and metamorphic rocks.
[D] Loose cohesionless soils are difficult to recover with most drive/push sampling devices unless retainers are used, especially when saturated. Materials in this category include saturated sensitive clays, silts and sands, sensitive organic silts, soft clays, unsaturated loose sands and silty sands. Very dense soil material is also difficult to penetrate with most drive/push sampling devices. Examples of dense materials would include compact tills and weakly cemented soil/rock.
[E] Numerous types of piston samplers have been developed, but only a few are commercially available; many are effective in sampling saturated, cohesive soils, but have varying effectiveness for sampling cohesionless soils.
[F] Denison sampler ratings are for soil sampling configuration with inner barrel advanced ahead of outer rotating core barrel. In the rock coring configuration ratings are same as for double tube RBD sampler.
[G] Numerous types of single- and double-tube rotating core samplers are available, with specific designs and cutting heads selected based on rock hardness and degree of jointing and fracturing.
[H] Only if gravels are very dense or cemented.

TABLE 5 Soil Terminology Related to Sample Device Selection[A]

Basic Soil Types	Density or Consistency	Range of Standard Penetration Resistance[B]	Range of Unconfined Compressive Strength[C]
Cohesionless	Very loose	Less than 4	Not applicable
	Loose	4 to 10	Not applicable
	Medium dense	10 to 30	Not Applicable
	Dense	30 to 50	Not applicable
	Very dense	Greater than 50	Not Applicable
Cohesive	Very soft	Less than 2	Less than 0.25 kg/cm^2
	Soft	2 to 4	0.25 to 0.5
	Medium stiff	4 to 8	0.5 to 1.0
	Stiff	8 to 15	1.0 to 2.0
	Very stiff	15 to 30	2.0 to 4.0
	Hard	Greater than 30	Greater than 4.0

[A] Source: Adapted from USACE **(13)**.
[B] N value (numbers of blows to advance standard split barrel 0.3 m [1 ft] using Practice D1586.
[C] Kg/cm^2 = tons/ft^2. Unconfined compressive strength (q_u) may also be approximated using a pocket penetrometer or Torvane shear apparatus.

are relatively cumbersome compared to hollow-stem augers and rotary drilling methods. Hollow-stem augers and rotary drilling methods (with and without casing advancement) are generally flexible in the types of sampling devices that can be used. Where deep holes are to be sampled, wireline sampling capabilities should be considered (see 7.2.2). Most drill rigs with rotary advancement capabilities allow use of rotating core samplers. Triple Tube Core Barrels are similar to a double tube core barrel, but have an additional inner liner consisting of either a clear plastic tube or a thin metal split tube, in which the core is retained. This core barrel best preserves fractured and poor quality rock cores.

NOTE 3—Refer to Shuter and Teasdale (**4**) for a description of coring procedures using cable tool and solid stem augers.

6.7 *Sample Continuity*—Continuous coring provides the highest quality samples for lithologic logging of boreholes, but generally takes more time and consequently is more expensive than intermittent sampling. Hollow stem auger continuous coring systems (see 7.6.3) vibratory/sonic coring, and conventional and wireline coring systems are commonly used ways for collecting continuous cores. The most appropriate time for collection of continuous cores is often during early stages of environmental investigations, but continuous coring may also be useful when defining the extent and pathways of a contaminant plume. Both discrete and continuous sampling may be appropriate in the same borehole. For example, when investigating a contaminant plume downgradient of the source area, discrete sampling may be adequate above the zone of contamination, while continuous coring may be desirable through the contaminated zone. If the same cores are used for both logging and testing, the full core should be described first. Most drilling methods provide the option of taking continuous or intermittent core samples. For investigations in relatively shallow unconsolidated material direct push systems allow continuous coring. Conventional single-tube rotary diamond drilling (see Practices D2113, and D6151) and vibratory/sonic coring provide continuous cores in bedrock materials. If continuous cores are desired when using a hollow-stem auger, a continuous barrel sampler that advances with the auger as described in Guide D4700 and Practice D6151 will generally be most efficient. This system essentially functions as a double-tube rotating core sampler with the auger representing the outer tube and is able to collect high quality cores even though the sampler construction does not meet the requirements of a thin-wall sampler. Continuous cores can also be obtained using appropriate rotating core samplers with a rotary drill rig.

6.8 *Sampler Materials*—Stainless steel is generally the preferred material for sampler construction when sampling for inorganic and organic chemical contaminants, unless liners are used. Other metals may be acceptable for chemical sampling provided that there is no likelihood of chemical interaction between the soil material and the metal that would affect analytes of interest. Use of liners of the appropriate material minimize contact of soil samples with the sampling device (see 6.9.3).

6.9 *Liners*—Liners facilitate sample handling and storage. Key considerations in the selection of liners include type (split or solid) and liner materials.

6.9.1 Split liners are recommended for use when logging and sampling for nonsensitive chemical constituents is being done in the field. Split liners allow for easy handling and inspection of samples. Most samplers with exception of the thin-wall tube can be designed to accommodate split liners.

6.9.2 Solid liners are often used when samples must be preserved for later laboratory analysis or stored for later logging. When samples are being preserved for physical testing they should be sealed and stored using methods in Practice D4220 for shipment to the laboratory. When samples are being collected for environmental chemical analysis they should be preserved, stored, and transported using the procedures appropriate for the analytes of concern. This can be accomplished by following Practice D3694 for preparation of sample containers and for preservation of organic constituents or other appropriate procedures specified by the client or regulatory authority. Examples of samplers with solid liners include ring-lined sampler (see 7.5.1), pitcher (see 7.6.1), Denison (see 7.6.2), and rock core barrels (see 7.7). A thin-wall tube functions as a liner if the ends are to be sealed for shipment. Sealing of liners should normally be performed by trimming away loose soil and inserting moisture proof plugs or by cutting the liner flush to the soil and capping the ends with moisture-proof material. Liners should be strong enough to support the core during shipment. Liners should be round and matched to the tolerances of the sampler. The best tolerance is achieved when the core fits in the liner without an air gap, but also without excessive core friction. If the core is over cut by a clearance ratio that is too large, oxidation and biological growths may occur with sustained storage.

6.9.3 *Liner Materials*—With split liners, the core is exposed to the material for short periods of time, so the material of manufacture is not as critical for chemical interactions. Since solid liners will be stored for a period of time, the material of manufacture for the liner is important for potential chemical interactions. Laboratory tests should be scheduled and promptly performed to minimize storage time. In general, the rule of thumb for selecting solid liner materials is metal for organic chemical compounds and plastics for metals chemical analysis. Metal liners are frequently made of steel or brass, but can be made of aluminum or other metals. Stainless steel liners are difficult to machine and cut open and are more expensive. Stainless steel could be selected for samples to be extruded in the laboratory. All steel liners rust to some extent with time, so iron oxides will be present. Coating materials for steel (zinc oxides or lacquers) are not effective at preventing rust in soils containing sands and gravels because the grains scratch through the material, but they may be effective in clay soils. Aluminum liners will oxidize, but the tendency is to develop a thin protective coating as opposed to iron which can be more mobile in the samples. Plastic liners are normally PVC or acrylics. Chemically inert materials such as Teflon should only be required for highly reactive mixed wastes. Plastic liners tend to have high moisture transmission, making them unsuitable for transporting samples for water content determinations.

6.10 *Prevention of Cross Contamination*—Open thin-wall and thick-wall samplers may cause cross-contamination of soil samples by including material from a higher interval. Casing advancement methods (including continuous sampling with a hollow-stem auger and double-tube vibratory/sonic drilling), or stable boreholes where the drilling method has a larger diameter than the sampler help minimize cross-contamination of sample from above the water table. Temporary seals for the barrel shoe that are pushed aside when the sampler enters the soil interval being sampled will prevent contact of the inside of the sampler with contaminated soil, soil gas or groundwater as it advances through an open borehole. When open thin-wall and thick-wall samplers are lowered through contaminated groundwater before collecting a sample, cross-contamination of deeper uncontaminated soil samples may occur either as a result of contaminated groundwater entering the open tube as it is lowered or by contact with the contaminated groundwater as the soil sample is pulled to the surface. Piston samplers results in less cross-contamination than open thin-wall and thick-wall samples both above and below a water table. Piston samplers used below the water table in contaminated aquifers should have good seals (O-rings or leather packing) to prevent water from entering the sampler before it is in position.

6.11 *Experience and Skill of Driller/Sampler*—Sampling equipment, even when appropriate for the type of materials and type of sample desired, can be damaged or fail, or sample integrity compromised if the personnel collecting the sample are inexperienced, or use inappropriate procedures or methods. Conversely, skilled personnel may be able to obtain adequate samples using equipment that may not be optimal for the material being sampled.

7. Core Sampling Devices

7.1 This guide classifies core sampling devices into four major categories thick-wall samplers (see 7.3), thin-wall samplers (see 7.4), rotating soil core samplers (see 7.6), and rotating rock core samplers (see 7.7). Piston samplers are a special type of thick-wall or thin-wall samplers in which the sampler is held in a fixed position and the cutting head is advanced mechanically or hydraulically into the soil (see 7.5). Thick-wall samplers can in turn be broadly classified as solid or split barrel. Rotating core samplers are broadly classified as single-tube and double-tube. Table 6 summarizes general characteristics of these samplers (available advancement methods and availability of liners). Many specific sampler designs have been developed and adapted over the years. Names applied to the same sampling device may vary regionally and the same name may be applied to entirely different sampling devices. When evaluating a specific sampler, specification drawings or the sampler itself should be examined to determine its type. Section 7.8 discusses some specialized samplers.

7.2 *Sampler Advancement Methods*—Method of advancement is an important consideration when selecting a sampling device. Four major methods for advancing samplers are push, drive, rotation, and vibration.

7.2.1 *Push Soil Sampling*—Push sampling involves application of sufficient steady force to overcome soil resistance so that the sampler advances in a continuous motion. Push samplers are usually hydraulically driven but mechanical application using sufficient weight to advance the sampler is also possible. Push sampling is the method most commonly used for thin-wall samplers, but thick-wall samplers may also be advanced this way in soft materials. Push advancement results in the least disturbance of most soil materials and is the most common method used to obtain intact core samples in soft materials. Highly plastic and compressible soil materials such as wet clays and organic silts are susceptible to disturbance even with push sampling. Push advancement is often not feasible in gravelly and very dense soil materials.

7.2.2 *Drive Soil Sampling*—Drive sampling advances the sampler by a series of discrete blows to the drill rods to which the sampler is attached. The standard weight drive assembly defined in Practice D1586 consists of a 63.5-kg [140-lb] weight, a driving head and a guide permitting a free fall of 0.76 m [30 in.] and is required whenever a standard penetration test is being conducted. Use of drive assembly that depart from this standard may be acceptable for environmental investigations (see Note 4). Thick-wall samplers are most commonly used with drive sampling, but thin-wall samplers can be driven in materials that are too dense for push advancement provided that the driving force does not damage the sampler (generally up to $N = 30$). An advantage of drive sampling is that the blow count (number of blows required to advance the sampler 305 mm [1.0 ft] or fraction thereof with 100 blows) is a useful

TABLE 6 Classification and Examples of Core Sampling Devices

Sampler Type	Advancement Method						Liner
	Drive	Push	Rotate	Vibrate	Drill Rod	Wire-line	
Thick-Wall Samplers							
Solid	X	X	. . .	X	X	X	X
Split	X	X	. . .	. . .	X	X	X
Piston	X	X	. . .	. . .	X	X (rare)	X
Thin-Wall Samplers							
Standard	X	X	. . .	X	X	. . .	X
Piston	. . .	X	. . .	. . .	X	. . .	X
Rotating Soil and Rock Core							
Single Tube	. . .	. . .	X	. . .	X	X	X
Double Tube	. . .	X	X	. . .	X	X	X
Triple Tube	. . .	X	X	. . .	X	X	X

indicator of variations in lithology and density. Drive samples are almost always disturbed and not suitable for Group C and D samples.

NOTE 4—The standard penetration test in Test Method D1586 was developed primarily to determine penetration resistance (*N*) of soils for engineering purposes. If N values are not essential for the purposes of an geoenvironmental investigations, modifications to Test Method D1586 may be desirable to obtain samples. Such modifications may include use of different size barrels, sample retainers, washing-in the sampler through caved materials, and use of different drive rods and hammer weights (**4**).

7.2.3 *Rotation Sampling*—Rotating core sampling advances the sampler by cutting soil or rock material away from around the core using a circular cutting shoe. Advantages and disadvantages of rotating core sampling are discussed further in 7.6.

7.2.4 *Vibratory/Sonic Sampling*—Vibratory/sonic drilling methods use variable frequency vibrations in some cases coupled with hydraulic force or rotation to advance a thin-wall or thick wall sampler into the ground, followed by an outer casing which maintains the borehole wall, prevents cross contamination and allows for the installation of monitoring wells and various borehole testing devices. Vibratory core sampling is a well established technique for sampling submerged sediments (see Guide D4823). Although the basic technology for sonic or vibratory soil and rock sampling was developed in the 1950s, relatively recent improvement in design, application, and reliability make it an attractive drilling method for environmental investigations (**14, 15, 16**). Sonic/vibratory drilling is an effective method of collecting continuous or intermittent large or small diameter core samples in all types of soil and rock, including thick unconsolidated gravel formations with cobbles and boulders, and saturated sand and gravel below water table. Rock core samples that require use of air or water to remove cuttings, can be collected to depths in excess of 150 m [500 ft] in most bedrock formations. Continuous cores can be taken in increments of 0.3 through 6 m [1 through 20 ft] or longer. In a drilling mode, vibratory/sonic rigs cause disturbance of soil material, as a result of material being pushed outward into the borehole wall or inward into the core barrel, depending upon the formation, sampling criteria and bit face design. Such samples are representative of the formation and many structure features survive, especially at the center portion of the core sample. The degree of sample disturbance can be reduced by reducing vibration frequency, reducing or eliminating rotation, and use of thinner wall sample barrels and bits or cutting shoes that are tapered outward. Intact soil samples can be collected by pausing drilling and using a thin-wall sampler to collect a core in advance of the cutting head of the outer casing.

NOTE 5—Most soil sampling using vibratory drilling methods involves use of specially designed drill rigs which can be converted for many other types of drilling and sampling methods, such as: hydraulic thin-wall samples, hydraulic and/or vibratory advancement of thick-wall samplers, hydraulic piston samplers, air hammer, air rotary drilling, wireline hard rock core drilling, tri-cone rotary drilling, dual was reverse air drilling, and a dual wall casing advancement system using reverse air with vibrations and rotation. With the appropriate equipment, sonic/vibratory rigs can also perform standard penetration tests. A direct push system has been developed that uses vibration to collect small-diameter cores in unconsolidated material (**17**).

7.2.5 *Drill-Rod Versus Wireline Sampling*—For shallow investigations (generally less than 45 m [150 ft]) sampling devices are most commonly attached to a sufficient number of drill rods to place the sample at the bottom of the hole. Once the sampler has been advanced a distance equal to the sampler length, it is retrieved by pulling and disassembling the drill rods. As the depth of the hole increases, the amount of time required to pull and replace the drill rod assembly increases. In wireline sampling, an inner barrel is raised and lowered inside drill rods with a wireline and attached to the outer rotating casing/rod bit with an overshot latching mechanism (see Fig. 1). Wireline soil push-core systems are also available, in which a spring provides the tension to keep a thin-wall tube some 150 mm [6 in.] in front of the rotating bit. If an obstruction is encountered the spring retracts to allow the bit to drill through or displace the obstruction, similar to a pitcher sampler (see 7.6.1). Retrieval and reinsertion of a sampler with a wireline system is faster than using a drill-rod assembly. The main disadvantage of wireline systems is that the coring devices are more complex than conventional thick-wall and thin-wall samplers and hence are more expensive. Use of wireline systems to sample sands below the water table may require special drilling techniques and extra care in managing drilling fluids to prevent jamming of the latching mechanism by sand in the water column. The depth at which wireline core sampling becomes more cost effective than drill-rod sampling typically ranges between 15 m [50 ft] to 45 m [150 ft].

7.3 *Thick-Wall Samplers*—A thick-wall sampler is any type of open tube or, less commonly, piston sampler that is advanced by push, drive or vibratory methods, where the wall thickness or wall area to outer diameter ratio, inner clearance ratio, length exceed specifications for a thin-wall sampler (see Table 2 and Table 7). Samples collected with thick-wall generally do not qualify as physically intact core samples.

7.3.1 *Types of Thick-Wall Samplers*—The most common types of thick-wall samplers are the split barrel, also called split spoon and ring-lined barrel, also called California barrel. The less common solid thick-wall samplers are either open-tube or piston-type (discussed in 7.5). Table 6 summarizes information on methods of advancement for thick-wall samplers. The diameter of thick-wall samplers used with drill rigs typically ranges from 37.5 to 75 mm [1.5 to 3 in.], but larger diameters up to 125 mm [5 in.] are possible. Fig. 2 shows the specifications for a split-barrel sampler (also called split-spoon sampler) used for the standard penetration test in Practice D1586. Thick-wall samplers can be used with liners, and a ring-lined barrel sampler used without a thin-walled extension falls in this category (see Fig. 3). Refer to Practice D3550 for procedures using this sampler.

7.3.2 *Applications*—See 7.5 for applications of piston samplers.

7.3.2.1 Collection of representative samples from cohesive sands, silts and clays for textural analysis and analysis of chemical constituents.

7.3.2.2 Assessing engineering properties using standard penetration test (see Practice D1586).

7.3.3 *Limitations:*

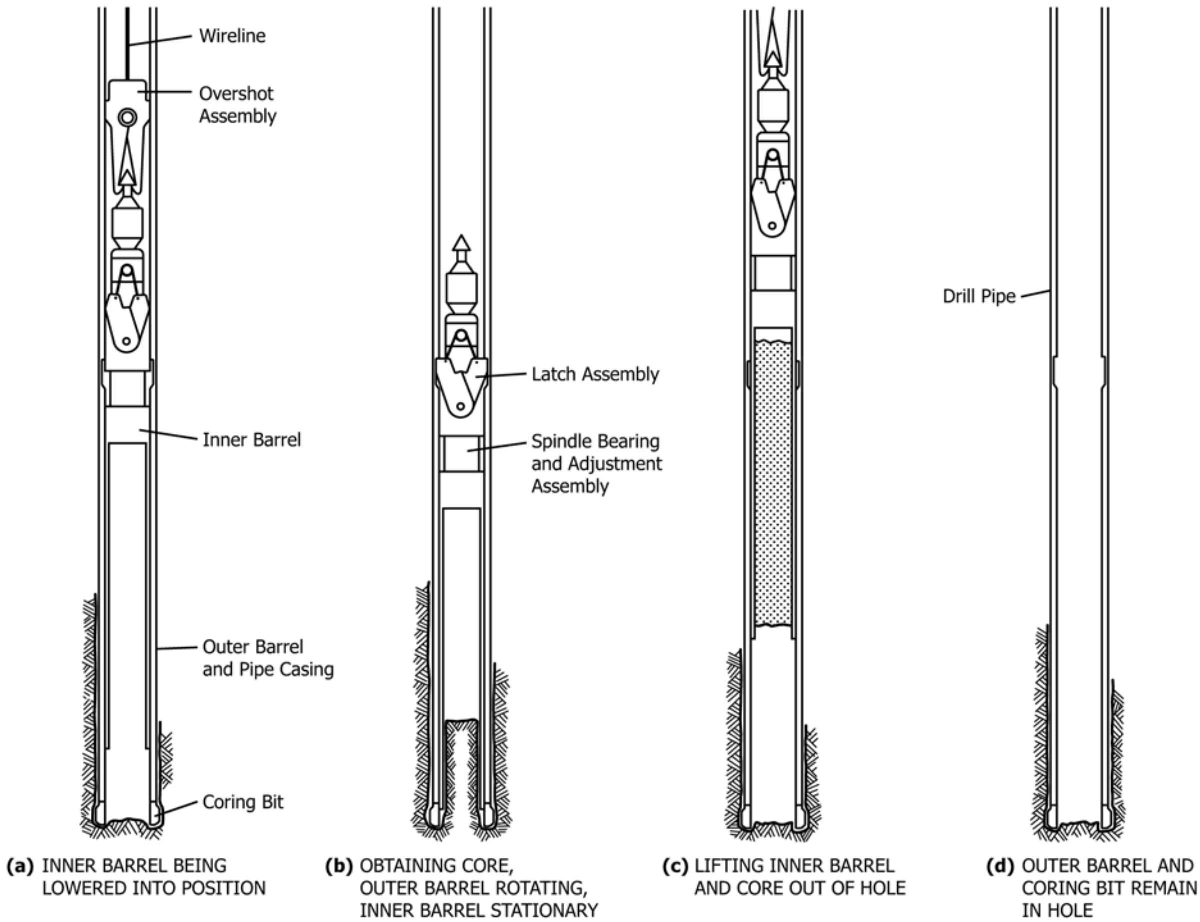


FIG. 1 Operating Principle of Wireline Core Barrel (18)

TABLE 7 General Recommendations for Thin-Wall, Open Push-Tube Sampling (19)

Soil type	Moisture condition	Consistency	Length of push, cm [in.]	Bit clearance ratio, %	Push tube sampler recovery	Recommendation for better recovery
Gravel			Thin-wall, open push tube samplers not suitable			
Sand	Moist	Dense	46 [18]	0 to ½	Fair to poor	
Sand	Moist	Loose	30 [12]	½	Poor	Recommend piston sampler
Sand	Saturated	Dense	45 to 60 [18 to 24]	0	Poor	Recommend piston sampler
Sand	Saturated	Loose	30 to 45 [12 to 18]	0	Poor	Recommend piston sampler
Silt	Moist	Firm	45 [18]	½	Fair to good	
Silt	Moist	Soft	30 to 45 [12 to 18]	½	Fair	
Silt	Saturated	Firm	45 to 60 [18 to 24]	0	Fair to poor	Recommend piston sampler
Silt	Saturated	Soft	30 to 45 [12 to 18]	0 to ½	Poor	Recommend piston sampler
Clay and shale	Dry to saturated	Hard	Thin wall, open push tube sampler not suitable			Recommend double-tube sampler
Clay	Moist	Firm	45 [18]	½ to 1	Good	
Clay	Moist	Soft	30 to 45 [12 to 18]	1	Fair to good	
Clay	Saturated	Firm	45 to 60 [18 to 24]	0 to 1	Good	
Clay	Saturated	Soft	45 to 60 [18 to 24]	½ to 1	Fair to poor	Recommend piston sampler
Clay	Wet to saturated	Expansive	45 to 110 [18 to 44]	½ to 1-½	Good	

7.3.3.1 Not suitable for collection of samples for laboratory tests requiring intact soil.

7.3.3.2 Ineffective recovery in cohesionless sands unless retainer is used.

7.3.3.3 Recovery and quality below water table may be a problem.

7.4 *Thin-Wall Samplers*—Thin-walled samplers meet the criteria for samplers that collect intact samples in Table 2.

7.4.1 *Types of Thin-Wall Samplers*—Thin-wall samplers are either open tube or piston-type (discussed in 7.4). Table 6 summarizes information on methods of advancement for thin-wall samplers, and Table 7 provides general recommendations

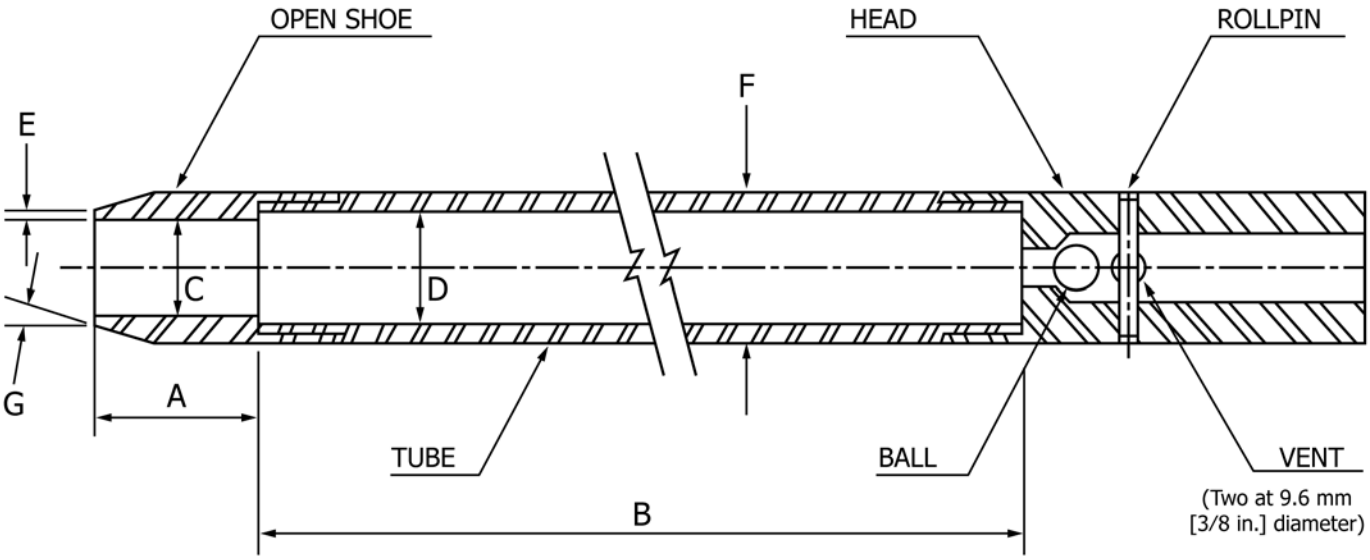
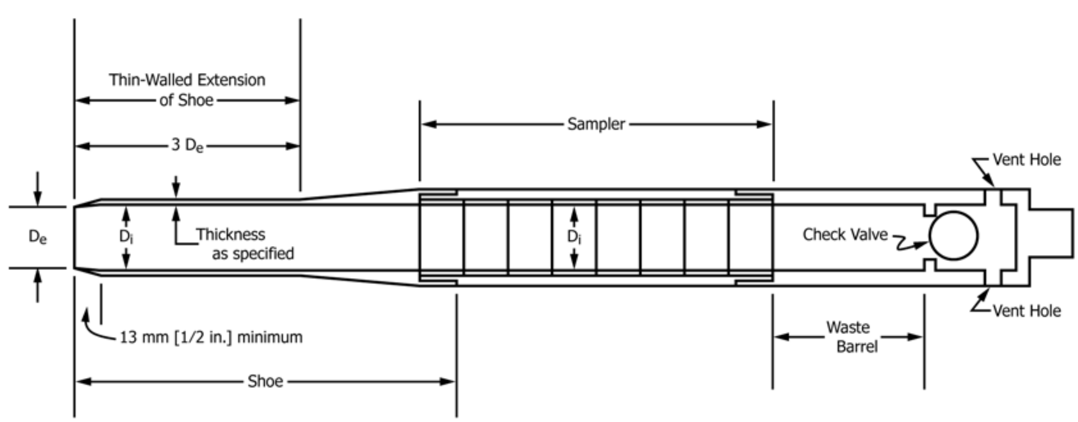


Fig. 2 Thick-Walled Sampler Dimensions

A	25 to 50 mm [1.0 to 2 in.]
B	0.457 to 0.762 m [18 to 30 in.]
C	35 ± 0.13 mm [1.375 ± 0.005 in.]
D	38.1 +1.3/-0.0 mm [1.50 +0.05/-0.00 in.]
E	2.54 ± 0.25 mm [0.10 ± 0.02 in.]
F	50.8 +1.3/-0.0 mm [2.00 +0.05/-0.00 in.]
G	16.0° to 23.0

NOTE 1—The 38 mm [1-½ in.] inside diameter split barrel may be used with a 1.59 mm [0.0566 in.] (16 gauge) wall thickness split liner. The penetrating end of the device may be slightly rounded. Metal or plastic retainers may be used to retain soil samples.

FIG. 2 Thick-Wall Sampler (see Test Method D1586)



NOTE 1—Inside clearance ration = $(D_i - D_e)/D_e$

NOTE 2—Dimensional tolerance of D_i = ±0.08 mm [±0.003 in.]

FIG. 3 Ring-Line Sampler (see Practice D3550)

for length of push and bit-clearance ratio for sampling different types of unconsolidated materials. Thin-walled samplers are typically 75 mm [3 in.] in diameter, but can range up to 125 mm [5 in.]. Fig. 4 illustrates key parameters specified in Practice D1587 for thin-wall samplers.

NOTE 6—The term "Shelby tube" sampler is often used for open-tube thin-wall samplers. The "Shelby Tubing" sampler was developed in 1936 at the request of A. Casagrande. The name derived from the trade name for hard-drawn seamless steel tubing manufactured by National Tube Company. Hvorslev (**1**) introduced the more generic term of thin-wall sampler.

7.4.2 *Applications*—See 7.5 for applications of piston samplers.

7.4.2.1 Collection of intact cores in silty and clayey sands (> 12 % fines), or silts and clays above the water table for laboratory testing of in situ physical and hydraulic properties. Collection of samples below the water table may require use of retainers (see 7.9.1) that may cause some sample disturbance.

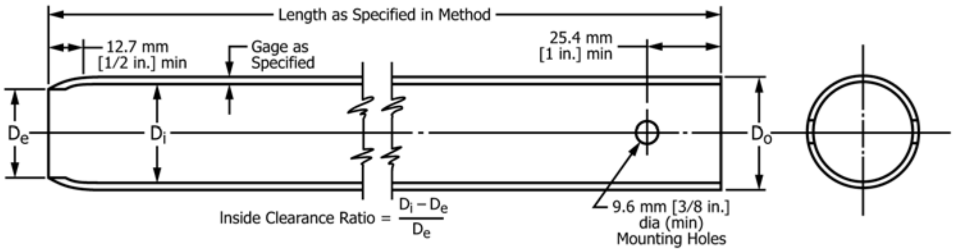


FIG. 4 Thin-Wall Sampler (see Practice D1587)

7.4.2.2 Collection of samples for chemical analysis. Sampling for sensitive chemical constituents will require special handling procedures (see 6.4).

7.4.2.3 Collection of high quality cores for visual description.

7.4.2.4 A ring-lined sampler can be used to collect intact samples in soft clays when used with a thin-wall extension (see Fig. 3).

7.4.3 *Limitations:*

7.4.3.1 Ineffective in cohesionless sands or gravelly soil.

7.4.3.2 May not be able to penetrate dense soils (*N* 20 to 30) without driving with consequent sample disturbance (or use Denison or Pitcher sampler).

7.5 *Piston Samplers*—There are both thin-wall and, less commonly, thick-wall piston samplers, but the basic operation of both types of samplers is the same. Piston samplers have several features that overcome limitations to open tube samplers: the core barrel is closed until the sampler is in position, reducing sample contamination from drilling mud and caved borehole material, provided that a good seal is maintained using O-rings or other packing material; the vacuum created by the piston helps retain materials that may not be retained by open tube samplers.

7.5.1 *Types of Piston Samplers*—Piston samplers are of two major types. Fixed-piston or stationary-piston samples hold the piston rigidly in its initial position as the tube advances. Various terms may be applied to piston samplers that are not fixed: free-piston, semifixed-piston and free-floating. With these samplers the piston is locked in place while the sampler is advanced to the point that the sample is to be collected. The piston is then unlocked and the sampler advanced as the piston rests on the sample entering the tube. The disadvantage of this arrangement compared to a fixed-piston samplers is that some compaction of the upper part of the sample may occur. The retractable plug sampler is a variant of this the free piston design, except that the plug is retracted and fixed before the sampler is advanced to collect a core. Drill-rod driven fixed piston samplers come in two basic types. Mechanically-activated samplers, such as the Hvorslev sampler uses an inner rod that extends to the surface that is used to fix the position of the piston with the force used to push the sampler applied at the ground surface (see Fig. 5). Hydraulically-activated samplers, called hydraulic-piston or Osterberg-type samplers use the drill rod to fix the position of the piston and fluid under pressure to advance the sampler (see Fig. 6). Hydraulic piston samplers are faster and easier to use than mechanically-activated samplers because use of piston rods is eliminated and it is easier to assemble, operate and disassemble. A disadvantage of hydraulic-piston samplers is that it is not possible to limit the length of push or determine the amount of partial sampler penetration during the push. Direct push sampling systems commonly use free-piston core samplers. Foil samplers are a specialized type of piston sampler that encases the core in metal foil as the tube advances.

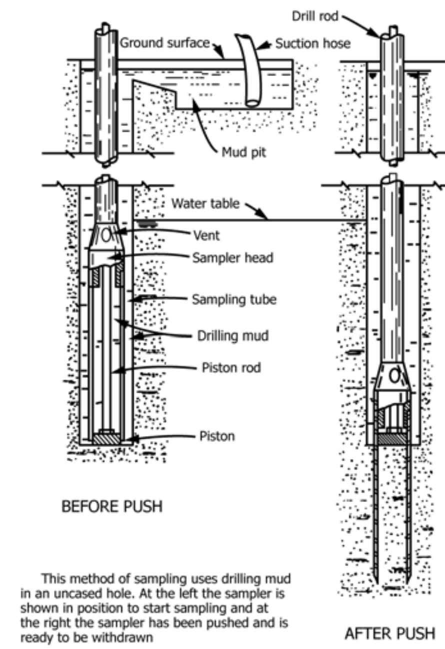


FIG. 5 Sampling With Hvorslev-Type Fixed-Piston Sampler (19)

7.5.2 *Applications:*

7.5.2.1 Fixed-piston samplers are used to collect intact or representative samples in saturated soils, cohesionless soils, or very soft soils where core recovery is poor with open tube samplers.

7.5.2.2 Free-piston samplers are used to collect representative samples in situations similar to open tube samplers, and to prevent contact of contaminated groundwater with the inside of the sampler prior to collection of a sample (alternative sealing methods may be available for open-tube samplers-see 6.9).

7.5.3 *Limitations:*

7.5.3.1 Sample collection is more time consuming than with open tube samplers (more so for mechanical fixed-piston than for hydraulic fixed-piston).

7.5.3.2 More complex construction increases possibility of malfunction.

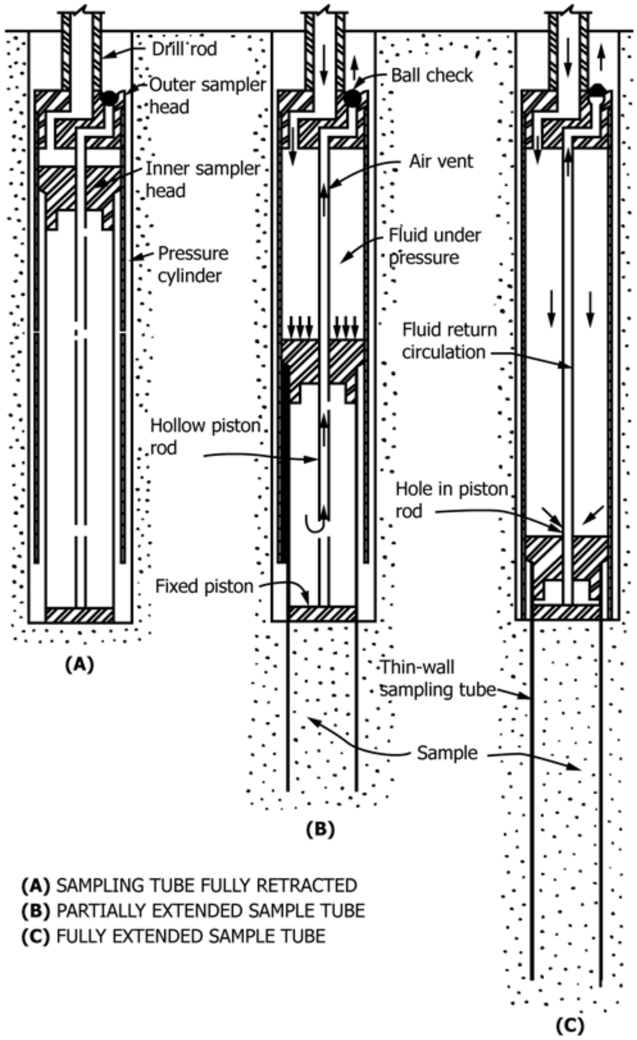


FIG. 6 Sampling With Osterberg-Type Thin-Wall Fixed-Piston Sampler (19)

7.6 *Rotating Soil Core Samplers*—Rotating soil core samplers advance by cutting away soil material using a circular cutting bit as the shoe of the stationary inner core barrel advances into the soil. The rotating cutting bit is typically carbide, although large-diameter diamond core barrels may also be used in soil material. In the case of the hollow-stem auger, the auger itself functions as the rotating outer barrel (see 7.6.3). Normally the inner barrel advances ahead of the outer rotating core barrel, but spring-loaded samplers, such as the pitcher sampler, the outer barrel may advance ahead of the inner barrel. When the distance between the inner and outer barrels is fixed, as in the case of the Denison and hollow-stem auger, the lead distance of the inner barrel may need to be adjusted, depending on the denseness of the material being sampled. Increasing the lead distance reduces contamination of the sample by drilling fluids. The three most commonly used types of rotating soil core samplers are the pitcher, Denison, and hollow-stem auger. These samples and their applications are described below.

7.6.1 The Pitcher sampler a consists of a spring-loaded stationary inner core barrel with a rotating outer barrel and carbide bit which cuts away materials outside and behind the inner barrel while the shoe is advanced by pushing it into the material ahead of the bit. As the density of the material increases, the rotating barrel moves closer to the advancing tube (see Fig. 7). Inner liners can be used with a pitcher sampler. It is especially useful for coring stratified material of varying density, especially firm to very stiff clay and dense sands.

7.6.2 The Denison sampler functions either as a soil or rock rotary core sampler, depending on how it is configured. In the soil-core configuration it is similar to the pitcher sampler, with an inner tube and liner that is pushed ahead of the cutting bit which cuts away material outside of and behind the sampling tube (see Fig. 8). In the rock-core configuration the cutting bit is ahead of the sampling tube and cuts a smaller diameter core

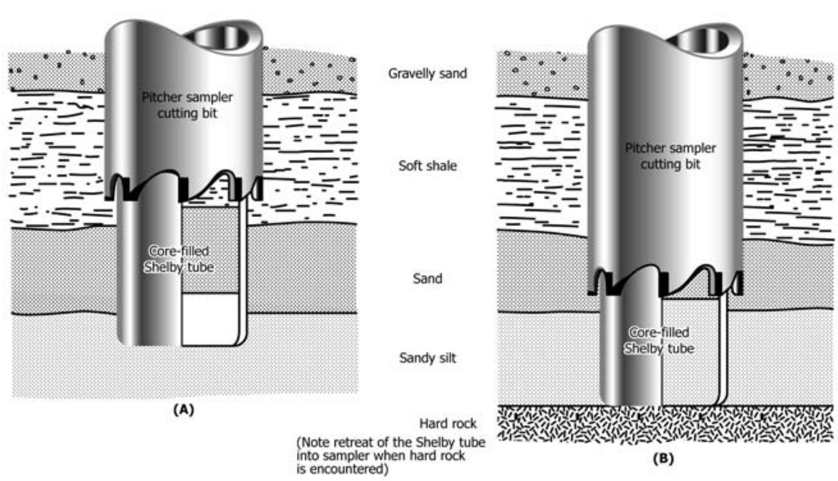


FIG. 7 Pitcher Sampler Operation: Inner Thin-Wall Barrel Extends Beyond Cutting Bit in Soft Formations (*A*) and Retracts into Cutting Barrel When Dense Formation is Encountered (*B*) (4)

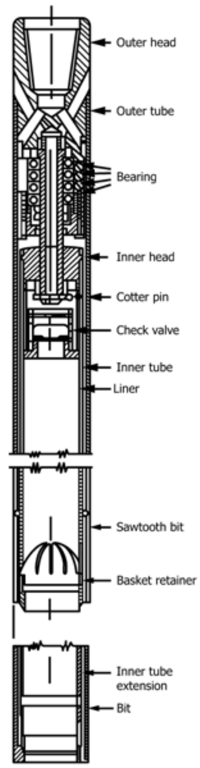


FIG. 8 Denison Sampler in Soil Sampling Configuration With Inner Core Barrel Ahead of Rotating Sawtooth Bit (8)

which then fits into the sampling tube. It is used to collect intact samples in materials that are too dense for a thin-wall sampler.

7.6.3 Continuous hollow-stem auger sampling, where an inner barrel advances with the auger, functions as a double wall rotating core sampler (see Fig. 9). In this configuration continuous, high-quality soil cores can be obtained. The inner core barrel can be advanced using either drill rods or a wireline system. The advantage of wireline systems is that the sampler can be emplaced and retrieved more quickly than drill-rod-attached samplers. However, wireline latching systems may be less effective in keeping the sampler from rotating than drill-rod-attached samplers, resulting in more sample disturbance.

7.6.4 *Vibratory/Sonic Soil Sampling*—As described in 7.2.4, vibratory/sonic rigs operated in a rotational mode function as rotating core soil samplers when soil samples are collected in an inner core barrel during drilling advancement.

7.7 *Rotating Rock Core Samplers*—Rotating core samplers advance by cutting away soil or rock material from around the core using a circular cutting bit. Major types of bits include carbide (for soft rock), surface-set-diamond and impregnated-diamond bits. These samplers can be advanced using drill rods (often called conventional coring—see Practice D2113), using wireline systems (see 7.2.5), or using vibratory/sonic coring (see 7.2.4).

7.7.1 *Types of Rock Core Samplers*—Two basic designs of rotating rock core samplers are single-tube, where drilling fluid circulates around the core (see Fig. 10), and double-tube where the drilling fluid circulates between the two walls of the core barrel, avoiding direct contact with the core. Single-tube core-barrels are used primarily to core concrete and soil cement and are rarely used at the present time for coring rock. For conventional diamond core drilling, DCDMA (**20**) has standardized dimensions for four series of rock core barrels (WG, WT, WM and large diameter (refer to Practice D2113 for summary information on bit and casing sizes)). Rigid-type conventional double-tube core barrels provide an inner barrel that rotates with the outer barrel providing protection from drilling fluid but may cause core abrasion by torsional forces (see Fig. 11(*a*)). Swivel-type double-tube core barrels permit rotation of the outer barrel without causing rotation of the inner barrel, and are required when collecting intact cores (see Fig.

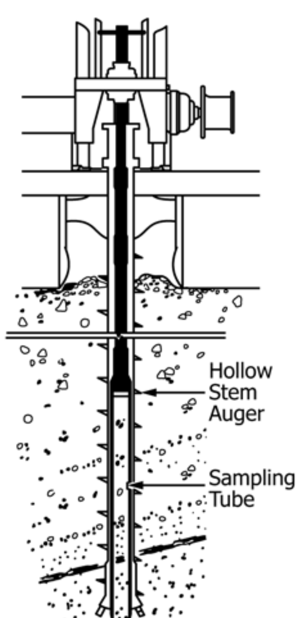


FIG. 9 Hollow-Stem Auger Continuous Sample Tube System (see Guide D4700 and Practice D6151)

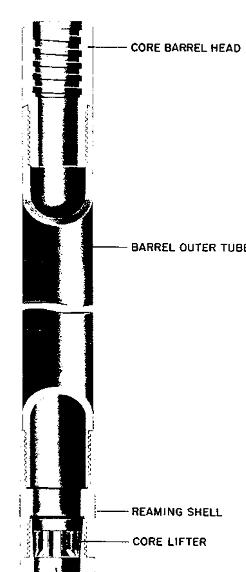


FIG. 10 G-Design Single Tube Core Barrel (22)

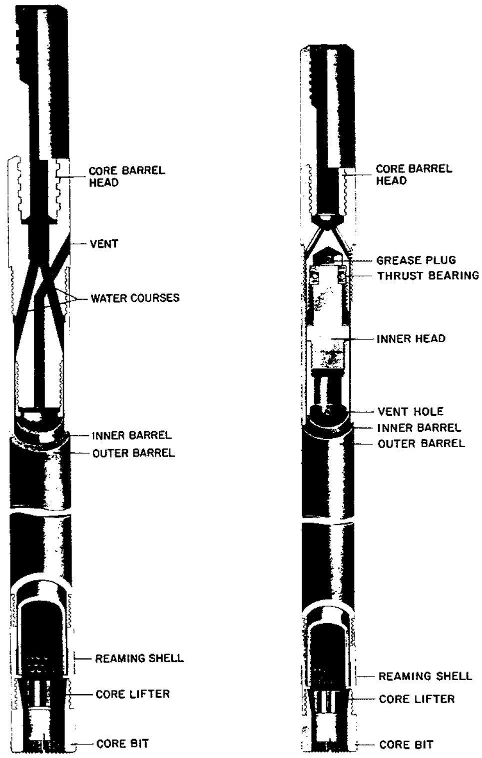


FIG. 11 G-Design Double Tube Core Barrels: (*A*) Rigid Type and (*B*) Swivel Type (22)

11(*b*)). Most double-tube core barrel inner tubes can be replaced with a split inner tube, which allow visual inspection and transfer of cores with a minimum of disturbance. Triple tube core barrels are modified double-tube barrels with the core received by a split tube inside a solid inner tube. This configuration reduces possible penetration of drilling fluid along the split tube. A wide variety of wireline core barrel systems are available, with most functioning in a manner similar to the conventional swivel-type double-tube barrels. The core lifter, which helps retain the core when the sampler is retrieved, is mounted in the inner barrel, usually in a special piece called the "lifter case" in the WM series and in all wireline systems. In the WG and WT series double barrels, the lifter is on the bit, similar to a single tube, and rotates with the bit and outer barrel. Wireline systems are typically used with fluid rotary drill rigs, which can create problems with drilling fluid contamination of cores even when double-tube core samplers are used. Teasdale and Pemberton (**21**) described modifications to a standard triple-tube wireline core barrel for air rotary advancement that allowed recovery of uncontaminated cores in unsaturated volcanic tuff.

7.7.2 *Applications:*

7.7.2.1 *Single-Tube*—Collection of continuous high quality cores in concrete and soil-cement for visual description.

7.7.2.2 *Double-Tube, Swivel-Type*—Collection of intact cores in rock formations for laboratory testing of in situ physical and hydraulic properties and chemical analysis. This type, with a split inner liner is recommended for most coring operations. Continuous rotary coring results in generally comparable rates of hole advancement to other direct rotary drilling methods, but the need to replace rotary core bits more frequently means that overall costs are commonly higher.

7.7.2.3 *Triple Tube or Large Diameter Double-Tube, Swivel-Type*—Collection of intact cores in friable, erodible, soluble or highly fractured rock formations for laboratory testing of in situ physical and hydraulic properties.

7.7.3 *Limitations:*

7.7.3.1 Vibration and rotation may alter in situ physical properties of the core.

7.7.3.2 Drilling fluids may alter sample physical and chemical properties (mainly a problem with single tube samplers, but depending on the design double-tube cores may also be affected).

7.7.3.3 Cores collected using air rotary are not suitable for measurement of in situ moisture content because of drying.

7.7.3.4 Single-tube cores are not suitable for Class C samples.

7.8 *Other Specialized Samplers*—Numerous specialized core samplers that are variants or operate on quite different principles from the major types of samplers described in this guide. Driscoll (**23**) describes a side-wall core sampler that uses a special gun to discharge small core barrels (usually about 45 mm [1.75 in.] long and 20.6 to 25.4 mm [0.8125 to 1.0 in.] in diameter) into the sidewall. After being fired electrically, the cores, which remain attached to the gun, are retrieved by the wireline used to lower the gun. It is used to collect representative samples to verify material present at a certain depth when cuttings are the primary method for lithologic description of a borehole. The rubber sleeve rock core barrel adapts the principle of the foil sampler to a rotating rock core sampler. O'Rourke et al. (**18**) should be referred to for more detailed information on these and other specialized samplers, such as foil samplers.

7.9 *Ancillary and Specialized Sampling Techniques*—Various techniques may be used in conjunction with various sampling devices to improve retention of cores in the sampling tube when difficult materials are sampled. Except for retainers, these specialized techniques are not routinely used in environmental investigations, but may have applicability for specialized situations. Refer to Hvorslev (1949) and O'Rourke et al. (**18**) for additional information on these and other specialized sampling techniques.

7.9.1 Retainers are devices that expand to allow the core to enter the tube and then close to keep the sample in place. Major types of retainers include the basket and finger types. Fig. 8 illustrates use of a basket retainer with a Denison sampler. Retainers are commonly used with split-barrel drive sampler to recover representative samples of sand.

7.9.2 Chemical solidification is used in cohesionless sands and involves injection of grout either into the bottom of the sample and letting the grout solidify before the sampler is withdrawn. Specialized grouts may be required for fine sands and silts. The major disadvantage of this method is that the grout alters the physical and chemical characteristics of the lower part of the core. This technique is used primarily for engineering studies.

7.9.3 Freezing is the method of last resort for collecting intact samples of clean cohesionless soils (gravelly soils and saturated clean sands). Freezing can be either used to solidify the bottom of the core after penetration, or a large portion of the strata, which is then cored. This technique is used primarily for engineering studies.

7.9.4 Conventional swivel-type rotating rock core samplers may result in some rotation of the core, preventing precise interpretation of strike and dip of sedimentary structures and fracture orientations. Collection of oriented cores requires special sampling devices that include scribing tools and photography or charts systems that document the core's orientation. O'Rourke et al. (**18**) described several such coring systems.

8. Other Borehole Sampling Devices and Methods

8.1 Two major types of non-core sampling devices or methods with drill rigs are available: rotating grab samplers with cutting heads that destroy the structural features of the sample, and cuttings from various drilling methods. Samples collected using these methods are generally considered to be nonrepresentative, and hence suitable only for lithologic logging unless sample collection procedures are designed to collect samples from well-defined intervals, in which case they may be considered representative for characterization of physical properties such as particle size distribution and chemical analysis for nonsensitive constituents (see 8.4).

8.2 *Borehole Grab Samplers*—Numerous types of grab samplers are available for use with drill rigs. Features common to these samplers are that they advance by rotation using some type of cutting shoe or head that breaks up the soil material before it moves into the portion of the device that retains the sample. Terms used to describe such samplers is quite variable. The terms pocket- or spoon-type sampler is often applied to samplers used with drill rigs that are similar to thick-wall samplers except they have a spiral or Iwan-type cutting shoe rather than a circular cutting shoe. Such samplers are usually used with solid stem augers to clean out loose cuttings prior to core sampling (**4**). The terms door- or window-type may be applied to larger diameter samplers of this type used with drill rigs which are used to sample gravels and sands (**24**). Sidewall grab samplers that scrape the side of a borehole (as distinct from the sidewall core samplers described in 7.8) have also been developed (**24, 25**).

8.2.1 Augers that retain the sample inside the device rather than on the surface of the device, as with helical-type or spiral-type augers, fall in the category of borehole grab samplers. Examples of such augers include barrel augers, such as the Vicksburg solid and hinged and McCart split auger, and bucket augers (**13**). Augers can be used to collect disturbed representative samples. Practice D1452 describes sampling procedures with augers. Barrel and bucket augers can provide representative samples for laboratory analysis of non-structural physical and chemical characteristics provided conditions described in 8.4 are met. Where contaminated groundwater is present, use of augers without casing advancement may result in cross-contamination of soil samples.

8.3 *Cuttings*—Cuttings collected from fluid rotary in uncased holes and return from auger flights provide the poorest quality because it is difficult to relate the sample to a particular interval in the subsurface. When fluid rotary is used it is very difficult to capture any clay or silt fraction when drilling soil. These particle sizes either do not settle out of the fluid or remain in suspension for long periods of time, even when clear water is the fluid. It is not generally practical to pass the fluid return through a screen or sieve with small enough opening to capture these particle sizes. When clay based mud is used, it is impossible. Consequently, cutting or wash samples understate any fines content. Air rotary with casing advancement, dual wall reverse circulation rotary and cable tool cuttings provide the best quality samples because it is easiest to relate cutting to a specific depth interval. Collection of cuttings during continuous air and fluid rotary drilling results in nonrepresentative samples because differently sized particles from the same interval tend to advance to the surface with the drilling fluid at different speeds. Such samples may provide acceptable lithologic data provided that drill bit diameter and drilling fluid flow rate are controlled to maintain optimum uphole velocity of cuttings and rate of advancement is carefully documented (**4**). Such samples would still be nonrepresentative for purposes of laboratory analysis. The appendix identifies additional major references on use of drill cuttings for lithologic and hydrogeologic interpretations.

8.4 *Collection of Non-Core Representative Samples*—Drill cuttings samples are unsuitable for most of the specific sampling objectives presented in Table 1 for coring devices, but may be suitable for some purposes. Major properties for which it may be possible to obtain representative samples using non-coring methods include grain-size distribution, mineralogy, stable chemical constituents (unless drilling fluids cause interferences), and lithology. Basic requirements for collection of representative non-core samples for these purposes include accurate placement of the depth interval from which the sample is collected and prevention of mixing of the sample with materials from other intervals. This generally requires advancement of a casing as drilling proceeds. With casing advancement, samples collected using grab samplers can be considered representative provided that the drilling method has not modified the textural characteristics of the soil (that is, hasn't broken up larger particles into smaller particles) and the diameter of the sampler is larger than the largest particle in the interval. Drill cuttings can be considered representative if casing advancement occurs and drilling advances and cuttings are collected incrementally. This requires pausing of drilling after each increment of advancement (typically 0.3 to 0.6 m [1 to 2 ft]) and circulation of fluids until all cuttings have been removed before drilling begins for the next interval. As with use of grab samplers, any reduction in particle size by the drill bit will result in a nonrepresentative sample.

9. Keywords

9.1 drilling; environmental site characterization; exploration; feasibility studies; field investigations; geological investigations; groundwater; hydrologic investigations; reconnaissance surveys; sampling; site characterization; site investigations; soil surveys; subsurface investigations

APPENDIX

(Nonmandatory Information)

X1. MAJOR NON-ASTM REFERENCES ON SOIL AND ROCK SAMPLING

X1.1 *Geoenvironmental Investigations*—Shuter and Teasdale (**4**) is recommended as the primary reference on coring and sampling techniques for hydrogeologic and other environmental investigations. Other useful references include: Aller et al. (**8**), Eggington et al. (**26**), Barrett et al. (**24**), Campbell and Lehr (**27**), Driscoll (**23**), Lehr et al. (**28**), Ruda and Bosscher (**29**), Roscoe Moss Company (**30**), and U.S. EPA (**31**).

X1.2 *Geotechnical Investigations*—Except as noted in the note for Test Method D1586, sampling devices and techniques developed for geotechnical investigations are applicable to environmental investigations. Two classic references with this focus, Acker (**32**) and Hvorslev (**1, 33**) are out of print. Major government-agency references that give guidance on soil sampling for geotechnical investigations include: Bureau of Reclamation (**19, 34**), AASHTO (**35**), USACE (**13, 36, 37, 38**), Marcuson and Franklin (**39**), and U.S. Naval Facilities Engineering Command (**40**). Additional useful major references include: ISSMFE (**41**), Mori (**42**), and O'Rourke et al. (**18**), which provides an excellent discussion of core recovery techniques for soft or poorly consolidated materials, and includes descriptions of many less-well-known sampling devices and techniques.

X1.3 *Rotary Diamond Drilling*—Rotary diamond drilling is a drilling method that by definition also collects core samples. The primary reference on specifications for diamond core drills is DCDMA (**20**). Major references that focus on diamond drilling include: Christensen Diamond (**43**), Cumming and Wickland (**44**), Heinz (**22**), and World Oil (**45**). Anderson (**46**) focusses on methods for analyzing cores.

X1.4 *Wireline Operations*—API (**47**) is the most comprehensive reference that focuses on wireline drilling and sampling operations.

X1.5 *Logging and Sampling of Drill Cuttings*—Shuter and Teasdale (**4**) provide guidance on logging of drill cuttings for environmental investigations. Other major references on this topic include: Hooper and Early (**48**), Johnson UOP (**49**), Maher (**50**), Matlock et al. (**51**), and Stevens (**52**).

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SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D6169 – 98 (2005)) that may impact the use of this standard. (Approved Aug. 1, 2013.)

(1) Replaced ‘undisturbed’ with ‘intact’ throughout.
(2) Added Practice D3740 to Section 2 and Note 1.
(3) Added Terminology D653 to Section 2 and Section .
(4) Removed definition from Section as no longer specific to this guide.
(5) Added information on Triple Tube Tools to 6.6, Table 4, and Table 6.