



Standard Practice for Rock Core Drilling and Sampling of Rock for Site Investigation¹

This standard is issued under the fixed designation D 2113; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the guidelines, requirements, and procedures for core drilling, coring, and sampling of rock for the purposes of site investigation. The borehole could be vertical, horizontal, or angled.

1.2 This practice is described in the context of obtaining data for the design, construction, or maintenance of structures, and applies to surface drilling and drilling from adits and exploratory tunnels.

1.3 This practice applies to core drilling in hard and soft rock.

1.4 This practice does not address considerations for core drilling for geo-environmental site characterization and installation of water quality monitoring devices (see Section 2).

1.5 The values stated in inch-pound units are to be regarded as standard. The SI values given in parentheses are provided for information purposes only.

1.6 This practice does not purport to comprehensively address all of the methods and the issues associated with coring and sampling of rock. Users should seek qualified professionals for decisions as to the proper equipment and methods that would be most successful for their site investigation. Other methods may be available for drilling and sampling of rock, and qualified professionals should have flexibility to exercise judgment as to possible alternatives not covered in this practice. This practice is current at the time of issue, but new alternative methods may become available prior to revisions; therefore, users should consult with manufacturers or producers prior to specifying program requirements.

1.7 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice 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.

1.8 *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. Also, the user must comply with prevalent regulatory codes, such as OSHA (Occupational Health and Safety Administration) guidelines, while using this practice. For good safety practice, consult applicable OSHA regulations and other safety guides on drilling (1).*

2. Referenced Documents

2.1 ASTM Standards:

D 420 Guide to Site Characterization for Engineering Design, and Construction Purposes²

D 653 Terminology Relating to Soil, Rock, and Contained Fluids²

D 4630 Test Method for Determining Transmissivity and Storage Coefficient of Low Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test²

D 5079 Practices for Preserving and Transporting Rock Core Samples²

D 5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock³

D 5782 Guide for the Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and Installation of Subsurface Water Quality Monitoring Devices³

D 5783 Guide for Use of Direct Rotary Drilling With Water-Based Drilling Fluid for Geoenvironmental Exploration and Installation of Subsurface Water Quality Monitoring Devices³

D 5876 Guide for Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices³

D 6032 Test Method for Determining Rock Quality Designation (RQD) of Rock Core³

D 6151 Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling³

2.2 American Petroleum Institute Standard:

¹ This Practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

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² Annual Book of ASTM Standards, Vol 04.08.

³ Annual Book of ASTM Standards, Vol 04.09.

3. Terminology

3.1 Definitions:

3.1.1 *blind hole*, *n*—borehole that yields no fluid recovery of the drilling fluids.

3.1.2 *casing*, *n*—hollow tubes of steel used to support bore hole walls or where fluid losses must be stopped.

3.1.3 *caving hole*, *n*—borehole whose walls or bottom are unstable and cave or collapse into the drilled borehole.

3.1.4 *core barrels*, *n*—hollow tubes of steel used to collect cores of drilled rock.

3.1.5 *core bits*, *n*—coring bits with surface set or impregnated diamonds in tungsten carbide mix of hardened steel, polycrystalline bits, or tungsten carbide (TC) inserts, mounted on a cylindrical coring bit that does the actual core cutting.

3.1.6 *drill rig*, *n*—includes drilling machine, mast or derrick, circulating pumps, and mounting platform.

3.1.7 *drill rod*, *n*—hollow steel tubes that are connected to the drill bit or core barrel and to the rotary head of the drilling machine.

3.1.8 *drill platform*, *n*—a platform for drilling rig.

3.1.8.1 *Discussion*—The platform may need to be constructed at the drilling site to provide a firm base upon which the drill rig is then placed. Platforms are also constructed in the vicinity of the drill hole for workers to hold equipment, serve as a datum, and to allow safe operations.

3.1.9 *drilling machine*, *n*—includes power unit, hoisting unit, controlled-feed rotary drill head, and water or mud pump.

3.1.10 *overshot*, *n*—a latching mechanism at the end of the hoisting line, specially designed to latch onto or release pilot bit or core barrel assemblies when using *wireline drilling*.

(D 5786)

3.1.11 *pilot bit assembly*, *n*—designed to lock into the end section of drill rod for *wireline drilling* without sampling. The pilot bit can be either drag, roller cone, or diamond plug types. The bit can be set to protrude from the rod coring bit depending on the formation being drilled.

(D 5786)

3.1.12 *squeezing hole*, *n*—borehole whose walls move into the drilled opening and squeeze on the drill rods.

3.1.13 *wireline drilling*, *n*—a rotary drilling process using special enlarged inside diameter drilling rods with special latching pilot bits or core barrels raised or lowered inside the rods with a wireline and overshot latching mechanism.

(D 5786)

3.2 Additional terms are defined in Terminology D 653.

4. Summary of Practice

4.1 Drilling:

4.1.1 Drilling is accomplished by circulating a drilling medium through the drill bit while rotating and lowering or

advancing the string of drill rods as downward force is applied to a cutting bit. The bit cuts and breaks up the material as it penetrates the formation, and the drilling medium picks up the cuttings generated by the cutting action of the bit. The drilling medium, with cuttings, then flows outward through the annular space between the drill rods and drill hole, and carries the cuttings to the ground surface, thus cleaning the hole. The string of drill rods and bit is advanced downward, deepening the hole as the operation proceeds.

4.1.1.1 Fluid drilling is accomplished by circulating water or a water-based fluid with additives. Additives such as bentonite or polymers are frequently added to water to lubricate and cool the bit and to circulate (transport) cuttings to the surface. Drill fluid can also act to prevent cave or collapse of the drill hole. After the drilling fluid reaches the surface, it flows to a ditch or effluent pipe and into a settling pit where the cuttings settle to the bottom. Cuttings are sometimes run through a shaker to remove the larger particles. From the settling pit, the drilling fluid overflows into the main pit, from which it is picked up by the suction line of the mud pump and recirculated through the drill string.

NOTE 1—The decrease of mud velocity upon entering the mud pit may cause gelling of the mud and prevent cuttings from settling. Agitation of the mud in the pit can remedy the problem.

4.1.1.2 Air drilling is performed where introduction of fluids is undesirable. Air rotary drilling requires use of an air compressor with volume displacement large enough to develop sufficient air velocity to remove cuttings. Cuttings can be collected at the surface in cyclone separators. Sometimes a small amount of water or foam may be added to the air to enhance return of cuttings. Air drilling may not be satisfactory in unconsolidated and cohesionless soils under the ground water table.

4.2 Coring:

4.2.1 Coring is the process of recovering cylindrical cores of rock by means of rotating a hollow steel tube (core barrel) equipped with a coring bit. The drilled core is carefully collected in the core barrel as the drilling progresses.

4.3 Sampling:

4.3.1 Once the core has been cut and the core barrel is full, the drill rods or overshot assembly are pulled and the core retrieved. Samples are packaged and shipped for testing (see Practices D 5079).

5. Significance and Use

5.1 Rock cores are samples of record of the existing subsurface conditions at given borehole locations. The samples are expected to yield significant indications about the geological, physical, and engineering nature of the subsurface for use in the design and construction of an engineered structure. The core samples need to be preserved using specific procedures for a stipulated time (Practices D 5079). The period of storage depends upon the nature and significance of the engineered structure.

5.2 Rock cores always need to be handled such that their properties are not altered in any way due to mechanical damage or changes in ambient conditions of moisture and temperature or other environmental factors.

⁴ Available from American Petroleum Institute, 2101 L St. NW, Washington, DC

⁵ Available from NSF International, P.O. Box 130140, Ann Arbor, MI 48113-0140.

6. Apparatus

6.1 *General*—Fig. 1 shows the schematic of a typical rock core drill setup (2). Essential components of the drilling equipment include the drilling rig with rotary power, hoisting systems, casing, rods, core barrels, including bits and liners, and pumps with circulating system. In addition, equipment should include necessary tools for hoisting and coupling and uncoupling the drill string and other miscellaneous items such as prefabricated mud pits and racks for rod stacking and layout. Normally, a drilling platform of planking is built up around the drilling site.

6.1.1 Rock coring operations can proceed at high rotation rates. It is imperative the drill rig, rods, and core barrels are straight and have a balanced center of gravity to avoid whipping and resulting damage to cores and expensive bits.

6.2 *Drilling Rig*—The drill rig provides the rotary power and downward (or advance) force or hold-back force on the core barrel to core the rock. The preferred diamond drill coring equipments are designs with hydraulic or gear-driven variable speed hollow spindle rotary drill heads, although some core rigs are manufactured with gear or chain pulldown/retract systems. Precise control over bit pressure can best be accomplished by a variable setting hydraulic pulldown/retract system. Hydraulic systems are often equipped with a detent valve, which allows downfeed (or advance) rate to be set at a certain speed regardless of tool weight or down pressure exerted on the

coring bit. Hydraulic feed drill rigs should be supplied with a hydraulic pressure gage that can be related to bit pressures. Deep hole drill rigs should be equipped with hydraulic hold-back control so, if required, the full weight of the drill rods is not exerted on the bit when drilling downward. Diamond drill rigs can apply high rotation rates as high as 1000 rpm as opposed to normal rotary drills operating at 60 to 120 rpm (3). Most diamond core drills are equipped with a mast and powered hoist for hoisting heavy drill strings. A second wireline hoist is helpful for wireline drilling.

6.2.1 The drill machine frame is either skid or truck mounted and should be equipped with a slide base for ease in working around the drill hole. In special cases, the drilling machine may be mounted on a trailer, barge (for overwater drilling), or columns (for underground work). Some drill rigs are designed to be broken down into several pieces for transport into remote areas. The drilling machine may be powered by hydraulics, air, electricity, gas, or diesel. Most surface skid or truck mounted rigs are diesel or gas powered.

6.2.2 Drilling directions are rarely vertical in underground applications, and smaller rigs are frequently equipped with swivel heads to accommodate drilling at angles. Special accommodations must be made for holding and breaking rods when drilling at high angles into crowns of adits. Either top drive drill or column mount machines with hydraulic or pneumatic rod jacks are equipped to handle up holes. For

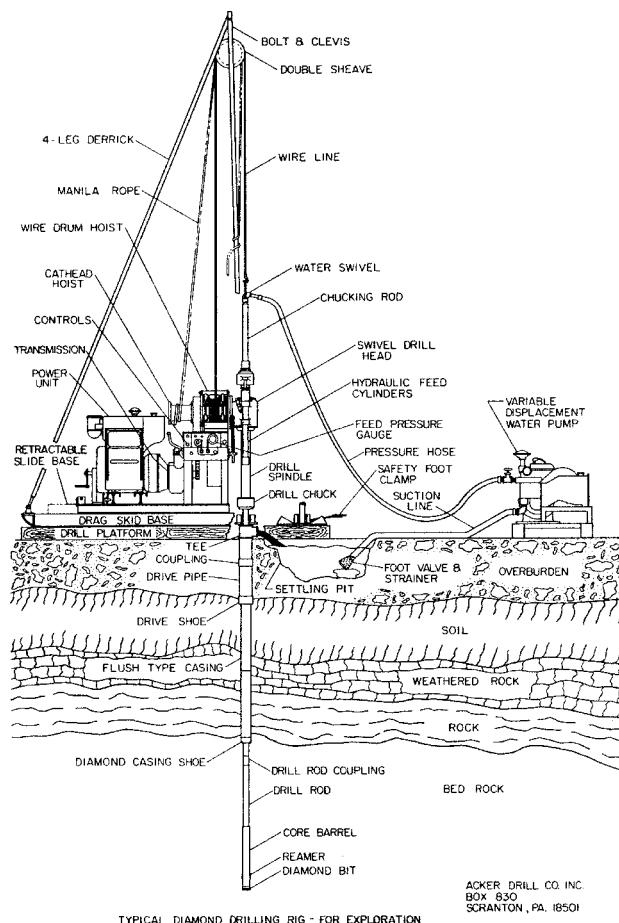


FIG. 1 Schematic of Typical Diamond Core Drill Set-up (2)

confined space drilling operations, drills are column mounted or mounted on small skids. Special power sources may be required for underground work due to air quality considerations. Remote power pack stations usually electric, hydraulic, compressed air, or a combination of the three. Electrically powered hydraulic systems are most common in underground use today.

6.3 Fluid or Air Circulation Systems:

6.3.1 *Selection of Drill Media*—The two primary methods for circulating drill cuttings are water or water-based fluids or air with or without additives. The predominant method of drilling is water-based fluids. Water-based drilling is effective in a wide range of conditions both above and below the water table. Air drilling is selected when water-sensitive soils such as swelling clays or low density collapsible soils are encountered. Air drilling may also be required above the water table if special testing is required in the unsaturated zone. Air drilling is also convenient in highly fractured igneous rocks and porous formations where water-based fluid losses are unacceptable. The primary functions of the drill fluid are:

- 6.3.1.1 Remove drill cuttings,
- 6.3.1.2 Stabilize the borehole,
- 6.3.1.3 Cool and lubricate the bit,
- 6.3.1.4 Control fluid loss,
- 6.3.1.5 Drop cuttings into a settling pit,
- 6.3.1.6 Facilitate logging of the borehole, and
- 6.3.1.7 Suspend cuttings in the drill hole during coring.

6.3.1.8 No single drill fluid mixture can satisfy all of the above requirements perfectly. In the sections below, considerations for materials that could be used in drilling medium are given.

6.3.2 The pressure hose conducts the drilling fluid or air from the circulation pump or compressor to the swivel.

6.3.3 The swivel directs the drilling fluid or air to a rotating kelly or drill-rod column.

6.3.4 *Rotary Drilling with Water-based Drilling Fluids*:

6.3.4.1 The mud pit is a reservoir for the drilling fluid, and, if properly designed and used, provides sufficient flow velocity reduction to allow separation of drill cuttings from the fluid before recirculation. The mud pit can be a shallow, open metal tank with baffles or an excavated pit with some type of liner, and designed to prevent loss of drilling fluid. The mud pit can be used as a mixing reservoir for the initial quantity of drilling fluid, and, in some circumstances, for adding water and additives to the drilling fluid as drilling progresses. It may be necessary to have additional storage tanks for preparing fluids while drilling progresses.

6.3.4.2 The suction line, sometimes equipped with a foot valve or strainer, or both, conducts the drilling fluid from the mud pit to the fluid circulation pump.

6.3.4.3 The fluid circulation pump must be able to lift the drilling fluid from the mud pit and move it through the system against variable pumping heads at a flow rate to provide an annular velocity that is adequate to transport drill cuttings out of the drill hole.

6.3.4.4 *Water-based Drilling Fluids*—The four main classes of water-based drilling fluids are: (1) clean, fresh water, (2) water with clay (bentonite) additives, (3) water with polymeric

additives, and (4) water with both clay and polymer additives. For commonly used materials added to water-based fluid, see Section 7 on Materials.

(1) Clean fresh water alone is often not acceptable for core drilling due to poor bit lubrication, erosion due to high velocities required for lifting cuttings, and excessive water loss. In water-sensitive soils, it is desirable to use drill additives to form drill hole wall cakes and prevent moisture penetration. In some cases, water may be required for piezometer installations where other fluid additives are not acceptable, but often newer synthetic polymer materials are acceptable for piezometer and well installations.

(2) Bentonitic drill muds are often used in rotary drilling applications. The bentonite should be added to water with vigorous mixing and recirculation to ensure uniform properties and to reach a dispersed deflocculated state. For diamond core drilling, low viscosity is usually required due to small clearances. The viscosity of a fluid-mud mixture is related to the solids content and particle shapes and alignments of the additives. During the high speed rotary drilling process, solids have a tendency to spin out and collect inside drill rods. For diamond drilling, low solids content is desirable. If mass is required to balance high hydrostatic pressures, additives such as barite or ilmenite (see 7.1.8) can be added to keep solids contents low.

(3) The need for low solids contents and good lubrication properties point to the use of polymer drill fluids. Natural or synthetic polymer fluids are the best additives for diamond core drilling. Polymer chains such as those from guar gum exhibit flow thinning characteristics in high velocity and shear conditions. Polymer fluids can be weighted with salts to balance hydrostatic pressures. Detergents or deflocculating agents can be added to discharge lines to assist in dropping cuttings to maintain fluid properties.

(4) Fluid management requires considerable experience for successful drilling and sampling. Important fluid parameters include viscosity and density, and these parameters can be tested to improve fluid properties. Test Method D 4380 and American Petroleum Institute (API) test procedures are available for testing drill fluids. Fluid design can be improved by consultation with manufacturers, suppliers, and by review of literature (2-8). Because of a large number of suppliers, varying grades of drill fluid products, and varying requirements of each project, providing an exact procedure for design and mixing of drill fluids, is impossible.

6.3.5 *Rotary Drilling Using Air As the Circulation Medium*:

6.3.5.1 The air compressor should provide an adequate volume of air, without significant contamination, for removal of cuttings. Air requirements depend upon the drill rod and bit type, character of the material penetrated, depth of drilling below ground water level, and total depth of drilling. Airflow rate requirements are usually based on an annulus upflow (or outflow) air velocity of about 3000 to 4000 ft/min (1000 to 1300 m/min) although air upflow (or outflow) rates of less than 3000 ft/min (1000 m/min) are often adequate for cuttings transport. Special reaming shells may be required to maintain air circulation between the annulus of the hole wall and large diameter drill rods (9). For some geologic conditions, air-blast

erosion may increase the borehole diameter in easily eroded materials such that the 1000 m/min (3000 ft/min) circulation rate may not be appropriate for cuttings transport.

6.3.5.2 Compressed air alone often can transport cuttings from the borehole and cool the bit. Pure air alone does not work well in very moist soils. In moist, clayey matrices, mud rings and bit balling may occur. For some geologic conditions, water injected into the air stream will help control dust or break down "mud rings" that can form on the drill rods. If water is injected, the depth(s) of water injection should be documented. In these cases, adding water and a foaming agent to make a misting mixture is desirable (3). Under other circumstances, for example if the borehole starts to produce water, injection of a foaming agent may be required. The depth at which a foaming agent is added should also be recorded. If water infiltration into the borehole impedes circulation, the use of stiffer foams or slurries may be needed (3). Air drilling may not be satisfactory in unconsolidated or cohesionless soils under the ground water table, and fluid drilling systems may be required.

6.3.5.3 The dust collector conducts air and cuttings from the borehole annulus past the drill rod column to an air cleaning device (cyclone separator).

6.3.5.4 The air cleaning device (cyclone separator) separates cuttings from the air returning from the borehole via the dust collector. A properly sized cyclone separator can remove practically all of the cuttings from the return air. A small quantity of fine particles is usually discharged to the atmosphere with the "cleaned" air. Some air cleaning devices consist of a cyclone separator alone and others use a cyclone separator combined with a power blower and sample collection filters. When foaming agents are used, a cyclone-type cuttings separator is not used and foam discharge is accumulated near the top of the borehole.

6.4 *Hole Diameters*—Selection of hole diameter and core size is the most important consideration when planning a coring program. Most rock coring operations are performed with casings and core barrels whose sizes have been standardized by the Diamond Core Drill Manufacturers Association (DCDMA) (5,10). Table 1 provides a summary of nomenclature used for drill hole sizing. For each size of hole, there is a family of casings, core barrels, bits, casing bits, and drill rods with the same primary letter symbol (A through Z) whose design is compatible. Furthermore, the size steps are such that the next smaller size letter equipment can be used inside the next larger group. This nesting of casings, barrels, and rods allows for tapering or telescoping of a drill hole through difficult formations. Since the core barrel must pass through the casings selected, anticipating the necessity for telescoping the hole is important so a large enough diameter is selected at the start.

NOTE 2—Inclusion of the following tables and use of letter symbols in the foregoing text is not intended to limit the practice to use of DCDMA tools. The table and the text references are included as a convenience to the user since the majority of tools in use do meet the DCDMA dimensional standards. Similar equipment of approximately equal size on the metric standard system is acceptable unless otherwise stipulated by the engineer or geologist.

6.4.1 Core diameter, barrel design, bit design, and drilling method have a direct influence on sample quality. Usually

when drilling in delicate formations, larger diameter samples provide higher quality samples. Often, obtaining samples of the weaker seams or joints in the rock is critical to design. A larger diameter core barrel can often reduce shearing stresses imparted to a seam or joint in the core and thus reduce mechanical breakage. For core operations related to most surface drilling project investigations, the minimum core size would correspond to "N" sized borings.

6.4.2 In concrete coring operations, the primary consideration for selecting a core diameter is the maximum size aggregate. For interface shear strength determinations on lift lines, the core diameter should be 2½ to 3 times the maximum size aggregate (11).

6.4.3 In underground hard rock drilling, smaller cores may be used for ease of operation.

6.5 *Casing*—For most coring operations, setting casings in overburden materials will be necessary, especially near the surface to control drill fluid circulation. Typically, water-sensitive soils and loose overburden soils are protected by casings that are set in competent bedrock or to firm seating at an elevation below the water-sensitive formation. The casing used should allow for unobstructed passage of the largest core barrel to be used, and should be free of upsets in inside diameter. A listing of DCDMA casing sizes is shown in Table 1. For rock coring operations, the flush inside diameter "W" series casing is used to allow for use of the matching core barrel. In some cases, flush coupled drive pipe can be used to support the hole. Drive pipe is available in thickness schedules 40, 80, and 160.

6.5.1 Casing and drill rod selection should be based on uphole (or outflow) velocity of the circulation system selected. Uphole (or outflow) velocity should be sufficient to bring up all drill cuttings.

6.5.2 Casing or temporary drill hole support can be accomplished through several methods. One casing advancement technique is to drill incrementally ahead of the casing and then drive the casing to the previous depth. Driven casings should be equipped with a hardened shoe to protect end threads. The inside diameter of the shoe should be flush with the casing inside diameter to avoid hang-ups of the core barrel. In some cases, water-sensitive zones may require cementing for stabilization. Casing can be equipped with diamond casing shoes that allow the casing to be advanced with rotary drilling. The casing shoe should have the same inside diameter as the casing. Casing "shoes" should not be confused with casing "bits" (10). Casing bits are only acceptable for temporary, rotary installation of casing where coring operations are not required, such as temporary installation of a large diameter telescoped casing. Casing "bits" have an inside diameter that is not large enough to pass a core barrel of the same nominal hole size. Hollow-stem augers may be used as casing through overburden soils. Liners may be used inside large diameter casings or augers to increase fluid circulation velocity and optimize cuttings return. If liners are used, they should not be driven and care should be taken to maintain true hole alignment.

6.6 *Drill Rods*—Drill rod selection should be based on consideration of the uphole (or outflow) velocity of the circulating fluids for the circulation system selected. Uphole

TABLE 1 Diamond Core Drill Manufacturers Association Casing Specifications (10)

NOTE 1—W series casing is known as “flush-coupled casing”. W series casing has flush inside diameter throughout, while X series casing has upset diameter with coupling inside diameter equal to flush wall inside diameter.

Size	DCDMA Casing Design									
	Outside Diameter		Inside Diameter W Series		Inside Diameter X Series		Gallons Per 100 ft	Mass Per ft	Threads Per Inch	
	in.	mm	in.	mm	in.	mm			W series	X series
RW, RX	1.44	36.5	1.20	30.5	1.20	302.0	5.7	1.8	5	8
EW, EX	1.81	46.0	1.50	38.1	1.63	41.3	9.2	2.8	4	8
AW, AX	2.25	57.2	1.91	48.1	2.00	50.8	14.8	3.8	4	8
BW, BX	2.88	73.0	2.38	60.3	2.56	65.1	23.9	7.0	4	8
NW, NX	3.50	88.9	3.00	76.2	3.19	81.0	36.7	8.6	4	8
HW, HX	4.50	114.3	4.00	100.0	4.13	104.8	65.3	11.3	4	5
PW, PX	5.50	139.7	5.00	127.0	5.13	130.2		14.0	3	5
SW, SX	6.63	168.3	6.00	152.4	6.25	158.8		16.0	3	5
UW, UX	7.63	193.7	7.00	177.8	7.19	182.6			2	4
ZW, ZX	8.63	219.1	8.00	203.2	8.19	208.0			2	4

velocity should be sufficient to bring up all drill cuttings. Most drilling operations are done with DCDMA drilling rods conforming to the dimensions given in Table 2. Drill rods are normally constructed of tubular steel and have a flush outside wall diameter. Drill rod sections usually have threaded female connections machined in each end. The rods are connected by either removable or welded pins (in one end) strengthened by addition of material at the inside walls. Some drill rod pins are constructed of high strength steel because the joints are a weak link and are subject to failure. Some larger rods are composed of composite materials to reduce weight. Nonmagnetic rods are available for drill holes requiring use of magnetic surveying equipment.

6.6.1 Tables 3 and 4 lists dimensions of wireline and API drill rods that also can be used. Wireline drill rod dimensions are not standardized and are specific to individual manufacturers. The API internal flush joint rods have upset walls on the outside joint and should not be used in air drilling, as air erosion of the formation could occur at the joints.

6.7 *Conventional Core Barrels*—Many types of core barrels are available. A conventional core barrel is attached to the

drilling rods (see 6.6) and the complete set of connected rods and barrel must be removed from the hole at the end of each core run. Torque is applied to the drill rods while the circulating fluid is pumped through the center of the drill rods to the bit. Fluid returns along the annulus between the borehole wall and barrel and drill rods. Conventional barrels are used in smaller drilling operations, such as short underground holes, or when intermittent sampling is to be performed. Most continuous high production coring today is performed with wireline equipment.

6.7.1 Several series of conventional core barrels have standardized dimensions set by the DCDMA (10) in North America. Other organizations such as the British Standards Institute have adopted DCDMA size conventions, while others have different standard dimensions such as metric or Swedish (Craelius) (4). The DCDMA WG, WM, WT series of barrels have standard dimensions as shown in Table 5. Most manufacturers make core barrels fitting the dimensional requirements of one of these series, but there may be variation of other design features such as inner liners, bearings, fluid routing, or

TABLE 2 Diamond Core Drill Manufacturers Association Drill Rod Specifications (10)

Rod Type	Drill Rods, W Series Drill Rod								Thread Type
	Outside Diameter		Inside Diameter		Coupling Identification		Mass Per Foot, lbm	Threads Per Inch	
	in.	mm	in.	mm	in.	mm			
RW	1.094	27.8	0.719	18.3	0.406	10.3	1.4	4	Regular
EW	1.375	34.9	0.938	22.2	0.437	12.7	2.7	3	Regular
AW	1.750	44.4	1.250	31.0	0.625	15.9	4.2	3	Regular
BW	2.125	54.0	1.500	44.5	0.750	19.0	6.1	3	Regular
NW	2.625	66.7	2.000	57.4	1.38	34.9	7.8	3	Regular
HW	3.500	88.9	3.062	77.8	2.375	60.3	9.5	3	Regular
WJ Series Drill Rod									
AWJ	1.75	44.5	1.43	36.4	0.63	16.1	3.6	5	Taper
BWJ	2.13	54.0	1.81	46.0	0.75	19.3	5.0	5	Taper
NWJ	2.63	66.7	2.25	57.0	1.13	28.8	6.0	4	Taper
KWJ	2.88	73.0	2.44	61.9	1.38	34.9	...	4	Taper
HWJ	3.50	88.9	2.88	73.1	1.75	44.5	...	4	Taper
Old Standard									
E	1.313	33.3	0.844	21.4	0.438	11.1	...	3	Regular
A	1.625	41.3	1.266	28.6	0.563	14.3	...	3	Regular
B	1.906	48.4	1.406	35.7	0.625	15.9	...	5	Regular
N	2.375	60.3	2.000	50.8	1.000	25.4	...	4	Regular

TABLE 3 Wireline Drill Rod Dimensions

Rod Type	Wireline Drill Rods				Gallons Per 100 ft	Weight Per lbm	Threads Per Inch	Thread Type
	Outside Diameter in.	Outside Diameter mm	Inside Diameter in.	Inside Diameter mm				
AQWL ^A	1.750	44.5	1.375	34.9	7.7	3.3	4	Taper
AXWL ^B	1.813	46.0	1.500	38.1	9.18	2.8	4	Regular
BQWL ^A	2.188	55.6	1.812	46.0	13.4	4.0	3	Taper
BXWL ^B	2.250	57.2	1.906	48.4	14.82	3.8	4	Regular
NQWL ^A	2.750	69.9	2.375	60.3	23.0	5.2	3	Taper
NXWL ^B	2.875	73.0	2.391	60.7	23.30	6.8	3	Regular
HQWL ^A	3.500	88.9	3.062	77.8	38.2	7.7	3	Taper
HXWL ^B	3.500	88.9	3.000	76.2	36.72	8.7	3	Regular
PQWL ^A	4.625	117.5	4.062	103.2
CPWL ^B	4.625	117.5	4.000	101.6

^A AQ Series rods are specific manufacturer's design.

^B BX Series rods are specific manufacturer's design.

TABLE 4 American Petroleum Institute Drill Rod Dimensions (12)

API Tool Joints—Regular External Flush (in.-lb System)				
Type/size	Rod o.d. (in.)	Rod o.d. (mm)	Rod i.d. (in.)	Rod i.d. (mm)
API 2-3/8	3.125	79.4	1	25.4
API 2-7/8	3.75	95.3	1.25	31.8
API 3-1/2	4.25	108.0	1.5	38.1
API 4	5.25	133.4	1.75	44.5
API 4-1/2	5.75	146.1	2.25	57.2
API 5 1/2	6.75	171.5	2.75	69.9
API 6 5/8	7.75	196.9	3.5	88.9
API 7 5/8	8.88	225.6	4.0	101.6
API 8 5/8	10.0	25.4	4.75	120.7
API Tool Joints—Regular Internal Flush				
Type/size	Rod o.d. (in.)	Rod o.d. (mm)	Rod i.d. (in.)	Rod i.d. (mm)
API 2-3/8	3.375	85.7	1.75	44.5
API 2-7/8	4.125	104.8	2.125	54.0
API 3-1/2	4.75	120.7	2.687	68.3
API 4	5.75	146.1	3.25	82.6
API 4-1/2	6.125	155.6	3.75	95.3

core extrusion methods. Some manufacturers make core barrels that do not fit dimensional DCDMA standards for core diameters. An example is the "D₃ and D₄" series core barrels shown in Table 5. Use of other nonstandardized core barrels is acceptable if the type of barrel is appropriate for the drilling conditions and the type of barrel used is reported.

6.7.2 For most investigations and when rock types are unknown, it is desirable to specify a swivel type, double tube core barrel with a split inner barrel, or solid inner barrel with split liners (also known as "triple tube"). The barrel should be equivalent to, or better than, "M" series design to reduce fluid exposure. If the formation is poorly lithified, and contains soil-like layers such as shales with interbedded clay seams, a large diameter core barrel may be specified to aid in recovery. These desired components are discussed below.

6.7.3 Core barrels generally come in 5- or 10-ft core run lengths. Ten-foot core runs can be performed with good rock conditions. If soft, friable, or highly fractured formations are encountered, it may be necessary to select barrels with 5-ft core runs to reduce the possibility of blockages and improve core recovery.

6.7.4 Important design components of a conventional core barrel are tube type (triple, double, or single), inner tube rotation (rigid or swivel), core bit type, including fluid discharge locations (internal discharge - contacting core, or face

TABLE 5 Approximated Core and Hole Diameters for Core Barrels

^A Core barrel type/group	Set bit dimension inside diameter = core diameter		Set reaming shell = hole diameter	
	in.	mm	in.	mm
Conventional Core Barrels ^B				
RWT (d)	0.735	18.7	1.175	29.8
EWD ₃	0.835	21.2	1.485	37.7
EWG (s.d.), EWM (d)	0.845	21.5	1.485	37.7
EWT (d)	0.905	23.0	1.485	37.7
AWD ₃ , AWD ₄	1.136	28.9	1.890	48.0
AWG (s.d.), AWM (d)	1.185	30.1	1.890	48.0
AWT (d)	1.281	32.5	1.890	48.0
BWD ₃ , BWD ₄	1.615	41.0	2.360	59.9
BWG (s.d.), BWM (d)	1.655	42.0	2.360	59.9
BWT (s.d.)	1.750	44.4	2.360	59.9
NWD ₃ , NWD ₄	2.060	52.3	2.980	75.7
NWG (s.d.), NWM (d)	2.155	54.7	2.980	75.7
NWT (s.d.)	2.313	58.8	2.980	75.7
HWD ₃ , HWD ₄	2.400	61.1	3.650	92.7
HWG (s.d.)	3.000	76.2	3.907	99.2
HWT (s.d.)	3.187	80.9	3.907	99.2
DCDMA Large Diameter—Double-Tube Swivel—Core Barrels				
2 3/4 × 3 7/8	2.690	68.3	3.875	98.4
4 × 5 1/2	3.970	100.8	5.495	139.3
6 × 7 3/4	5.970	151.6	7.750	196.8
Wireline Core Barrel Systems ^C				
AXWL (joy)	1.016	25.8	1.859	47.2
AQWL	1.065	27.1	1.890	48.0
BXWL	1.437	36.5	2.375	60.3
BQWL	1.432	36.4	2.360	60.0
BQ ₃ WL	1.313	33.4	2.360	60.0
NXWL	2.000	50.8	2.984	75.8
NQWL	1.875	47.6	2.980	75.7
NQ ₃ WL	1.75	44.4	2.980	75.7
HXWL	2.400	61.0	3.650	92.7
HQWL	2.500	63.5	3.790	96.3
HQ ₃ WL	2.375	60.3	3.790	96.3
CPWL	3.345	85.0	4.827	122.6
PQWL	3.345	85.0	4.827	122.6
PQ ₃ WL	3.25	82.6	4.827	122.6

^As = single tube; d = double tube.

^BConventional double-tube core barrels are available in either rigid or swivel designs. The swivel design inner barrel is preferred for sampling because it aids in preventing core rotation. In general, smallest core for given hole size results in best recovery in difficult conditions, that is, triple-tube core barrels. Use of double-tube-swivel type barrels with split liners is recommended in geotechnical investigations for best recovery and least sample damage.

^CWireline dimensions and designations may vary according to manufacturer.

discharge and waterway design), core lifter, and reaming shell.

6.7.5 *Single Tube Core Barrel*—The single tube core barrel

is the simplest in design (see Fig. 2). The core is subjected to drill fluid circulation over its entire length. Once the core in the barrel is broken from parent material, it will rotate with the assembly. These effects break up all but the most competent core (4, 12). Because of fluid exposure and rotational effects, this barrel should not be used to sample weak, friable, and water-sensitive materials. Additional disadvantages of this core barrel include: poor diamond performance of the cutting bit in fractured or friable formations, frequent core blocking, and severe diamond erosion due to re-drilling of broken fragments. This system is only suitable for sampling massive, hard,

competent, homogeneous rock or concrete. Due to these disadvantages, this core barrel type is not recommended for routine investigations.

6.7.5.1 In shallow applications, generally less than 5 ft (2 m) competent concrete or soil cement is cored with single tube masonry core barrels with portable drill rigs (11). If there is evidence of excessive core erosion, breakage, or blocking, use of double tube swivel type barrels should be considered.

6.7.6 *Double Tube Core Barrel*—Double tube core barrels contain an inner barrel that protects the core from contact with drill fluid and from erosion or washing from the circulating

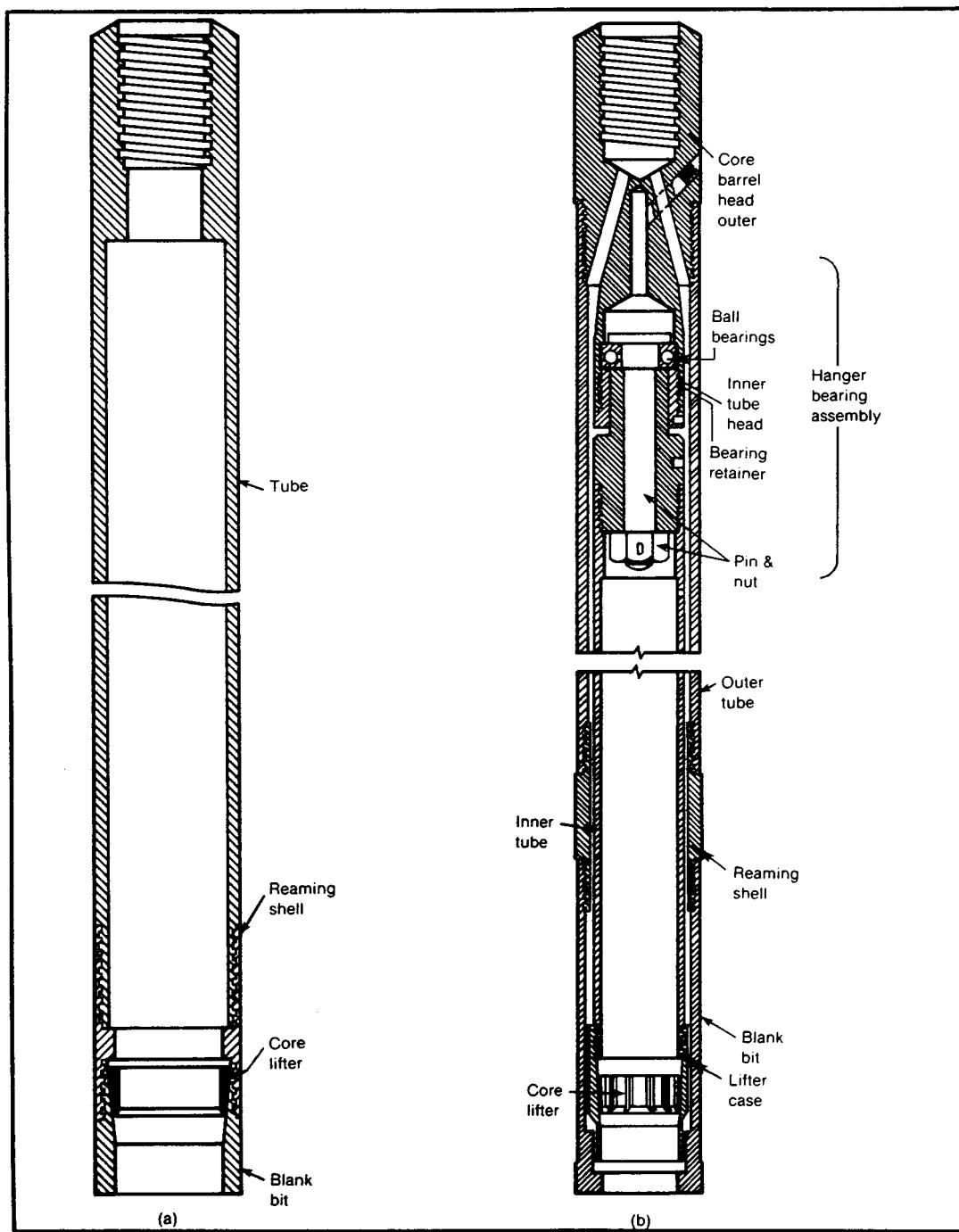


FIG. 2 Diagram of Two Types of Core Barrels: (a) Single Tube and (b) Double Tube

fluid. The bottom of the core may be subjected to fluid exposure depending on the locations of fluid discharge. Some barrel designs have fluid discharge near the lifter, near the bit, or on the bit face (see 6.7.7). The advantage of double tube design is greater protection of the core. Washing erosion is reduced and weaker zones can be recovered.

6.7.6.1 The inner barrel of double tube core barrels may be either solid or split. The barrel may be designed to accept split liners. Barrels accepting liners require a special inside diameter bit gage. Use of a split barrel or inner liners is preferred for easier handling of cores. Sections of the cores containing weak seams are more likely to remain intact. The cores may be rolled onto PVC half rounds. The use of split liners or PVC half rounds aids in placement of core in core boxes and handling of cores that require sealing for moisture preservation. In certain materials, such as expansive shales or blocked high fractured materials, the split liner may spring apart even though it is taped before sampling. In these cases, removing the inner barrel may be difficult. Remedies include use of a shorter core barrel, triple tube design with extruder (see 6.7.7.1), or the solid liner.

6.7.6.2 Double tube core barrels come in two designs, either rigid or swivel type.

(1) *Rigid Double Tube Barrel*—This barrel is rarely used in practice today due to limitations listed below. In the rigid barrel design, the inner barrel is fixed and it spins at the same rate as the outer barrel. Rigid tube barrels have fewer working parts, but suffer from similar disadvantages as single tube barrels. Core recovery is poor and diamond wear in friable and fractured formations is excessive. In softer deposits, there will be rotation of broken core, core blockage, and resulting crushing and grinding, which causes excessive bit wear. This type of design is not preferred for routine investigations where rock conditions are not known, as the equipment is only acceptable in hard competent formations.

(2) *Swivel Type Double Tube Barrels*—In the swivel type barrel (Fig. 3 and Fig. 4 show typical barrels) the inner barrel is connected to the drill string through a bearing that allows the inner barrel to remain stationary during coring. The core is completely protected once it enters the liner. This design reduces rock crushing and grinding and resulting blockages. Depending on the fluid discharge point, the core may be exposed to fluids near the bottom of the barrel and there could be erosion of soft or fractured formations.

(3) Double tube swivel type core barrels are the best selection for drilling rock of varying hardness and fracture. This type of barrel is typically the minimum requirement when drilling investigations are for engineering structures where varying conditions would be encountered.

6.7.7 *Triple Tube Core Barrels*—The triple tube barrel is essentially a double tube barrel with a liner inside the inner tube. The inner liner is made from either split metal half rounds or tubular acrylic. The use of split liners increases efficiency in handling and logging. If the purpose of the investigation is solely for logging of cores, the use of solid acrylic liners may be acceptable.

6.7.7.1 Many manufacturers offer the triple tube option and barrels are available that also have hydraulic core extrusion

systems. These systems help with removing the inner liners by use of a piston in the top of the inner barrel. This feature is especially helpful if split liners are bowed apart by lateral expansion of the core. The extrusion systems allow for simple loading and unloading of liners.

6.7.8 *Conventional Barrel Standardized Designs*—DCDMA standardized barrels come in three designs, WG, WM, and WT series.

6.7.8.1 The “G” series barrels are the most simple in design and have a simple pin threaded bit into which the core lifter is inserted. Due to the simplicity of design, these barrels are the most rugged, with fewer parts and less maintenance. The only disadvantage is that the fluid exits above the lifter and the bottom of the core is exposed to fluids during drilling.

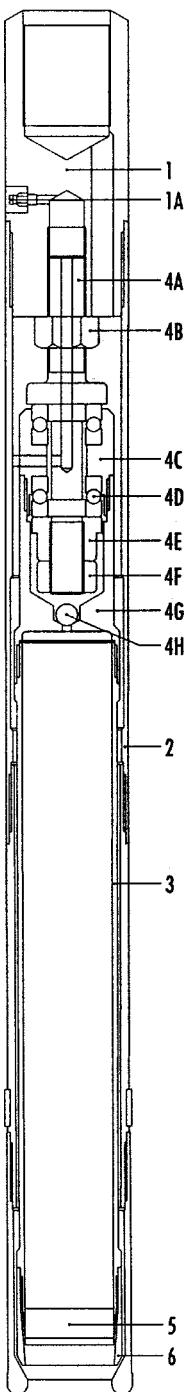
6.7.8.2 The “M” design core barrel is the best available tool for recovering of rock cores even in the most friable and caving strata. The inner barrel is equipped with a lifter case that extends into the bit shank and therefore reduces exposure of the core to fluid during drilling. The fluid only contacts the core near the crown of the bit, and washing or eroding of the core is minimized. Face discharge bits are also available for almost no core exposure to fluids. The DCDMA “M” designs have been modified by individual manufacturers. Barrels such as the D₄ type barrels are equivalent to “M” design barrels.

6.7.8.3 The “T” series design stands for thin walled or thin kerf. This design provides larger core-to-hole size ratio. This barrel style has a thin kerf and requires fewer diamonds and less torque for drilling. It gives good performance in hard, dense, and friable shattered rock formations (4). This type of core barrel is thin and lightweight and must be handled with care.

6.7.9 *Large Diameter, Double Tube, Swivel Design*—The large diameter conventional core barrel is similar in design to the double tube, swivel type, “WM” design, but with the addition of a ball valve in all the three sizes to control fluid flow. A sludge barrel to catch heavy cuttings is also incorporated on the two larger sizes (Fig. 5). The three sizes standardized by DCDMA are 2³/₄-in. (69.8 mm) by 3⁷/₈-in. (98.4 mm), 4-in. (101.6 mm) by 5¹/₂-in. (139.7 mm), and 6-in. (152.4 mm) by 7³/₄-in. (196.8 mm). Other sizes such as 4⁵/₈-in. (117.5 mm) by 3-in. (76.2 mm), 5³/₄-in. (146 mm) by 4-in. (101.6 mm), and 8-in. (203.2 mm) by 5⁷/₈-in. (149.2 mm) have been designed by individual manufacturers. The larger barrels with increased annulus are suitable for larger rotary rig mud pumps and air compressors. Options include either conventional or face discharge bits with either conventional core lifter or spring finger basket retainers. Some core barrel systems can be converted to soil coring operations, but require carbide bit and a projecting cutting shoe. Some large diameter barrels are convertible from conventional to wireline coring operation.

6.8 *Wireline Core Barrels*—Wireline drilling for investigation in rock is a principal drilling system used for deep rock coring applications using surface mounted drill rigs (Fig. 6 and Fig. 7). In the wireline system, the drill rods are only removed from the hole to replace the coring bit, to free a stuck inner barrel, or to adjust the headspace of the inner barrel. The inner core barrel can be removed and replaced without removing the drill rods, allowing for continuous coring. The drill rods

NWD4-SERIES D4 CORE BARREL



NWD4 SERIES D4 CORE BARREL					
HOLE SIZE	CORE SIZE	OUTER TUBE O.D.	OUTER TUBE I.D.	INNER TUBE O.D.	INNER TUBE I.D.
2.980 in	2.060 in	2.906 in	2.562 in	2.375 in	2.135 in
75.7 mm	51.3 mm	73.8 mm	65.1 mm	60.3 mm	54.2 mm
NWD4 SERIES D4 CORE BARREL ASSEMBLIES					
PART DESCRIPTION					
Core Barrel Assembly - 5 ft (1.5 m)					
Core Barrel Assembly - 10 ft (3.0 m)					
Core Barrel Assembly - 5 ft (1.5 m) Split					
Core Barrel Assembly - 10 ft (3.0 m) Split					
SPARE PARTS FOR NWD4 SERIES D4 CORE B					
1. Core Barrel Head, NW Rod					
A. Grease Fitting					
2. Outer Tube, 5 ft (1.5 m), C.P. Ends					
Outer Tube, 10 ft (3.0 m), C.P. Ends					
3. Inner Tube, 5 ft (1.5 m), C.P. ID					
Inner Tube, 10 ft (3.0 m), C.P. ID					
Inner Tube, Split, 5 ft (1.5 m) C.P. ID					
Inner Tube, Split, 10 ft (3.0 m) C.P. ID					
4. Bearing Assembly					
A. Bearing Shaft					
B. Lock Nut					
C. Bearing Retainer					
D. Bearing, Thrust Ball (2 Required)					
E. Hex Nut, Flanged					
F. Hex Nut, Regular					
G. Inner Tube Connector					
H. Ball					
5. Core Lifter, Skirtless					
6. Inner Tube Shoe/Case, C.P. ID					
7. Thread Protector Sub					

FIG. 3 Typical Double Tube Swivel Type-Conventional Core Barrel

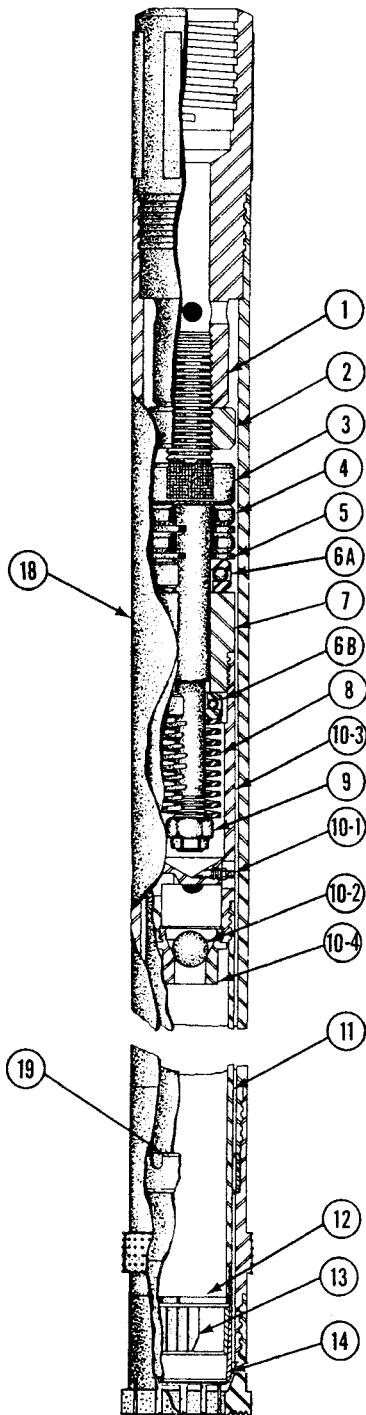
also act as a casing, and fluid is circulated from the bit through the annulus between the drill hole wall and drill rod. Wireline drill rod dimensions are not standardized. Table 3 lists the typical wireline rod sizes and Table 5 lists core barrel sizes of predominant types of wireline equipment available. Other systems such as heavy duty systems with differing dimensions may be available and are acceptable for use if dimensions are reported.

6.8.1 The inner barrel assembly is locked into the lead section of wireline drill rod by means of a retrievable overshot latching mechanism. A latching device locks into a complementary recess in the wall of the leading outer tube such that the outer tube could be rotated without causing the rotation of the inner tube. After the core run, the overshot mechanism is lowered through the rods and latches onto a spearhead on the top of the core barrel assembly and is hoisted to the surface

Double-Tube Swivel Type
STANDARD CONVENTIONAL SYSTEM

Parts List

NV2" Core Barrel



Item No.	Description	No. Req'd	Unit Weight
			lbs kg
1-20	Core Barrel Assy 5 ft	—	76.0 34,5
1-20	Core Barrel Assy 10 ft	—	126.0 57,2
-	Core Barrel Assy 15 ft **	—	178.0 80,8
1-10	Head Assy	—	19.0 8,6
1	Outer Tube Head	1	8.7 3,9
2	Lock Nut	1	*
3	Spindle	1	3.1 1,4
4	Shut Off Valve	2	*
5	Valve Adjusting Washer	2	*
6A	Ball Thrust Bearing	1	*
6B	Hanger Bearing	1	*
7	Spindle Bearing	1	1.6 0,7
8	Compression Spring	1	*
9	Self Locking Nut	1	*
10	Inner Tube Cap Assy	—	3.6 1,6
10-1	Hydraulic Grease Fitting	1	*
10-2	Stainless Steel Ball	1	*
10-3	Inner Tube Cap	1	3.2 1,5
10-4	Check Valve Body	1	*
11	Inner Tube, 5 ft	1	12.3 5,6
11	Inner Tube, 10 ft	1	24.5 11,1
11	Inner Tube, 15 ft	1	38.0 17,2
12	Stop Ring	1	*
13	Fluted Core Lifter	1	*
14	Core Lifter Case	1	*
18	Outer Tube, 5 ft	1	44.0 20,0
18	Outer Tube, 10 ft	1	77.6 35,2
19	Inner Tube Stabilizer	1	*
20	Thread Protector (not shown)	1	2.5 1,1

Weighs less than one pound (0,45 kg)

The Core Barrel Assembly 15 foot, consists of one Head Assembly, one each inner Tube 15 foot, Stop Ring, Core Lifter, Core Lifter Case, Outer Tube 5 foot, Outer Tube 10 foot, Thread Protector and two Inner Tube Stabilizers.

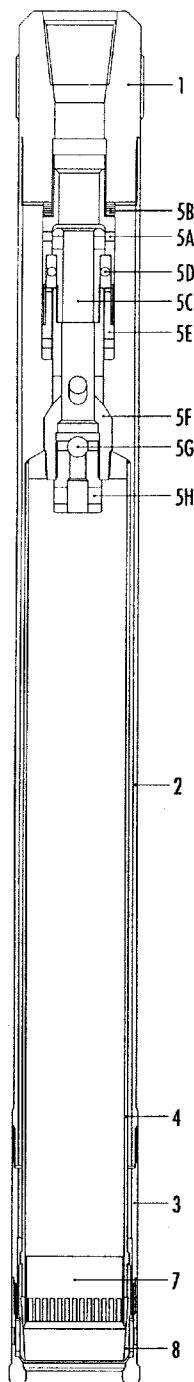
FIG. 4 Typical Double Tube Swivel Type-Core Barrel

with cable and wireline winch. The inner tube assembly consists of an inner tube with removable core lifter case and core lifter at one end, and a removable inner tube head swivel bearing, suspension adjustment, and a latching device with a release mechanism at the opposite end. If continuous coring is

not required, the retrievable inner core barrel assembly can be replaced with a pilot bit for hole advancement.

6.8.2 Wireline coring systems are designed for long life bits with wide kerf and impregnated or surface set diamonds. Both internal discharge and face discharge bits are available. The

7 - 3 / 4 in X 5 - 7 / 8 in CORE BARREL



7-3/4 in X 5-7/8 in CORE BARREL					
HOLE SIZE	CORE SIZE	OUTER TUBE O.D.	OUTER TUBE I.D.	INNER TUBE O.D.	INNER TUBE I.D.
8.000 in 203.2 mm	5.875 in 149.2 mm	7.500 in 190.5 mm	7.000 in 177.8 mm	6.500 in 165.1 mm	6.125 in 155.6 mm
7-3/4 in X 5-7/8 in CORE BARREL ASSEMBLIES					
PART DESCRIPTION					
Core Barrel Assembly - 5 ft (1.5 m)					
Core Barrel Assembly - 10 ft (3.0 m)					
Core Barrel Assembly - 5 ft (1.5 m) Split					
Core Barrel Assembly - 10 ft (3.0 m) Split					
SPARE PARTS FOR 7-3/4 in X 5-7/8 in CORE					
1. Core Barrel Head (4-1/2" A.P.I. Reg.)					
2. Outer Tube, 5 ft (1.5 m)					
Outer Tube 10 ft (3.0 m)					
3. Outer Tube Sub					
4. Inner Tube 5 ft (1.5 m), CP, ID					
Inner Tube 10 ft (3.0 m), CP, ID					
Inner Tube 5 ft (1.5 m) Split					
Inner Tube 10 ft (3.0 m) Split					
5. Bearing Assembly					
A. Cartridge Cap					
B. Shim, Set					
C. Bearing Retainer					
D. Bearing, Thrust, Ball					
E. Cartridge Plug					
F. Inner Tube Plug					
G. Ball					
H. Pressure Relief Plug					
6. Inner Tube Connector, Split					
7. Core Lifter, HF					
8. Inner Tube Shoe, BW					
9. Thread Protector Sub					
10. Tube Clamp, 7-1/2 in (190.5 mm) (outer)					
OPTIONAL EQUIPMENT					
11. Core Lifter, Skirtless, HF					

Note: If you do not see the item or size you are looking for, please contact your supplier for additional product information.

FIG. 5 Typical Large Diameter Series —Conventional Core Barrel

inner core barrel has a dual shut-off valve that stops fluid circulation to alert the driller of a core blockage.

6.8.3 The advantages of wireline drilling are:

6.8.3.1 Significant reduction in rod handling time compared with conventional core barrels.

6.8.3.2 Increased coring bit life with decreased diamond loss.

6.8.3.3 High core recovery.

6.8.3.4 Caving is reduced and rods aid to stabilize the drill hole walls.

6.8.3.5 Rods are flush or near flush both inside and outside and can be used as a temporary casing.

6.8.3.6 Various in-hole instrumentation packages can be sent through the end of the drill string to test the bottom of the hole. Wireline packer systems can be used for pressure water test (Test Method D 4630).

NQ Core Barrel

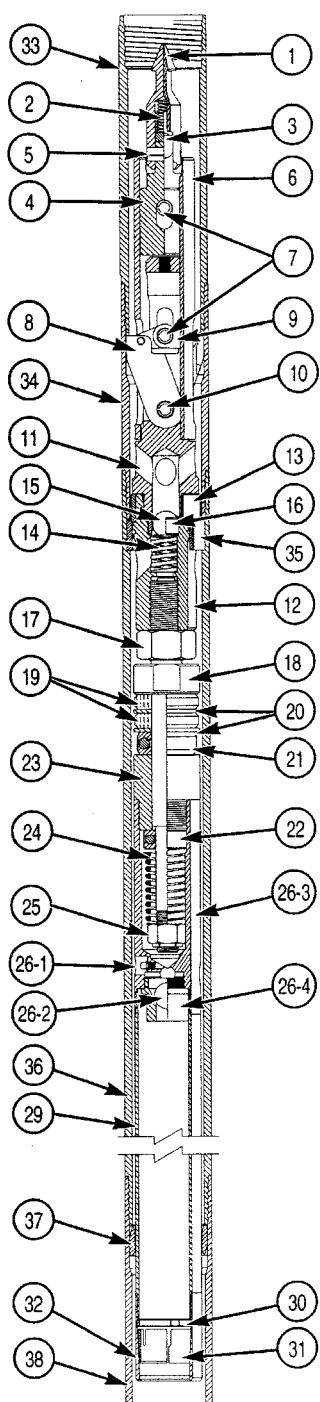


FIG. 6 Typical Wireline Rock Coring System

6.8.3.7 Two inner barrel assemblies can be used for maximum productivity in continuous coring operations.

6.8.4 The disadvantages of wireline drilling are:

6.8.4.1 Equipment is more expensive than conventional equipment, and

6.8.4.2 Wireline systems are complicated and operations require additional training.

6.8.5 Table 5 lists common wireline core barrel sizes. They are available in "A" through "P" size. When rock samples are

Item No.	Description	No. Req'd	Unit Weight	
		lbs	kg	
1-38	Core Barrel Assy 5 ft	—	—	
1-38	Core Barrel Assy 10 ft	—	—	
1-32	Inner Tube Assy 5 ft	—	—	
1-32	Inner Tube Assy 10 ft	—	—	
1-28	Head Assy	—	—	
1	Spearhead Point	1	*	
2	Compression Spring	1	*	
3	Detent Plunger	1	*	
4	Spearhead Base	1	1.3	0,6
5	Spiral Pin, 7/16" x 1"	1	*	
6	Retracting Case	1	—	
7	Spring Pin, 1/2" x 2"	2	*	
8	Latch	2	*	
9	Link	2	*	
10	Spring Pin, 1/2" x 1-1/2"	1	*	
11	Upper Latch Body	1	2.9	1,3
12	Lower Latch Body	1	3.1	1,4
13	Landing Shoulder	1	—	
14	Dry Hole Spring, Light (not installed)			
15	Stainless Steel Ball, 22 mm (not installed)			
16	Bushing (not installed)			
17	Hex Nut	1	*	
18	Spindle	1	3.1	1,4
19	Shut Off Valve, Hard	2	*	
20	Valve Adjusting Washer	2	*	
21	Thrust Bearing	1	—	
22	Hanger Bearing	1	*	
23	Spindle Bearing	1	1.6	0,7
24	Compression Spring	1	*	
25	Self Locking Nut	1	*	
26	Inner Tube Cap Assy	—	3.3	1,5
26-1	(consists of 26-1, -2, -3, -4)			
26-1	Hydraulic Grease Fitting	1	*	
26-2	Stainless Steel Ball, 22 mm	1	*	
26-3	Inner Tube Cap	1	2.9	1,3
26-4	Check Valve Body	1	*	
27	Landing Indicator Bushing (not installed)			
28	Dry Hole Spring, Medium (not installed)			
29	Inner Tube, 5 ft	1	12.3	5,6
29	Inner Tube, 10 ft	1	24.5	11,1
30	Stop Ring	1	—	
31	Core Lifter	1	*	
32	Core Lifter Case	1	1.6	0,7
33	Full-Hole HT Tanged Locking Coupling**	1	5.9	2,7
34	Adapter Coupling	1	3.2	1,5
35	Landing Ring	1	*	
36	Outer Tube, 5 ft	1	44.0	20,0
36	Outer Tube, 10 ft	1	77.6	35,2
37	Inner Tube Stabilizer	1	*	
38	Thread Protector	1	2.5	1,1

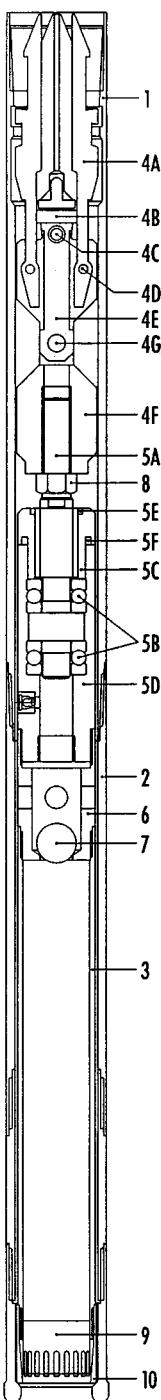
Weighs less than 1.0 lb (0,45 kg)

"HT" means "Heat-Treated"

to be obtained for testing of engineering properties, "H" size is recommended, "N" is minimum, and "P" size will result in better recovery of difficult formations.

6.8.6 The wireline core barrel is essentially a double tube swivel type core barrel. Since the core lifter is part of the inner barrel assembly, exposure of the core to drill fluid is minimized similar to "M" style conventional core barrels. Most systems can be adjusted for front discharge (inside above bit gage) or face discharge.

N X B W I R E L I N E C O R E B A R R E L



NXB WIRELINE CORE BARREL					
HOLE SIZE	CORE SIZE	OUTER TUBE O.D.	OUTER TUBE I.D.	INNER TUBE O.D.	INNER TUBE I.D.
2.980 in 75.7 mm	1.075 in 47.6 mm	2.875 in 73.0 mm	2.391 in 60.7 mm	2.200 in 55.9 mm	1.969 in 50.0 mm
NXB WIRELINE CORE BARREL ASSEMBLIES					
PART DESCRIPTION					
Core Barrel Assembly - 5 ft Complete (1.5 m)					
Core Barrel Assembly - 10 ft Complete (3.0 m)					
Core Barrel Assembly 5 ft (1.5 m) Split					
Core Barrel Assembly 10 ft (3.0 m) Split					
SPARE PARTS FOR NXB WIRELINE CORE BA					
1. Locking Coupling					
Locking Coupling, NQ Box Thread					
2. Outer Tube 5 ft (1.5 m)					
Outer Tube 10 ft (3.0 m)					
3. Inner Tube 5 ft (1.5 m)					
Inner Tube 10 ft (3.0 m)					
Inner Tube, Split, 5 ft (1.5 m)					
Inner Tube, Split, 10 ft (3.0 m)					
4. Quad-Latch Pivot Head Assembly					
A. Quad latch (4 required)					
B. Spring - Blue (Top)					
C. Spring - Red (Bottom)					
D. Pin (4 required)					
E. Head Base (Top)					
F. Head Base (Bottom)					
G. Pin					
5. Bearing Assembly					
A. Bearing Shaft					
B. Bearing (2 required)					
C. Bearing Retainer					
D. Housing w/Zerk & cap					
E. O-Ring					
F. O-Ring					
6. Inner Tube Connector					
InnerTube Connection, Split					
7. Ball					
8. Nut					
9. Core Lifter, Skirtless, Buttress					
10. Inner Tube Shoe/Case, CP					

FIG. 7 Typical Wireline Rock Coring System

6.8.7 Most manufacturers offer a triple tube barrel, which is preferred for most operations. The third tube is a split inner liner that facilitates sample handling.

6.8.8 Some wireline barrels systems are convertible from soil sampling to rock sampling operation. These barrels are equipped with soil barrels that can lead in front of the core bit. Some systems are equipped with spring loaded soil core barrels. These systems are advantageous when soils or soft rock are encountered.

6.9 *Core Barrel Bits*— One of the most important equipment decisions in rock core drilling is the bit selection. Both the bit and reaming shell act together to cut the hole. There are many bit design factors involved when selecting the proper bit for good core recovery. Factors included in selection are:

- 6.9.1 Diamond type—source,
- 6.9.2 Diamond matrix (surface set or impregnated),
- 6.9.3 Rock hardness, grain size, and formation,
- 6.9.4 Drill power, and

6.9.5 Barrel type.

6.9.6 Bit selection is a trial and error process that may require several iterations. After a bit is selected, it is tried with the drill to be used. Penetration rate and bit life should be evaluated and a different design selected if necessary.

6.9.7 Important features of diamond drilling bits include crown shape, diamonds, and waterways. The crown is the end of the bit that contains a kerf equipped with cutting media. A round or semi-round kerf is frequently used with conventional core barrels. Flat, stepped, or v-ring designs are often used with wireline drilling with impregnated bits.

6.9.8 Important features of the diamonds themselves are the size, quality, quantity, setting, and matrix quality (4). Surface set bits are used in most conventional coring operations. The size of diamonds is expressed in equivalent stones per carat (SPC). The typical SPC range is from 20 to 100 for surface set bits, with the finer stones being used for harder rock matrixes. Larger diamonds are used for softer, more friable formations. Impregnated bits are fragments mixed with metal and pressed and sintered into the bit. The diamond fragments are throughout the crown and the bit is, in a sense, self-sharpening. Impregnated bits are used in more severe drilling conditions and in wireline drilling where long life is essential.

6.9.9 Waterway design is also an important aspect of bit selection. Surface channel routing of the fluids from inside gage to outside is typical in conventional and wireline drilling for most crystalline rocks that are not sensitive to fluid erosion. Face discharge bits should be used for soft friable formations where fluid erosion is detrimental. Step-face discharge configurations further inhibit core erosion. Special flush discharge air ports are used with air and air-foam drilling operations. The softer the matrix, the larger the waterways must be to avoid blocking and plugging.

6.9.10 For very soft materials, it is not necessary to use diamonds as the cutting media. Diamonds can often be replaced with tungsten carbide or polycrystalline inserts for coring soft materials. Carbide and polycrystalline bits often have cutting teeth arranged in a sawtooth fashion. Polycrystalline bits (diamond grown to tungsten carbide substrates that are soldered or furnace onto the crown) have replaced natural diamonds for coring in some softer sedimentary formations. Some core barrels, such as the large diameter series, can readily be changed from diamond rock coring to carbide soil sampling modes.

6.9.11 Manufacturers are an excellent resource to assist in selecting the matrix and style of bit, depending on rock conditions, drill power, and barrel type. Most manufacturers have a method for rating diamond matrices and bits into different series and groups (3). DCDMA has selection codes for impregnated bits (10). Manufacturers should be consulted for initial recommendations for your specific drilling conditions, and as the project progresses, they can work with the driller to refine designs and drilling technique. Based on wear patterns, it may be possible to switch series or design to optimize results. In hard competent formations, bit selection may be drill rig-dependent (rotation rate and advance forces). It is beyond the scope of this practice to address drill bit selection. In addition to manufacturers' advice, there are

several useful references to provide information in evaluating causes for wear (3, 4, 10).

6.9.12 Most diamond bits have salvage value and should be returned to manufacturers for credit toward future purchases.

6.10 *Reaming Shells*—The reaming shell is a subassembly of a row or strip of material placed on the outside of the core barrel for some distance behind the core bit. It is designed to ream and enlarge the hole to a final diameter and must allow for adequate fluid circulation to the surface. The shell also acts as a collar or centralizer for the barrel. Manufacturers should be consulted for appropriate reaming shell designs for the formations to be drilled. They may be surface set with diamond bits, impregnated with diamond particles, inserted with tungsten carbide strips or slugs, hard faced with various types of hard surfacing materials, or furnished blank, as appropriate to the formation being cored.

6.11 *Core Lifters*—Core lifters are used to break the core from parent material at the end of a core run. As coring progresses, the lifter floats up in its beveled recessed slot in the shoe. After an increment of core has been drilled that corresponds to core barrel length, the rotation is stopped. Fluid is circulated until cuttings are cleared, and then the drill pipe is steadily retracted. The lifter will slide down the beveled shoe and impart an increasing grip on the core. The core frequently breaks near the base of the hole, and often a snap can be felt in the drill pipe as the core breaks from parent material.

6.11.1 Core lifters of the split ring type, either plain or hard surfaced, are recommended and must be maintained in good condition, along with core lifter cases or inner tubes extensions or inner tube shoes. Basket or finger type lifters with any necessary adapters may be used with core barrels if directed by the engineer or the geologist.

6.12 *Core Boxes*—These are durable waxed cardboard or wooden boxes with partitioned compartments for storing the core samples (see Practice D 5079).

6.13 *Auxiliary Equipment*—The following auxiliary equipment is typically used for the rock core drilling project:

6.13.1 *Drilling bits*—roller rock bits, drag bits, chopping bits, boulder busters, and fishtail bits;

6.13.2 *Tools*—pipe wrenches, core barrel wrenches, chain tong, strap wrench, watch, RPM counter, lubrication equipment, core splitters, rod wicking, extruders, hand sieves or strainers, and marking and packaging tools;

6.13.3 *Rod holding equipment*—closed pulling ring, open iron ring, knife edge holding dog, holding iron, chucking rods, safety foot clamp, manila rope, bolt, and clevis pins;

6.13.4 *Fluid circulation equipment*—hoses, positive displacement pump along with packing and seals, water swivel, pressure gages, flow meters, water-level meters, and mud pit; and

6.13.5 *Drill area, platform, and leveling*—cribbing, planking, lumber, saw horses, metal saw horses with chain vise.

7. Reagents and Materials

7.1 *Water-Based Drill Fluid Additives*—Listed below are commonly used additives for water-based drilling fluids. Drilling additives in contact with drinking water aquifers should meet the requirements of NSF 60-1988.

NOTE 3—In some areas, certain types of drill fluid products are not allowed by state and local environmental authorities. Before using any drill fluid product, check with the authorities to determine its acceptability.

7.1.1 Beneficiated bentonite, a primary viscosifier and drill hole sealer, consists of montmorillonite with other naturally occurring minerals and various additives such as guar gum, sodium carbonate, or polyacrylates, or a combination thereof.

7.1.2 Unbeneficiated bentonite, a primary viscosifier and drill hole sealer, consists of montmorillonite with other naturally occurring minerals, but without additives such as guar gum, sodium carbonate, or polyacrylates.

7.1.3 Sodium carbonate powder (soda ash) is used to precipitate calcium carbonate from the drilling fluid water-base before adding other components. An increase in pH will occur with the addition of sodium carbonates. Sodium hydroxides (caustic soda) generally should not be used for this application.

7.1.4 Carboxymethylcellulose powder (CMC) is sometimes used in a water-based fluid as a viscosifier and as an inhibitor to clay hydration. Some additives to water-based drilling-fluid systems retard clay hydration, thus inhibiting swelling of clays on the drill hole wall and “balling” or “smearing” of the bit.

7.1.5 Potassium chloride (muriated potash) or diammonium phosphate can be used as an inhibitor to clay hydration.

7.1.6 Polyacrylamide, a primary viscosifier and clay hydration inhibitor, is a polymer mixed with water to create a drilling fluid.

7.1.7 Guar gum, a primary viscosifier, drill-hole sealer, and hydration inhibitor, is a starch mixed with a water base. The water must be neutral to slightly acidic and hydrochloric acid is sometimes used to pre-treat the water base. Guar gum will degrade with time, but various chemicals can be used to accelerate decomposition.

7.1.8 Barium sulfate increases the density of water-based drilling fluids to help support the borehole wall. It is a naturally occurring high-specific gravity mineral processed to a powder for rotary drilling fluid applications.

7.1.9 Lost-circulation materials are added to the drilling fluid to seal the drill-hole wall when fluids are being lost through large pores, cracks, or joints. These additives usually consist of various coarse textured materials such as shredded paper or plastic, bentonite chips, wood fibers, or mica.

7.1.10 Attapulgite, a primary viscosifier for rotary drilling in high-salinity environments, is a clay mineral drilling-fluid additive.

8. Precautions

8.1 The drilling and sampling equipment shall be complete and in good order. A sufficient amount of drill rods, casings, drill bits, core barrels, core barrel liners, water meters, pumps, and pressure gages shall be in hand before the start of drilling. Measurement devices such as pressure gages and RPM counters shall be functioning in conformance with the manufacturer's specifications.

8.2 The use of fluid or air under high pressure may cause damage to formation materials by fracturing or excessive erosion if drilling conditions are not carefully maintained and monitored. If formation damage is evident and undesirable,

other drilling method(s) should be considered.

8.2.1 Fluid pressure should be monitored during drilling. Fluid pressure at the bit should be as low as possible to maintain circulation and to reduce possibility of hydraulic fracturing or excessive erosion of surrounding materials. Normally, injection fluid pressures are fully monitored. Changes in fluid return and circulation pressure may indicate occurrence of excessive erosion, formation fluid loss, core blockage, or formation fracturing. Any abrupt changes or anomalies in the fluid pressure should be noted and documented, including the depth(s) of occurrence(s).

9. Procedure

9.1 Perform site inspections to determine locations of boreholes, and to select disposal sites for waste products during drilling.

9.1.1 Evaluate applicable methods for environmental protection and traffic regulation during core drilling.

9.1.2 Determine site accessibility and availability of water for core drilling operation. Check around the drill site for overhead obstructions or hazards, such as power lines, before raising the mast. A survey of underground and all other utilities is required before drilling to evaluate hazards.

9.2 Fabricate and assemble the drill mounting platform. The platform can take a variety of forms. The type of platform will depend on the terrain encountered, the stipulated depth of the borehole, and the accessibility of the drill site. Specialized mountings such as a barge or stilts or specially constructed towers are necessary to mount platforms for drilling over water.

9.3 For water-based fluid drilling operation, a mud pit is positioned to collect and filter fluid return flow. An initial quantity of drilling fluid is mixed, usually using the mud pit as the primary mixing reservoir.

9.3.1 For air-based circulation systems, the dust collector or cyclone separator is positioned and “sealed” to the ground surface.

9.4 Case any interval of the borehole that penetrates the overburden. This will prevent collapsing of loose materials into the borehole or loss of drill fluid. The casing should extend through the overburden and extend at least 5 ft (1.5 m) into the rock. Casing may be omitted if the borehole will stand open without caving. Deeper casing(s) or nested casing(s) may be required to facilitate adequate drill hole fluid circulation and hole control. Records of casing(s) lengths and depth intervals installed should be maintained and documented.

9.4.1 Surface casings can be installed using a variety of drilling methods. Hollow-stem auger drilling (D 6151) has been used successfully for surface casing and has an added benefit of obtaining samples of the overburden soils. The surface casing is normally backfilled, pressed, or sealed in place with bentonite or cement, or both.

9.4.2 A datum for measuring drill hole depth should be established and documented. This datum normally consists of a stake driven into stable ground surface, the top of the surface casing, or the drilling deck. If there is possibility for movement of the surface casing, it should not be used as a datum. If the hole is to be later surveyed for elevation, record and report the height of the datum to the ground surface.

9.5 The core barrel is assembled following manufacturers' instructions. Keep core barrels cleaned and lubricated and free from damage, dents, or other defects that might affect core quality. Inspect barrels for wear, clearances, dents, or galls. Check condition of core lifters, fluid passages, relief holes, ball checks, valve rubbers, and inner barrel stabilizers, if present. Assemble and disassemble core barrels with the correct tools for the job.

9.5.1 The inner tube of double tube core barrels must be positioned correctly for proper operation. For both conventional and wireline systems where fluid circulates between the bit and lifter case, check that the proper clearance is maintained for circulation. For wireline systems, this will require engaging the inner barrel while the outer barrel is held vertically. If clearances are not correct, they should be adjusted using the adjustment screw on top of the barrel assembly.

9.5.2 For swivel type inner barrels, inspect the bearing assemblies and confirm the inner barrel is free to rotate smoothly when assembled.

9.6 An initial assembly of lead drill rod and core barrel is attached to the drill mechanism through a spindle or below the drill head, and placed within the top of the surface casing. Hole depth is determined by keeping track of the length of the rod-bit assemblies and comparing its position relative to the established surface datum. Hole depth for increments of drilling, coring, and sampling is recorded on the drill log.

9.7 The drilling-fluid circulation pump or air compressor is activated, causing drilling fluid or air to circulate through the system.

9.8 Drilling fluid or air circulation is initiated and rotation and axial force are applied to the drill rod and bit until drilling progresses to a depth where: (1) when the core sample has fully entered the core barrel or blockage is apparent, (2) sampling or in-situ testing will be performed, or (3) the length of the drill-rod column limits further penetration.

9.8.1 Maintain fluid circulation at a rate suitable for the formation to be drilled. Fluid should be circulated at a rate sufficient to circulate cuttings and cool the bit. Fluid pressures should be monitored during drilling. Avoid drilling at excessive advance rate, which could cause plugging of the bit and core blockage and damage. Changes in fluid return and circulation pressures may indicate occurrence of excessive erosion, formation fluid loss, or formation fracturing. Any abrupt changes or anomalies in fluid pressure should be noted and documented, including depth(s) of occurrence(s).

9.8.2 Maintain air circulation at a rate suitable for the formation, and avoid circulation losses. Add water or foam as necessary to maintain circulation. Zones of low air return or no air return should be documented. Should air-blast erosion occur, depth(s) of the occurrence(s) should be noted and documented. Air is particularly susceptible to blocking off circulation and causing uplift to occur very quickly.

9.8.3 Samples of drill cuttings can be collected for analysis of materials penetrated. If cuttings samples are obtained, the depth(s) and interval(s) should be documented.

9.8.4 The selection of proper rotation rate and down feed (advance) or hold-back pressure depends on many factors. The drilling process is iterative in nature. Diamond drilling in a

harder matrix usually requires higher rotation rates and down force pressures. With the correct material and equipment configurations, diamond bit performance is generally optimum at rotation rates of at least 400 rpm or greater. Rates of up to 1000 rpm can be used, depending on the material. However, too high a rate can cause tearing of the formation and core recovery problems. Softer materials with other bits such as polycrystalline, require slower rotation rates. Vibration is extremely important to the drill hole and core quality and must be minimized. Sufficient thrust needs to be transmitted to the bit so that bit elements can cut the rock. The goal is to find the rotation rate and thrust that will result in high quality core and acceptable bit life.

9.8.4.1 Monitor advance or down force pressure, or hold-back pressures, and rotation rates of drill rods during drilling. Observe the penetration rate and drill cuttings as they relate to the geologic strata being penetrated. Document occurrences of any significant abrupt changes and anomalies during drilling.

9.9 Rotation is stopped, the advance or down force pressure is released, and circulation is continued for a short time until the drill cuttings are removed from the borehole annulus. Circulation is stopped and the barrel is rested on the hole bottom to determine hole depth.

9.10 Remove the core barrel and the core from the borehole. Disassemble the core barrel and remove the core.

9.10.1 With double tube barrels, when the barrel is retracted, the core lifter grips the core and the core is normally broken from the base material at the base of the hole. The core lifter is located inside the barrel above the bit typically about 0.1ft. When the core is broken there will be a small pedestal of core left in the hole. As long as the lifter is not slipping, and core is of good quality, successive recoveries will be close to 100%. If for some reason, the lifter case slips, there will be low recovery recorded and there will be a longer pedestal on the subsequent sampling event. If there appears to be excessive core on the subsequent run, or there is visible evidence of the lifter slipping, these occurrences should be noted. If it is obvious the pedestal was present, the length can be accounted for in determination of recovery (see 10.1) of the previous run. These occurrences and corrections should be appropriately noted in the drill report.

9.10.2 With single tube core barrels in shallow drilling operations, the core can be broken with a wedge and lifted by wire hoop to the surface.

9.11 Reassemble the core barrel and return it to the borehole. Check for proper barrel conditions as noted in 9.7. The use of two barrels can greatly speed coring operations; as one barrel is cleaned and reassembled the other is in use in coring.

9.12 Drilling depth is increased by attaching an additional drill-rod section(s) to the top of the previously advanced drill-rod column and resuming drilling operations in accordance with 9.8-9.12.

9.13 *Rock Core Handling*—Use of split inner barrel liners greatly increases the efficiency of handling of cores, especially in broken formations. Cores can be transferred into plastic half rounds for logging and sealing. Log, preserve, and place core samples in core boxes in accordance with Practice D 5079.

9.14 *Rock Core Recovery*—Rock core shall be recovered

continuously in the borehole. If recovery drops below 100 % (see Section 10), modify the drilling procedure, that is, adjust the drilling RPM, down feed pressure, the drilling fluid type and flow, or change the type and the size of core barrel or bit used, until core recovery is improved to a level acceptable to the project geologist or project engineer. Minimize mechanical breaks in the core during core drilling as much as possible.

9.14.1 *Poor Recovery*—Stop core drilling when recovery equals or falls below 50 %. If recovering samples is important, select a better core barrel or bit design. In some cases, it may be necessary to attempt soil sampling techniques (11).

9.15 If conditions prevent advance of the drill hole to the stipulated depth, the borehole shall be cemented and redrilled, or reamed and cased, cased and advanced with a smaller size drill bit and core barrel, or abandoned, as directed by the engineer or geologist.

9.16 Prepare boring logs and place the rock sample in core boxes, and mark and pack them in accordance with Practice D 5079.

10. Calculation

10.1 *Calculate Percent Core Recovery*—Determine the rock core recovery as the ratio of length of core recovered to the length drilled, and express as a percent.

$$\text{Percent core recovery} = \frac{\text{Length of the recovered core}}{\text{Total length of the core run}} \times 100 \quad (1)$$

10.2 Calculate Rock Quality Designation (RQD) in accordance with D 6032.

11. Report

11.1 Report the following information:

11.1.1 *Site Conditions*—Site description: description of the site and any unusual circumstances.

11.1.2 *Personnel*—document all personnel at the site during the drilling process, including the driller, helpers, geologist or logger, engineer, and other monitors or visitors.

11.1.3 Weather conditions during drilling.

11.1.4 Working hours, operating times, break-down times, and sampling times. Report any long-term delays in the drilling and installation process.

11.1.5 Report any unusual occurrences that may have happened during the investigation.

11.1.6 *Drilling Methods*:

11.1.6.1 Description of the coring system including type, sizes, core barrels, fluid pump, fluid circulation, and discharge systems. Note intervals of equipment change or drilling method changes and reasons for change.

11.1.6.2 Type, quantities, and drill hole locations of use of additives added to the circulation media. If changes to the circulating medium are made, such as addition of water or conversion to foam, the depth(s) or interval(s) of these changes should be documented.

11.1.6.3 Descriptions of circulation rates, cuttings returns, including quantities, over intervals used. Note the quantity and locations of loss of circulation and probable cause.

11.1.6.4 Descriptions of drilling conditions related to drilling pressures, rotation rates, and general ease of drilling related to subsurface materials encountered. These descriptions can be

very general, and should report how the sampling of different materials progressed.

11.1.6.5 *Records of casing installed*—Report type, amount and times of installation. Record water levels (dates and elevation) observed during drilling.

11.1.7 *Sampling*—When core sampling or undisturbed sampling at the base of the boring separate from coring operations, report condition of the base of the boring before sampling and any slough or cuttings present in the recovered sample. Samples of fluid circulation cuttings can be collected for analysis of materials being penetrated. If cuttings samples are taken, the depth(s) and interval(s) should be documented.

11.1.8 *In-situ Testing*:

11.1.8.1 For devices inserted below the base of the drill hole, report the depths below the base of the hole and any unusual conditions during testing.

11.1.8.2 For devices testing or seating at the drill hole wall, report any unusual conditions of the drill hole wall such as inability to seat pressure packers.

11.1.9 *Installations*—A description of completion materials and methods of placement, approximate volumes placed, intervals of placement, methods of confirming placement, and areas of difficulty or unusual occurrences.

11.2 *Boring Logs*—Boring logs should be completed in accordance with Guide D 5434. Some information that the boring log should include is:

11.2.1 Project identification, boring number, location, orientation, date boring began, date boring completed, and drillers' name(s).

11.2.2 Elevation coordinates of the top of the borehole.

11.2.3 Elevation of, or depth to, ground water surface, and any changes in water level, including the dates and times measured.

11.2.4 Elevations or depths at which the drilling fluid returns were lost and amount of return with depth. Report advance or down feed and hold-back pressures, rotation rates of drill rods, fluid/gas pressure, and circulations return during drilling. Report the penetration rate and drill cuttings as they relate to the geologic strata being penetrated. Document any significant abrupt changes and anomalies that occur during drilling.

11.2.5 Size, type, and design of core barrels used. Size, type, and set of core bits and reaming shells used. Size, type, and design and lengths of all casing used, and locations or elevations of casings used. Records of casing(s) lengths and depth intervals installed should be maintained and documented.

11.2.6 Length of each core run and the percentage of core recovery.

11.2.7 Driller's description of the core in each run, if no engineer or geologist was present.

11.2.8 Geologist's or engineer's description of the core recovered in each run. Subsurface description, including dip of strata, jointing, cavities, fissures, core loss, and any other observations made by the geologist, engineer, or the driller that could yield information about the formation encountered during drilling. Depth, thickness, and apparent nature of the filling of each soft seam or cavity encountered. Report the

calculated RQD and D 6032.

11.2.9 Any change in the character of the drilling fluid or drilling fluid return.

11.2.10 Reservoir, tidal, or current information, if the drilling is near or over a body of water.

11.2.11 Drilling time in minutes per foot and down feed gage pressure, when applicable, and the RPM of the drill rods.

11.2.12 Notations of character of drilling, that is, soft, slow, easy, smooth, and others.

12. Precision and Bias

12.1 This practice does not produce numerical data; therefore, a precision and bias statement is not applicable.

12.2 The boring log reflects the subjective opinions of the engineer, the geologist, or the driller. Therefore, the designer must exercise proper prudence when interpreting the boring logs.

12.3 This procedure produces data on rock type and rock quality and recovery factors such as RQD (D 6032) that may reflect the biases of the persons collecting the data. Precision for determination of RQD will be addressed in D 6032.

13. Keywords

13.1 diamond drilling; exploration; rock; rock coring; rock investigations; site characterization

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SUMMARY OF CHANGES

This section identifies the principal changes to this practice that have been incorporated since the last issue. There have been significant changes to the standard. The previous standard was developed in the 1970's. Since that time wireline systems have gained preference in industry.

- (1) Expanded Section 1 to add reference to other drilling standards and safety standards.
- (2) Added logging and transport and storage standards to Section 2.
- (3) Added a Terminology section and defined drilling-related terms.
- (4) Added Section 4, Summary of Practice, to describe drilling, coring, and sampling processes.
- (5) Expanded Apparatus section to discuss the advantages and disadvantages of selecting specific designs. Added sections on fluid and air drilling. Changed and expanded section on wireline drilling methods.
- (6) Added section on materials and presented major drill fluid materials and additives.
- (7) Removed section on transportation and storage of rock core and referred to Practice D 5079.
- (8) Added new Section 8, Precautions, to warn against fracturing and drill hole disturbance.
- (9) Added section on Calculations and added recovery and RQD. Referred to RQD as a separate D 6032.
- (10) Changed section Boring Log to Report and referred to Guide D 5434.

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Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass¹

This standard is issued under the fixed designation D 2216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 This test method covers the laboratory determination of the water (moisture) content by mass of soil, rock, and similar materials where the reduction in mass by drying is due to loss of water except as noted in 1.4, 1.5, and 1.7. For simplicity, the word "material" hereinafter also refers to either soil or rock, whichever is most applicable.

1.2 Some disciplines, such as soil science, need to determine water content on the basis of volume. Such determinations are beyond the scope of this test method.

1.3 The water content of a material is defined in 3.2.1.

1.4 The term "solid material" as used in geotechnical engineering is typically assumed to mean naturally occurring mineral particles of soil and rock that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement, and the like) may require special treatment or a qualified definition of water content. In addition, some organic materials may be decomposed by oven drying at the standard drying temperature for this method (110°C). Materials containing gypsum (calcium sulfate dihydrate or other compounds having significant amounts of hydrated water) may present a special problem as this material slowly dehydrates at the standard drying temperature (110°C) and at very low relative humidities, forming a compound (calcium sulfate hemihydrate) which is not normally present in natural materials except in some desert soils. In order to reduce the degree of dehydration of gypsum in those materials containing gypsum, or to reduce decomposition in highly organic soils, it may be desirable to dry these materials at 60°C or in a desiccator at room temperature. Thus, when a drying temperature is used which is different from the standard drying temperature as defined by this test method, the resulting water content may be different from standard water content determined at the standard drying temperature.

NOTE 1—Test Methods D 2974 provides an alternate procedure for determining water content of peat materials.

1.5 Materials containing water with substantial amounts of soluble solids (such as salt in the case of marine sediments)

when tested by this method will give a mass of solids which includes the previously soluble solids. These materials require special treatment to remove or account for the presence of precipitated solids in the dry mass of the specimen, or a qualified definition of water content must be used. For example, see Noorany² regarding information on marine soils.

1.6 This test method requires several hours for proper drying of the water content specimen. Test Method D 4643 provides for drying of the test specimen in a microwave oven which is a shorter process. Also see Gilbert³ for details on the background of this test method.

1.7 This standard requires the drying of material in an oven at high temperatures. If the material being dried is contaminated with certain chemicals, health and safety hazards can exist. Therefore, this standard should not be used in determining the water content of contaminated soils unless adequate health and safety precautions are taken.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

- D 653 Terminology Relating to Soil, Rock, and Contained Fluids⁴
- D 2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils⁴
- D 4220 Practice for Preserving and Transporting Soil Samples⁴
- D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils⁴
- D 4643 Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method⁴
- D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil and Rock Testing⁴

¹ This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

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² Noorany, I., "Phase Relations in Marine Soils", Journal of Geotechnical Engineering, ASCE, Vol. 110, No. 4, April 1984, pp. 539–543.

³ Gilbert, P.A., "Computer Controlled Microwave Oven System for Rapid Water Content Determination", Tech. Report GL-88-21, Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, MS, November 1988.

⁴ Annual Book of ASTM Standards, Vol 04.08.

D 6026 Guide for Using Significant Digits in Calculating and Reporting Geotechnical Test Data⁵
 E 145 Specification for Gravity-Convection And Forced-Ventilation Ovens⁶

3. Terminology

3.1 Refer to Terminology D 653 for standard definitions of terms.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *water content (of a material)*—the ratio expressed as a percent of the mass of “pore” or “free” water in a given mass of material to the mass of the solid material. A standard temperature of $110^{\circ} \pm 5^{\circ}\text{C}$ is used to determine these masses.

4. Summary of Test Method

4.1 A test specimen is dried in an oven at a temperature of $110^{\circ} \pm 5^{\circ}\text{C}$ to a constant mass. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

5. Significance and Use

5.1 For many materials, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and its index properties.

5.2 The water content of a material is used in expressing the phase relationships of air, water, and solids in a given volume of material.

5.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limits as determined by Test Method D 4318, is used to express its relative consistency or liquidity index.

6. Apparatus

6.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, meeting the requirements of Specification E 145 and capable of maintaining a uniform temperature of $110 \pm 5^{\circ}\text{C}$ throughout the drying chamber.

6.2 *Balances*—All balances must meet the requirements of Specification D 4753 and this section. A Class GP1 balance of 0.01g readability is required for specimens having a mass of up to 200 g (excluding mass of specimen container) and a Class GP2 balance of 0.1g readability is required for specimens having a mass over 200 g. However, the balance used may be controlled by the number of significant digits needed (see 8.2.1 and 12.1.2).

6.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and change in mass upon repeated heating, cooling, exposure to materials of varying pH, and cleaning. Unless a dessicator is used, containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used (see Note 7). One container is needed for each water content determination.

NOTE 2—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination.

6.4 *Desiccator*—A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium sulfate. It is preferable to use a desiccant which changes color to indicate it needs reconstitution. See 10.5.

NOTE 3—Anhydrous calcium sulfate is sold under the trade name Drierite.

6.5 *Container Handling Apparatus*, gloves, tongs, or suitable holder for moving and handling hot containers after drying.

6.6 *Miscellaneous*, knives, spatulas, scoops, quartering cloth, sample splitters, etc, as required.

7. Samples

7.1 Samples shall be preserved and transported in accordance with Practice 4220 Groups B, C, or D soils. Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight. Disturbed samples in jars or other containers shall be stored in such a way as to prevent or minimize moisture condensation on the insides of the containers.

7.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as thin-walled steel tubes, paint cans, etc.) or plastic sample bags are used.

8. Test Specimen

8.1 For water contents being determined in conjunction with another ASTM method, the specimen mass requirement stated in that method shall be used if one is provided. If no minimum specimen mass is provided in that method then the values given below shall apply. See Howard⁷ for background data for the values listed.

8.2 The minimum mass of moist material selected to be representative of the total sample shall be in accordance with the following:

Maximum particle size (100 % passing)	Standard Sieve Size	Recommended minimum mass of moist test specimen for water content reported to $\pm 0.1\%$	Recommended minimum mass of moist test specimen for water content reported to $\pm 1\%$
2 mm or less	No. 10	20 g	20 g ^A
4.75 mm	No. 4	100 g	20 g ^A
9.5 mm	3/8-in.	500 g	50 g
19.0 mm	3/4-in.	2.5 kg	250 g
37.5 mm	1 1/2 in.	10 kg	1 kg
75.0 mm	3-in.	50 kg	5 kg

^ATo be representative not less than 20 g shall be used.

8.2.1 The minimum mass used may have to be increased to obtain the needed significant digits for the mass of water when reporting water contents to the nearest 0.1 % or as indicated in 12.1.2.

⁵ Annual Book of ASTM Standards, Vol 04.09.

⁶ Annual Book of ASTM Standards, Vol 14.02.

⁷ Howard, A. K., “Minimum Test Specimen Mass for Moisture Content Determination”, Geotechnical Testing Journal, A.S.T.M., Vol. 12, No. 1, March 1989, pp. 39-44.

8.3 Using a test specimen smaller than the minimum indicated in 8.2 requires discretion, though it may be adequate for the purposes of the test. Any specimen used not meeting these requirements shall be noted on the test data forms or test data sheets.

8.4 When working with a small (less than 200g) specimen containing a relatively large gravel particle, it is appropriate not to include this particle in the test specimen. However, any discarded material shall be described and noted on the test data forms or test data sheets.

8.5 For those samples consisting entirely of intact rock, the minimum specimen mass shall be 500 g. Representative portions of the sample may be broken into smaller particles, depending on the sample's size, the container and balance being used and to facilitate drying to constant mass, see 10.4. Specimen sizes as small as 200 g may be tested if water contents of only two significant digits are acceptable.

9. Test Specimen Selection

9.1 When the test specimen is a portion of a larger amount of material, the specimen must be selected to be representative of the water condition of the entire amount of material. The manner in which the test specimen is selected depends on the purpose and application of the test, type of material being tested, the water condition, and the type of sample (from another test, bag, block, and the likes.)

9.2 For disturbed samples such as trimmings, bag samples, and the like, obtain the test specimen by one of the following methods (listed in order of preference):

9.2.1 If the material is such that it can be manipulated and handled without significant moisture loss and segregation, the material should be mixed thoroughly and then select a representative portion using a scoop of a size that no more than a few scoopfuls are required to obtain the proper size of specimen defined in 8.2.

9.2.2 If the material is such that it cannot be thoroughly mixed or mixed and sampled by a scoop, form a stockpile of the material, mixing as much as possible. Take at least five portions of material at random locations using a sampling tube, shovel, scoop, trowel, or similar device appropriate to the maximum particle size present in the material. Combine all the portions for the test specimen.

9.2.3 If the material or conditions are such that a stockpile cannot be formed, take as many portions of the material as practical, using random locations that will best represent the moisture condition. Combine all the portions for the test specimen.

9.3 Intact samples such as block, tube, split barrel, and the like, obtain the test specimen by one of the following methods depending on the purpose and potential use of the sample.

9.3.1 Using a knife, wire saw, or other sharp cutting device, trim the outside portion of the sample a sufficient distance to see if the material is layered and to remove material that appears more dry or more wet than the main portion of the sample. If the existence of layering is questionable, slice the sample in half. If the material is layered, see 9.3.3.

9.3.2 If the material is not layered, obtain the specimen meeting the mass requirements in 8.2 by: (1) taking all or one-half of the interval being tested; (2) trimming a repre-

tative slice from the interval being tested; or (3) trimming the exposed surface of one-half or from the interval being tested.

NOTE 4—Migration of moisture in some cohesionless soils may require that the full section be sampled.

9.3.3 If a layered material (or more than one material type is encountered), select an average specimen, or individual specimens, or both. Specimens must be properly identified as to location, or what they represent, and appropriate remarks entered on the test data forms or test data sheets.

10. Procedure

10.1 Determine and record the mass of the clean and dry specimen container (and its lid, if used).

10.2 Select representative test specimens in accordance with Section 9.

10.3 Place the moist test specimen in the container and, if used, set the lid securely in position. Determine the mass of the container and moist material using a balance (see 6.2) selected on the basis of the specimen mass. Record this value.

NOTE 5—To prevent mixing of specimens and yielding of incorrect results, all containers, and lids if used, should be numbered and the container numbers shall be recorded on the laboratory data sheets. The lid numbers should match the container numbers to eliminate confusion.

NOTE 6—To assist in the oven-drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

10.4 Remove the lid (if used) and place the container with moist material in the drying oven. Dry the material to a constant mass. Maintain the drying oven at $110 \pm 5^\circ\text{C}$ unless otherwise specified (see 1.4). The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors. The influence of these factors generally can be established by good judgment, and experience with the materials being tested and the apparatus being used.

NOTE 7—In most cases, drying a test specimen overnight (about 12 to 16 h) is sufficient. In cases where there is doubt concerning the adequacy of drying, drying should be continued until the change in mass after two successive periods (greater than 1 h) of drying is an insignificant amount (less than about 0.1%). Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

NOTE 8—Since some dry materials may absorb moisture from moist specimens, dried specimens should be removed before placing moist specimens in the same oven. However, this would not be applicable if the previously dried specimens will remain in the drying oven for an additional time period of about 16 h.

10.5 After the material has dried to constant mass remove the container from the oven (and replace the lid if used). Allow the material and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents and/or its being heated. Determine the mass of the container and oven-dried material using the same type/capacity balance used in 10.3. Record this value. Tight fitting lids shall be used if it appears that the specimen is absorbing moisture from the air prior to determination of its dry mass.

NOTE 9—Cooling in a desiccator is acceptable in place of tight fitting lids since it greatly reduces absorption of moisture from the atmosphere during cooling especially for containers without tight fitting lids.

11. Calculation

11.1 Calculate the water content of the material as follows:

$$w = [(M_{cws} - M_{cs})/(M_{cs} - M_c)] \times 100 = \frac{M_w}{M_s} \times 100 \quad (1)$$

where:

w	= water content, %,
M_{cws}	= mass of container and wet specimen, g,
M_{cs}	= mass of container and oven dry specimen, g,
M_c	= mass of container, g,
M_w	= mass of water ($M_w = M_{cws} - M_{cds}$), g, and
M_s	= mass of solid particles ($M_s = M_{cds} - M_c$), g.

12. Report

12.1 Test data forms or test data sheets shall include the following:

12.1.1 Identification of the sample (material) being tested, such as boring number, sample number, test number, container number etc.

12.1.2 Water content of the specimen to the nearest 1 % or 0.1 %, as appropriate based on the minimum sample used. If this method is used in concert with another method, the water content of the specimen should be reported to the value required by the test method for which the water content is being determined. Refer to Guide D 6026 for guidance concerning significant digits, especially if the value obtained from this test method is to be used to calculate other relationships such as unit weight or density. For instance, if it is desired to express dry unit weight to the nearest 0.1 lbf/f³(0.02 kN/m³), it may be necessary to use a balance with a greater readability or use a larger specimen mass to obtain the required significant digits the mass of water so that the water content can be determined to the required significant digits. Also, the significant digits in Guide D 6026 may need to be increased when calculating phase relationships requiring four significant digits.

12.1.3 Indicate if test specimen had a mass less than the minimum indicated in 8.2.

12.1.4 Indicate if test specimen contained more than one material type (layered, etc.).

12.1.5 Indicate the temperature of drying if different from $110 \pm 5^\circ\text{C}$.

12.1.6 Indicate if any material (size and amount) was excluded from the test specimen.

12.2 When reporting water content in tables, figures, etc., any data not meeting the requirements of this test method shall be noted, such as not meeting the mass, balance, or temperature requirements or a portion of the material is excluded from the test specimen.

13. Precision and Bias

13.1 *Statement on Bias*—There is no accepted reference value for this test method; therefore, bias cannot be determined.

13.2 Statements on Precision:

13.2.1 *Single-Operator Precision (Repeatability)*—The single-operator coefficient of variation has been found to be 2.7 percent. Therefore, results of two properly conducted tests by the same operator with the same equipment should not be considered suspect unless they differ by more than 7.8 percent of their mean.⁸

13.2.2 *Multilaboratory Precision (Reproducibility)*⁹—The multilaboratory coefficient of variation has been found to be 5.0 percent. Therefore, results of two properly conducted tests by different operators using different equipment should not be considered suspect unless they differ by more than 14.0 percent of their mean.

14. Keywords

14.1 consistency; index property; laboratory; moisture analysis; moisture content; soil aggregate; water content

⁸ These numbers represent the (1s) and (d2s) limits as described in Practice C 670.

⁹ These numbers represent the (1s %) and (d2s %) limits as described in Practice C 670.

SUMMARY OF CHANGES

Committee D-18 has identified the location of selected changes to this standard since the last issue. (D 2216-92) that may impact the use of this standard.

- (1) Title was changed to emphasize that mass is the basis for the standard.
- (2) Section 1.1 was revised to clarify “similar materials”.
- (3) New 1.2 was added to explain a limitation in scope. The other sections were renumbered as appropriate.
- (4) An information reference was included in 1.5.
- (5) An information reference was included in 1.6
- (6) A new ASTM referenced document was included in 2.1.
- (7) New Footnotes 2, 3, and 5 were added and identified. Other footnotes were renumbered where necessary for sequential identification.
- (8) Information concerning balances was added in 6.2
- (9) Section 6.3 was revised to clarify the use of close-fitting lids, and a reference to Note 8 was added.

- (10) In 6.4, “anhydrous calcium phosphate” was changed to “anhydrous calcium sulfate” to correct an error and to agree with Note 3.
- (11) A typo in 8.1 was corrected from “before” to “below” and a footnoted reference was added for information.
- (12) A portion of 8.2 was deleted for clarity.
- (13) A new 8.2.1 was added to clarify minimum mass requirements.
- (14) Sections 8.3, 8.4, 9.3.3, and 12.1 were changed to substitute “test data form/sheet” for “report”.
- (15) Footnote seven was identified.
- (16) Section 9.2.1 was revised to improve clarity and intent.
- (17) The word “possible” was changed to “practical” in 9.2.3.

- (18) Section 9.3.1 and 9.3.2 were revised to improve clarity and for practicality.
- (19) A reference to Guide D 6026 was added in 12.1.2.
- (20) Footnotes 8 and 9 were added to 13.2.1 and 13.2.2, respectively. These were inadvertently omitted from the 1992

version. These explanations provide clarity and information to the user.

- (21) A Summary of Changes was added to reflect D-18's policy.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Standard Test Method for Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements¹

This standard is issued under the fixed designation D 2664; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the strength of cylindrical rock core specimens in an undrained state under triaxial compression loading. The test provides data useful in determining the strength and elastic properties of rock, namely: shear strengths at various lateral pressures, angle of internal friction, (angle of shearing resistance), cohesion intercept, and Young's modulus. It should be observed that this method makes no provision for pore pressure measurements. Thus the strength values determined are in terms of total stress, that is, not corrected for pore pressures.

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

D 4543 Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances²

E 4 Practices for Force Verification of Testing Machines³

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process⁴

3. Significance and Use

3.1 Rock is known to behave as a function of the confining pressure. The triaxial compression test is commonly used to simulate the stress conditions under which most underground rock masses exist.

4. Apparatus

4.1 *Loading Device*—A suitable device for applying and measuring axial load to the specimen. It shall be of sufficient

capacity to apply load at a rate conforming to the requirements specified in 7.2. It shall be verified at suitable time intervals in accordance with the procedures given in Practices E 4 and comply with the requirements prescribed in the method.

4.2 *Pressure-Maintaining Device*—A hydraulic pump, pressure intensifier, or other system of sufficient capacity to maintain constant the desired lateral pressure, σ_3 .

NOTE 1—A pressure intensifier as described by Leonard Obert in U.S. Bureau of Mines Report of Investigations No. 6332, "An Inexpensive Triaxial Apparatus for Testing Mine Rock," has been found to fulfill the above requirements.

4.3 *Triaxial Compression Chamber*⁵—An apparatus in which the test specimen may be enclosed in an impermeable flexible membrane; placed between two hundred platens, one of which shall be spherically seated; subjected to a constant lateral fluid pressure; and then loaded axially to failure. The platens shall be made of tool steel hardened to a minimum of Rockwell 58 HRC, the bearing faces of which shall not depart from plane surfaces by more than 0.0005 in. (0.0127 mm) when the platens are new and which shall be maintained within a permissible variation of 0.001 in. (0.025 mm). In addition to the platens and membrane, the apparatus shall consist of a high-pressure cylinder with overflow valve, a base, suitable entry ports for filling the cylinder with hydraulic fluid and applying the lateral pressure, and hoses, gages, and valves as needed.

4.4 *Deformation and Strain-Measuring Devices*—High-grade dial micrometers or other measuring devices graduated to read in 0.0001-in. (0.0025-mm) units, and accurate within 0.0001 in. (0.0025 mm) in any 0.0010-in. (0.025-mm) range, and within 0.0002 in. (0.005 mm) in any 0.0100-in. (0.25-mm) range shall be provided for measuring axial deformation due to loading. These may consist of micrometer screws, dial micrometers, or linear variable differential transformers securely attached to the high pressure cylinder.

4.4.1 Electrical resistance strain gages applied directly to the rock specimen in the axial direction may also be used. In addition, the use of circumferentially applied strain gages will permit the observation of data necessary in the calculation of

¹ This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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² Annual Book of ASTM Standards, Vol 04.08.

³ Annual Book of ASTM Standards, Vols 03.01, 14.02.

⁴ Annual Book of ASTM Standards, Vol 14.02.

⁵ Assembly and detail drawings of an apparatus that meets these requirements and which is designed to accommodate 2 1/8-in. (53.975-mm) diameter specimens and operate at a lateral fluid pressure of 10 000 psi (689 MPa) are available from Headquarters. Request Adjunct No. 12-426640-00.

Poisson's ratio. In this case two axial (vertical) gages should be mounted on opposite sides of the specimen at mid-height and two circumferential (horizontal) gages similarly located around the circumference, but in the direction perpendicular to the axial gages.

4.5 Flexible Membrane—A flexible membrane of suitable material to exclude the confining fluid from the specimen, and that shall not significantly extrude into abrupt surface pores. It should be sufficiently long to extend well onto the platens and when slightly stretched be of the same diameter as the rock specimen.

NOTE 2—Neoprene rubber tubing of $1/16$ -in. (1.588-mm) wall thickness and of 40 to 60 Durometer hardness, Shore Type A or various sizes of bicycle inner tubing, have been found generally suitable for this purpose.

5. Sampling

5.1 The specimen shall be selected from the cores to represent a true average of the type of rock under consideration. This can be achieved by visual observations of mineral constituents, grain sizes and shapes, partings and defects such as pores and fissures.

6. Test Specimens

6.1 *Preparation*—The test specimens shall be prepared in accordance with Practice D 4543.

6.2 Moisture condition of the specimen at the time of test can have a significant effect upon the indicated strength of the rock. Good practice generally dictates that laboratory tests be made upon specimens representative of field conditions. Thus it follows that the field moisture condition of the specimen should be preserved until the time of test. On the other hand, there may be reasons for testing specimens at other moisture contents, including zero. In any case the moisture content of the test specimen should be tailored to the problem at hand and reported in accordance with 9.1.6.

7. Procedure

7.1 Place the lower platen on the base. Wipe clean the bearing faces of the upper and lower platens and of the test specimen, and place the test specimen on the lower platen. Place the upper platen on the specimen and align properly. Fit the flexible membrane over the specimen and platen and install rubber or neoprene O-rings to seal the specimen from the confining fluid. Place the cylinder over the specimen, ensuring proper seal with the base, and connect the hydraulic pressure lines. Position the deformation measuring device and fill the chamber with hydraulic fluid. Apply a slight axial load, approximately 25 lbf (110 N), to the triaxial compression chamber by means of the loading device in order to properly seat the bearing parts of the apparatus. Take an initial reading on the deformation device. Slowly raise the lateral fluid pressure to the predetermined test level and at the same time apply sufficient axial load to prevent the deformation measuring device from deviating from the initial reading. When the predetermined test level of fluid pressure is reached, note and record the axial load registered by the loading device. Consider this load to be the zero or starting load for the test.

7.2 Apply the axial load continuously and without shock until the load becomes constant, or reduces, or a predetermined

amount of strain is achieved. Apply the load in such a manner as to produce a strain rate as constant as feasible throughout the test. Do not permit the strain rate at any given time to deviate by more than 10 % from that selected. The strain rate selected should be that which will produce failure of a similar test specimen in unconfined compression, in a test time of between 2 and 15 min. The selected strain rate for a given rock type shall be adhered to for all tests in a given series of investigation (Note 3). Maintain constant the predetermined confining pressure throughout the test and observe and record readings of deformation as required.

NOTE 3—Results of tests by other investigators have shown that strain rates within this range will provide strength values that are reasonably free from rapid loading effects and reproducible within acceptable tolerances.

7.3 To make sure that no testing fluid has penetrated into the specimen, the specimen membrane shall be carefully checked for fissures or punctures at the completion of each triaxial test. If in question, weigh the specimen before and after the test.

8. Calculation

8.1 Make the following calculations and graphical plots:

8.1.1 Construct a stress difference versus axial strain curve (Note 5). Stress difference is defined as the maximum principal axial stress, σ_1 , minus the lateral pressure, σ_3 . Indicate the value of the lateral pressure, σ_3 , on the curve.

NOTE 4—If the specimen diameter is not the same as the piston diameter through the chamber, a correction must be applied to the measured load to account for differences in area between the specimen and the loading piston where it passes through the seals into the chamber.

NOTE 5—If the total deformation is recorded during the test, suitable calibration for apparatus deformation must be made. This may be accomplished by inserting into the apparatus a steel cylinder having known elastic properties and observing differences in deformation between the assembly and steel cylinder throughout the loading range. The apparatus deformation is then subtracted from the total deformation at each increment of load in order to arrive at specimen deformation from which the axial strain of the specimen is computed.

8.1.2 Construct the Mohr stress circles on an arithmetic plot with shear stresses as ordinates and normal stresses as abscissas. Make at least three triaxial compression tests, each at a different confining pressure, on the same material to define the envelope to the Mohr stress circles.

NOTE 6—Because of the heterogeneous nature of rock and the scatter in results often encountered, it is considered good practice to make at least three tests of essentially identical specimens at each confining pressure or single tests at nine different confining pressures covering the range investigated. Individual stress circles shall be plotted and considered in drawing the envelope.

8.1.3 Draw a “best-fit,” smooth curve (the Mohr envelope) approximately tangent to the Mohr circles as in Fig. 1. The figure shall also include a brief note indicating whether a pronounced failure plane was or was not developed during the test and the inclination of this plane with reference to the plane of major principal stress.

NOTE 7—If the envelope is a straight line, the angle the line makes with the horizontal shall be reported as the angle of interval friction, ϕ (or the slope of the line as $\tan \phi$ depending upon preference) and the intercept of this line at the vertical axis reported as the cohesion intercept, C . If the envelope is not a straight line, values of ϕ (or $\tan \phi$) should be determined

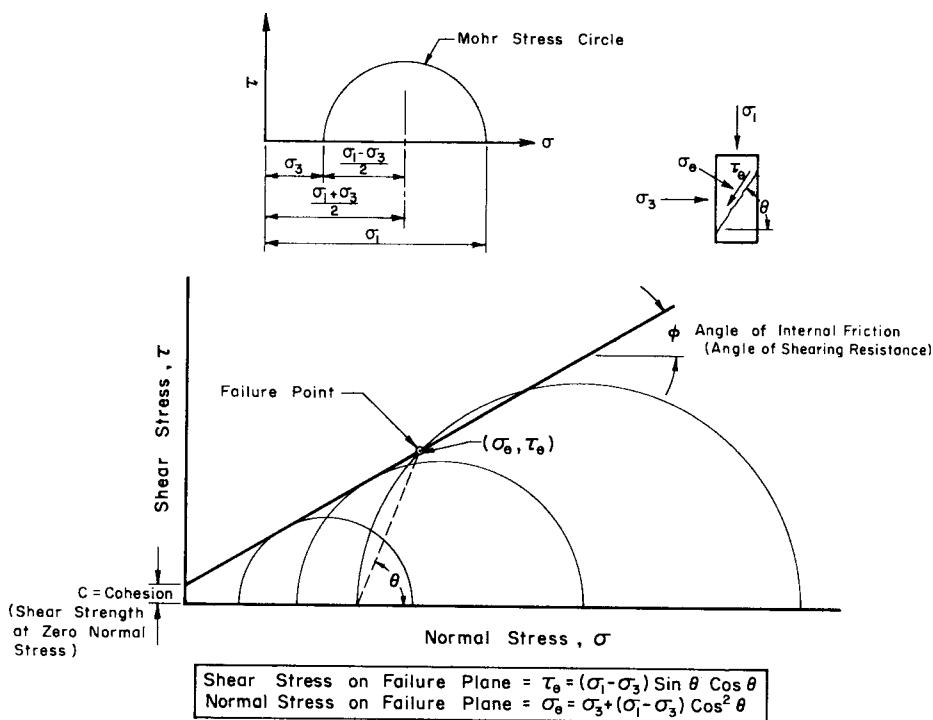


FIG. 1 Typical Mohr Stress Circles

by constructing a tangent to the Mohr circle for each confining stress at the point of contact with the envelope and the corresponding cohesion intercept noted.

9. Report

9.1 The report shall include as much of the following as possible:

9.1.1 Sources of the specimen including project name and location, and if known, storage environment. The location is frequently specified in terms of the borehole number and depth of specimen from collar of hole.

9.1.2 Physical description of the specimen including rock type; location and orientation of apparent weakness planes, bedding planes, and schistosity; large inclusions or inhomogeneities, if any.

9.1.3 Dates of sampling and testing.

9.1.4 Specimen diameter and length, conformance with dimensional requirements.

9.1.5 Rate of loading or deformation or strain rate.

9.1.6 General indication of moisture condition of the specimen at time of test such as: as-received, saturated, laboratory air-dry, or oven dry. It is recommended that the moisture condition be more precisely determined when possible and reported as either water content or degree of saturation.

9.1.7 Type and location of failure. A sketch of the fractured specimen is recommended.

NOTE 8—If it is a ductile failure and $\sigma_1 - \sigma_3$, is still increasing when the test is terminated, the maximum strain at which $\sigma_1 - \sigma_3$ is obtained shall be clearly stated.

10. Precision and Bias

10.1 An interlaboratory study was conducted in which six laboratories each tested five specimens of three different rocks,

three confining pressure and four replications. The specimens were prepared by a single laboratory from a common set of samples and randomly distributed to the testing laboratories for testing. The study was carried out in accordance with Practice E 691. Details of the study are given in ISR Research Report "Interlaboratory Testing Program for Rock Properties (ITP/RP) Round Two," 1994. Tables 1-3 give the repeatability (within a laboratory) and reproducibility (between laboratories) for the method at confining pressure of 10, 25 and 40 MPa.

10.1.1 The probability is approximately 95 % that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit. Likewise, the probability is approximately 95 % that two test results obtained in different laboratories on the same material will not differ by more than the reproducibility limit.

11. Keywords

11.1 compression strength; compression testing; loading tests; rock; triaxial compression

TABLE 1 Compressive Strength (MPa) @ 10 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	127	173	282
Repeatability	5.29	32.2	13.5
Reproducibility	22.5	38.3	25.7

TABLE 2 Compressive Strength (MPa) @ 25 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	179	206	366
Repeatability	8.69	43.3	22.5
Reproducibility	34.7	51.8	31.0
Average Value	215	237	N/A
Repeatability	7.95	42.4	N/A
Reproducibility	52.0	73.5	N/A

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TABLE 3 Compressive Strength (MPa) @ 40 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	179	206	366
Repeatability	8.69	43.3	22.5
Reproducibility	34.7	51.8	31.0
Average Value	215	237	N/A
Repeatability	7.95	42.4	N/A
Reproducibility	52.0	73.5	N/A



Standard Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock¹

This standard is issued under the fixed designation D 2845; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 This test method describes equipment and procedures for laboratory measurements of the pulse velocities of compression waves and shear waves in rock (1)² (Note 2) and the determination of ultrasonic elastic constants (Note 1) of an isotropic rock or one exhibiting slight anisotropy.

NOTE 1—The elastic constants determined by this test method are termed ultrasonic since the pulse frequencies used are above the audible range. The terms sonic and dynamic are sometimes applied to these constants but do not describe them precisely (2). It is possible that the ultrasonic elastic constants may differ from those determined by other dynamic methods.

1.2 This test method is valid for wave velocity measurements in both anisotropic and isotropic rocks although the velocities obtained in grossly anisotropic rocks may be influenced by such factors as direction, travel distance, and diameter of transducers.

1.3 The ultrasonic elastic constants are calculated from the measured wave velocities and the bulk density. The limiting degree of anisotropy for which calculations of elastic constants are allowed and procedures for determining the degree of anisotropy are specified.

1.4 The values stated in U.S. customary units are to be regarded as the standard. The metric equivalents of U.S. customary units are rationalized.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

D 653 Terminology Relating to Rock, Soil, and Contained Fluids³

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved June 10, 2000. Published August 2000. Originally published as D 2845 – 69. Last previous edition D 2845 – 95ε¹.

² The boldface numbers in parentheses refer to the list of references at the end of this test method.

³ Annual Book of ASTM Standards, Vol 14.02.

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction³
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method³

3. Terminology

3.1 For common definitions of terms in this standard, refer to Terminology D 653.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *compression wave velocity*—the dilational wave velocity which is the propagation velocity of a longitudinal wave in a medium that is effectively infinite in lateral extent. It is not to be confused with bar or rod velocity.

NOTE 2—The compression wave velocity as defined here is the dilational wave velocity. It is the propagation velocity of a longitudinal wave in a medium which is effectively infinite in lateral extent. It should not be confused with the bar or rod velocity.

4. Summary of Test Method

4.1 Details of essential procedures for the determination of the ultrasonic velocity, measured in terms of travel time and distance, of compression and shear waves in rock specimens include requirements of instrumentation, suggested types of transducers, methods of preparation, and effects of specimen geometry and grain size. Elastic constants may be calculated for isotropic or slightly anisotropic rocks, while anisotropy is reported in terms of the variation of wave velocity with direction in the rock.

5. Significance and Use

5.1 The primary advantages of ultrasonic testing are that it yields compression and shear wave velocities, and ultrasonic values for the elastic constants of intact homogeneous isotropic rock specimens (3). Elastic constants are not to be calculated for rocks having pronounced anisotropy by procedures described in this test method. The values of elastic constants often do not agree with those determined by static laboratory methods or the *in situ* methods. Measured wave velocities likewise may not agree with seismic velocities, but offer good approximations. The ultrasonic evaluation of rock properties is useful for preliminary prediction of static properties. The test method is useful for evaluating the effects of uniaxial stress and

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

water saturation on pulse velocity. These properties are in turn useful in engineering design.

5.2 The test method as described herein is not adequate for measurement of stress-wave attenuation. Also, while pulse velocities can be employed to determine the elastic constants of materials having a high degree of anisotropy, these procedures are not treated herein.

NOTE 3—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 D 3740 are generally considered capable of competent and objective testing and sampling. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *General*—The testing apparatus (Fig. 1) should have impedance matched electronic components and shielded leads to ensure efficient energy transfer. To prevent damage to the apparatus allowable voltage inputs should not be exceeded.

6.2 *Pulse Generator Unit*—This unit shall consist of an electronic pulse generator and external voltage or power amplifiers if needed. A voltage output in the form of either rectangular pulse or a gated sine wave is satisfactory. The generator shall have a voltage output with a maximum value after amplification of at least 50 V into a 50- Ω impedance load. A variable pulse width, with a range of 1 to 10 μ s is desirable. The pulse repetition rate may be fixed at 60 repetitions per second or less although a range of 20 to 100 repetitions per second is recommended. The pulse generator shall also have a trigger-pulse output to trigger the oscilloscope. There shall be a variable delay of the main-pulse output with respect to the trigger-pulse output, with a minimum range of 0 to 20 μ s.

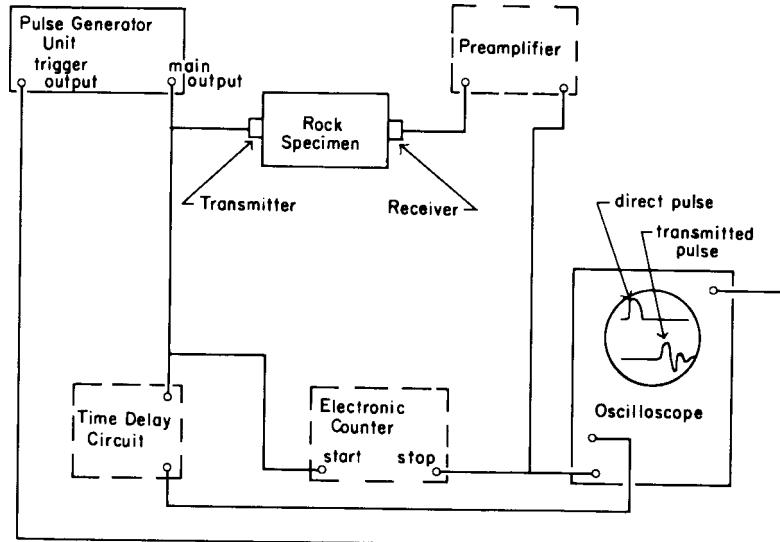
6.3 *Transducers*—The transducers shall consist of a transmitter that converts electrical pulses into mechanical pulses and a receiver that converts mechanical pulses into electrical pulses. Environmental conditions such as ambient temperature,

moisture, humidity, and impact should be considered in selecting the transducer element. Piezoelectric elements are usually recommended, but magnetostrictive elements may be suitable. Thickness-expander piezoelectric elements generate and sense predominately compression-wave energy; thickness-shear piezoelectric elements are preferred for shear-wave measurements. Commonly used piezoelectric materials include ceramics such as lead-zirconate-titanate for either compression or shear, and crystals such as a-c cut quartz for shear. To reduce scattering and poorly defined first arrivals at the receiver, the transmitter shall be designed to generate wavelengths at least $3 \times$ the average grain size of the rock.

NOTE 4—Wavelength is the wave velocity in the rock specimen divided by the resonance frequency of the transducer. Commonly used frequencies range from 75 kHz to 3 MHz.

6.3.1 In laboratory testing, it may be convenient to use unhoisted transducer elements. But if the output voltage of the receiver is low, the element should be housed in metal (grounded) to reduce stray electromagnetic pickup. If protection from mechanical damage is necessary, the transmitter as well as the receiver may be housed in metal. This also allows special backings for the transducer element to alter its sensitivity or reduce ringing (4). The basic features of a housed element are illustrated in Fig. 2. Energy transmission between the transducer element and test specimen can be improved by (1) machining or lapping the surfaces of the face plates to make them smooth, flat, and parallel, (2) making the face plate from a metal such as magnesium whose characteristic impedance is close to that of common rock types, (3) making the face plate as thin as practicable, and (4) coupling the transducer element to the face plate by a thin layer of an electrically conductive adhesive, an epoxy type being suggested.

6.3.2 Pulse velocities may also be determined for specimens subjected to uniaxial states of stress. The transducer housings in this case will also serve as loading platens and should be designed with thick face plates to assure uniform loading over the ends of the specimen (5).



NOTE 1—Components shown by dashed lines are optional, depending on method of travel-time measurement and voltage sensitivity of oscilloscope.

FIG. 1 Schematic Diagram of Typical Apparatus

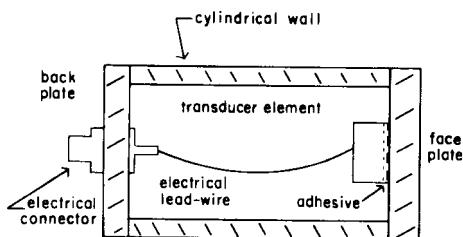


FIG. 2 Basic Features of a Housed Transmitter or Receiver

NOTE 5—The state of stress in many rock types has a marked effect on the wave velocities. Rocks *in situ* are usually in a stressed state and therefore tests under stress have practical significance.

6.4 *Preamplifier*—A voltage preamplifier is required if the voltage output of the receiving transducer is relatively low or if the display and timing units are relatively insensitive. To preserve fast rise times, the frequency response of the preamplifier shall drop no more than 2 dB over a frequency range from 5 kHz to 4 \times the resonance frequency of the receiver. The internal noise and gain must also be considered in selecting a preamplifier. Oscilloscopes having a vertical-signal output can be used to amplify the signal for an electronic counter.

6.5 *Display and Timing Unit*—The voltage pulse applied to the transmitting transducer and the voltage output from the receiving transducer shall be displayed on a cathode-ray oscilloscope for visual observation of the waveforms. The oscilloscope shall have an essentially flat response between a frequency of 5 kHz and 4 \times the resonance frequency of the transducers. It shall have dual beams or dual traces so that the two waveforms may be displayed simultaneously and their amplitudes separately controlled. The oscilloscope shall be triggered by a triggering pulse from the pulse generator. The timing unit shall be capable of measuring intervals between 2 μ s and 5 ms to an accuracy of 1 part in 100. Two alternative classes of timing units are suggested, the respective positions of each being shown as dotted outlines in the block diagram in Fig. 1: (1) an electronic counter with provisions for time interval measurements, or (2) a time-delay circuit such as a continuously variable-delay generator, or a delayed-sweep feature on the oscilloscope. The travel-time measuring circuit shall be calibrated periodically with respect to its accuracy and linearity over the range of the instrument. The calibration shall be checked against signals transmitted by the National Institute of Standards and Technology radio station WWV, or against a crystal controlled time-mark or frequency generator that can be referenced back to the signals from WWV periodically. It is recommended that the calibration of the time measuring circuit be checked at least once a month and after any severe impact that the instrument may receive.

7. Test Specimens

7.1 *Preparation*—Exercise care in core drilling, handling, sawing, grinding, and lapping the test specimen to minimize the mechanical damage caused by stress and heat. It is recommended that liquids other than water be prevented from contacting the specimen, except when necessary as a coupling medium between specimen and transducer during the test. The surface area under each transducer shall be sufficiently plane that a feeler gage 0.001 in. (0.025 mm) thick will not pass

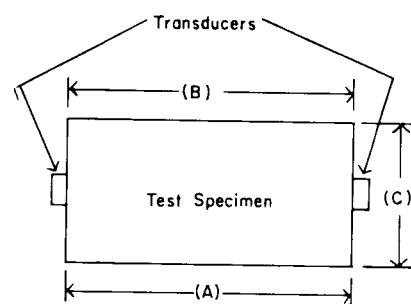
under a straightedge placed on the surface. The two opposite surfaces on which the transducers will be placed shall be parallel to within 0.005 in./in. (0.1 mm/20 mm) of lateral dimension (Fig. 3). If the pulse velocity measurements are to be made along a diameter of a core, the above tolerance then refers to the parallelism of the lines of contact between the transducers and curved surface of the rock core. Moisture content of the test specimen can affect the measured pulse velocities (see 7.2). Pulse velocities may be determined on the velocity test specimen for rocks in the oven-dry state (0 % saturation), in a saturated condition (100 % saturation), or in any intermediate state. If the pulse velocities are to be determined with the rock in the same moisture condition as received or as exists underground, care must be exercised during the preparation procedure so that the moisture content does not change. In this case it is suggested that both the sample and test specimen be stored in moisture-proof bags or coated with wax and that dry surface-preparation procedures be employed. If results are desired for specimens in the oven-dried condition, the oven temperature shall not exceed 150°F (66°C). The specimen shall remain submerged in water up to the time of testing when results are desired for the saturated state.

7.2 *Limitation on Dimensions*—It is recommended that the ratio of the pulse-travel distance to the minimum lateral dimension not exceed 5. Reliable pulse velocities may not be measurable for high values of this ratio. The travel distance of the pulse through the rock shall be at least 10 \times the average grain size so that an accurate average propagation velocity may be determined. The grain size of the rock sample, the natural resonance frequency of the transducers, and the minimum lateral dimension of the specimen are interrelated factors that affect test results. The wavelength corresponding to the dominant frequency of the pulse train in the rock is approximately related to the natural resonance frequency of the transducer and the pulse-propagation velocity, (compression or shear) as follows:

$$\Lambda \approx V/f, \quad (1)$$

where:

Λ = dominant wavelength of pulse train, in. (or m),
 V = pulse propagation velocity (compression or shear),
 in./s (or m/s), and
 f = natural resonance frequency of transducers, Hz.



NOTE 1—(A) must be within 0.1 mm of (B) for each 20 mm of width (C).

FIG. 3 Specification for Parallelism

The minimum lateral dimension of the test specimen shall be at least $5 \times$ the wavelength of the compression wave so that the true dilatational wave velocity is measured (Note 6), that is,

$$D \geq 5A, \quad (2)$$

where:

D = minimum lateral dimension of test specimen, in. (or m).

The wavelength shall be at least $3 \times$ the average grain size (See 4.3) so that

$$\Lambda \geq 3d, \quad (3)$$

where:

d = average grain size, in. (or m).

Eq 1, Eq 2, and Eq 3 can be combined to yield the relationship for compression waves as follows:

$$D \geq 5(V_p/f) \geq 15d, \quad (4)$$

where:

V_p = pulse propagation velocity (compression), in./s (or m/s).

Since V_p and d are inherent properties of the material, f and D shall be selected to satisfy Eq 4 (Fig. 4) for each test specimen. For any particular value of V_p/f the permissible values of specimen diameter D lie above the diagonal line in Fig. 4, while the permissible values of grain size d lie below the diagonal line. For a particular diameter, the permissible values for specimen length L lie to the left of the diagonal line.

NOTE 6—Silaeva and Shamina (6) found the limiting ratio of diameter to wavelength to be about 2 for metal rods. Data obtained by Cannady (3) on rock indicate the limiting ratio is at least 8 for a specimen length-to-diameter ratio of about 8.

8. Procedure

8.1 *Determination of Travel Distance and Density*—Mark off the positions of the transducers on the specimen so that the line connecting the centers of the transducer contact areas is not inclined more than 2° (approximately 0.1 in. in 3 in. (1 mm in 30 mm)) with a line perpendicular to either surface. Then

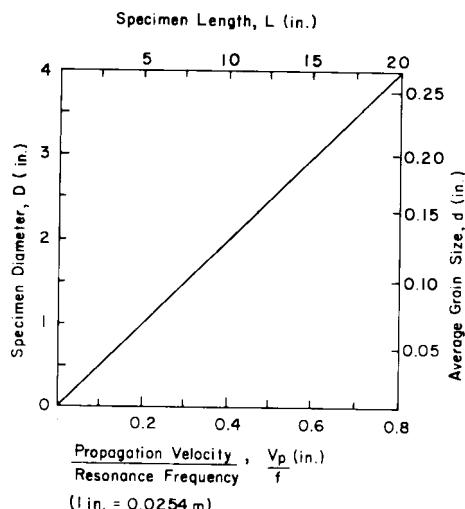


FIG. 4 Graph Showing Allowable Values of Specimen Diameter and Grain Size Versus the Ratio of Propagation Velocity to Resonance Frequency

measure the pulse-travel distance from center to center of the transducer contact area to within 0.1 %. The density of the test specimen is required in the calculation of the ultrasonic elastic constants (see 8.2). Determine the density of the test specimen from measurements of its mass and its volume calculated from the average external dimensions. Determine the mass and average dimensions within 0.1 %. Calculate the density as follows:

$$p = m/V$$

where:

p = density, lb sec²/in.⁴ (or kg/m³),

m = mass of test specimen, lb sec²/386.4 in. (or kg), and

V = volume of test specimen, in.³ (or m³).

8.2 *Moisture Condition*—The moisture condition of the sample shall be noted and reported as explained in 8.1.3.

8.3 Determination of Pulse-Travel Time:

8.3.1 Increase the voltage output of the pulse generator, the gain of the amplifier, and the sensitivity of the oscilloscope and counter to an optimum level, giving a steeper pulse front to permit more accurate time measurements. The optimum level is just below that at which electromagnetic noise reaches an intolerable magnitude or triggers the counter at its lowest triggering sensitivity. The noise level shall not be greater than one tenth of the amplitude of the first peak of the signal from the receiver. Measure the travel time to within 1 part in 100 for compression waves and 1 part in 50 for shear waves by (1) using the delaying circuits in conjunction with the oscilloscope (see section 7.1.1) or (2) setting the counter to its highest usable precision, (see section 6.3.2).

8.3.1.1 The oscilloscope is used with the time-delay circuit to display both the direct pulse and the first arrival of the transmitted pulse, and to measure the travel time. Characteristically, the first arrival displayed on the oscilloscope consists of a curved transition from the horizontal zero-voltage trace followed by a steep, more or less linear, trace. Select the first break in a consistent manner for both the test measurement and the zero-time determination. Select it either at the beginning of the curved transition region or at the zero-voltage intercept of the straight line portion of the first arrival.

8.3.1.2 The counter is triggered to start by the direct pulse applied to the transmitter and is triggered to stop by the first arrival of the pulse reaching the receiver. Because a voltage change is needed to trigger the counter, it can not accurately detect the first break of a pulse. To make the most accurate time interval measurements possible, increase the counter's triggering sensitivity to an optimum without causing spurious triggering by extraneous electrical noise.

8.3.2 Determine the zero time of the circuit including both transducers and the travel-time measuring device and apply the correction to the measured travel times. This factor remains constant for a given rock and stress level if the circuit characteristics do not change. Determine the zero time accordingly to detect any changes. Determine it by (1) placing the transducers in direct contact with each other and measuring the delay time directly, or (2) measuring the apparent travel time of some uniform material (such as steel) as a function of length, and then using the zero-length intercept of the line through the data points as the correction factor.

8.3.3 Since the first transmitted arrival is that of the compression wave, its detection is relatively easy. The shear-wave arrival, however, may be obscured by vibrations due to ringing of the transducers and reflections of the compression wave. The amplitude of the shear wave relative to the compression wave may be increased and its arrival time determined more accurately by means of thickness shear-transducer elements. This type of element generates some compressional energy so that both waves may be detected. Energy transmission between the specimen and each transducer may be improved by using a thin layer of a coupling medium such as phenyl salicylate, high-vacuum grease, or resin, and by pressing the transducer against the specimen with a small seating force.

8.3.4 For specimens subjected to uniaxial stress fields, first arrivals of compression waves are usually well defined. However, the accurate determination of shear-wave first arrivals for specimens under stress is complicated by mode conversions at the interfaces on either side of the face plate and at the free boundary of the specimen (4). Shear-wave arrivals are therefore difficult to determine and experience is required for accurate readings.

8.4 *Ultrasonic Elastic Constants*—The rock must be isotropic or possess only a slight degree of anisotropy if the ultrasonic elastic constants are to be calculated (Section 9). In order to estimate the degree of anisotropy of the rock, measure the compression-wave velocity in three orthogonal directions, and in a fourth direction oriented at 45° from any one of the former three directions if required as a check. Make these measurements with the same geometry, that is, all between parallel flat surfaces or all across diameters. The equations in 9.2 for an isotropic medium shall not be applied if any of the three compression-wave velocities varies by more than 2 % from their average value. The error in E and G (see 9.2) due to both anisotropy and experimental error will then normally not exceed 6 %. The maximum possible error in μ , λ , and K depends markedly upon the relative values of V_p and V_s as well as upon testing errors and anisotropy. In common rock types the respective percent of errors for μ , λ , and K may be large as or even higher than 24, 36, and 6. For greater anisotropy, the possible percent of error in the elastic constants would be still greater.

9. Calculation

9.1 Calculate the propagation velocities of the compression and shear waves, V_p and V_s respectively, as follows:

$$V_p = L_p/T_p$$

$$V_s = L_s/T_s$$

where:

V = pulse-propagation velocity, in./s (or m/s),

L = pulse-travel distance, in. (or m),

T = effective pulse-travel time (measured time minus zero time correction), s,

and subscripts p and s denote the compression wave and shear wave, respectively.

9.2 If the degree of velocity anisotropy is 2 % or less, as specified in 6.4, calculate the ultrasonic elastic constants as follows:

$$E = [pV_s^2(3V_p^2 - 4V_s^2)]/(V_p^2 - V_s^2)$$

where:

E = Young's modulus of elasticity, psi (or Pa), and
 p = density, lb/in.³ (or kg/m³);

$$G = \rho V_s^2$$

where:

G = modulus of rigidity or shear modulus, psi (or Pa);

$$\mu = (V_p^2 - 2V_s^2)[2(V_p^2 - V_s^2)]$$

where:

μ = Poisson's ratio;

$$\lambda = p(V_p^2 - 2V_s^2)$$

where:

λ = Lamé's constant, psi (or Pa); and

$$K = \rho(3V_p^2 - 4V_s^2)/3$$

where:

K = bulk modulus, psi (or Pa).

10. Report

10.1 The report shall include the following:

10.1.1 Identification of the test specimen including rock type and location,

10.1.2 Density of test specimen,

10.1.3 General indication of moisture condition of sample at time of test such as as-received, saturated, laboratory air dry, or oven dry. It is recommended that the moisture condition be more precisely determined when possible and reported as either water content or degree of saturation.

10.1.4 Degree of anisotropy expressed as the maximum percent deviation of compression-pulse velocity from the average velocity determined from measurements in three directions,

10.1.5 Stress level of specimens,

10.1.6 Calculated pulse velocities for compression and shear waves with direction of measurement,

10.1.7 Calculated ultrasonic elastic constants (if desired and if degree of anisotropy is not greater than specified limit),

10.1.8 Coupling medium between transducers and specimen, and

10.1.9 Other data such as physical properties, composition, petrography, if determined.

11. Precision and Bias

11.1 An interlaboratory study of longitudinal and transverse pulse velocity (LPV and TPV) of intact specimens of four rock types was conducted in accordance with Practice E 691 in six laboratories with five replications per rock type. The results of this study are reported in ISR Research Report No. PS D18.12-R01, 1992, and its Addendum, 1994.

11.2 The repeatability and reproducibility statistics reported in Table 1 refer to within-laboratory and between-laboratory

TABLE 1 Repeatability and Reproducibility Statistics

	Barre Granite	Berea Sandstone	Salem Limestone	Tennessee Marble
Mean x	3.47	LPV, km/s 2.28	4.15	6.15
Repeatability limit r	0.22	0.15	0.27	0.44
Reproducibility limit R	0.48	0.30	0.58	0.45
Mean x	2.37	TPV, km/s 1.45	2.30	3.33
Repeatability limit r	0.14	0.07	0.21	0.25
Reproducibility limit R	0.80	0.58	0.61	0.55

precision, respectively. Each entry in the tables has the dimensions of km/s.

11.3 The probability is approximately 95 % that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit r . Likewise, the probability is approximately 95 % that two test results obtained in different laboratories on the same material will not differ by more than the reproducibility limit R . The precision statistics are calculated from:

$$r = 2 \sqrt{2s_r}$$

where:

s_r = the repeatability standard deviation, and

$$R = 2 \sqrt{2s_R}$$

where:

s_R = the reproducibility standard deviation.

11.4 It should be noted here that the anisotropy for TPV in Barre Granite is about 5 %, depending on the orientation of the plane of polarization for shear waves. The data presented here are "average" results.

11.5 *Bias*—There is no accepted reference value for this test method; therefore bias cannot be determined.

12. Keywords

12.1 compression testing; isotropy; ultrasonic testing; velocity-pulse

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SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (1995) that may impact the use of the standard.

- (1) Added section 1.5, safety caveat statement.
- (2) Added D 653 and D 3740 to *ASTM Standards* in section 2.1; added new section 3.2 *Definitions of Terms Specific to This Standard*; and moved Note 2 from Scope to 3.2.1.
- (3) Added Note 3 caveat regarding use of D 3740 to section 5

Significance and Use.

- (4) Changed the symbol " $>$ " to " \geq " in formulas (Eq 2) and (Eq 3) in section 7.2. *Limitation on Dimensions* because the narrative says "at least".

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Standard Test Method for Direct Tensile Strength of Intact Rock Core Specimens¹

This standard is issued under the fixed designation D 2936; 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.

^{ε1} Note—Figure 1 was added editorially in August 2002.

1. Scope

1.1 This test method covers the determination of the direct tensile strength of intact cylindrical rock specimens.

1.2 The values stated in SI units are to be regarded as standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass²

D 4543 Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances²

E 4 Practices for Force Verification of Testing Machines³

E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for Characteristic of a Lot or Process⁴

3. Summary of Test Method

3.1 A rock core sample is cut to length and its ends are cemented to metal caps. The metal caps are attached to a testing machine and the specimen is loaded in tension until it fails.

4. Significance and Use

4.1 Rock is much weaker in tension than in compression. Thus, in determining the failure condition for a rock structure, many investigators employ tensile strength of the component rock as the failure strength for the structure. Direct tensile stressing of rock is the most basic test for determining the tensile strength of rock.

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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² Annual Book of ASTM Standards, Vol 04.08.

³ Annual Book of ASTM Standards, Vols 03.01.

⁴ Annual Book of ASTM Standards, Vol 14.02.

5. Apparatus

5.1 *Loading Device*, to apply and measure axial load on the specimen, of sufficient capacity to apply the load at a rate conforming to the requirements of 8.2. The device shall be verified at suitable time intervals in accordance with the procedures given in Practices E 4 and shall comply with the requirements prescribed therein.

5.2 *Caps*—Cylindrical metal caps that, when cemented to the specimen ends, provide a means through which the direct tensile load can be applied. The diameter of the metal caps shall not be less than that of the test specimen, nor shall it exceed the test specimen diameter by more than 1.10 times. Caps shall have a thickness of at least 30 mm (1¼ in.). Caps shall be provided with a suitable linkage system for load transfer from the loading device to the test specimen. The linkage system shall be so designed that the load will be transmitted through the axis of the test specimen without the application of bending or torsional stresses. The length of the linkages at each end shall be at least two times the diameter of the metal end caps. One such system is shown in Fig. 1.

NOTE 1—Roller of link chain of suitable capacity has been found to perform quite well in this application. Because roller chain flexes in one plane only, the upper and lower segments should be positioned at right angles to each other to effectively reduce bending in the specimen. Ball-and-socket, cable, or similar arrangements have been found to be generally unsuitable as their tendency for bending and twisting makes the assembly unable to transmit a purely direct tensile stress to the test specimen.

6. Sampling

6.1 Select the specimen from the cores to represent a valid average of the type of rock under consideration. This can be achieved by visual observations of mineral constituents, grain sizes and shape, partings, and defects such as pores and fissures, or by other methods such as ultrasonic velocity measurements.

7. Test Specimens

7.1 *Preparation*—Prepare test specimens in accordance with Practice D 4543, except that the degree of flatness and smoothness of the specimen ends is not critical. End surfaces, such as result from sawing with a diamond cutoff wheel, are

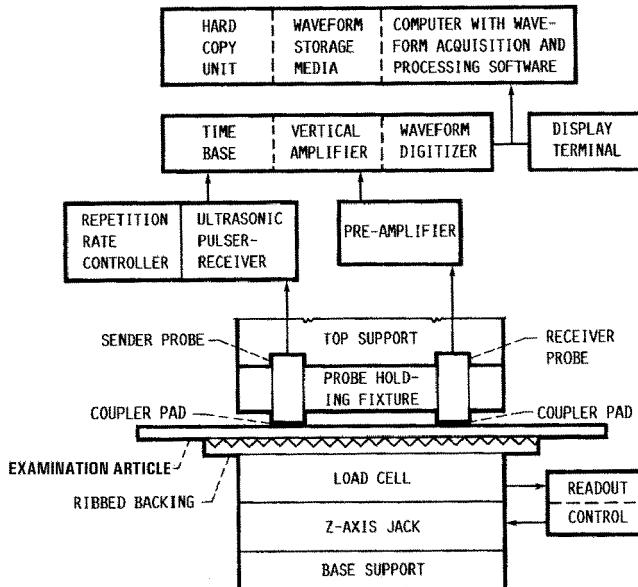


FIG. 1 Direct Tensile Strength Test Assembly

entirely adequate. Grinding, lapping, or polishing beyond this point serves no useful purpose, and in fact, may adversely affect the adhesion of the cementing medium.

7.2 Water content of the specimen at the time of test can have a significant effect upon the deformation of the rock. Good practice generally dictates that laboratory tests be made upon specimens representative of field conditions. Thus, it follows that the field water content of the specimen should be preserved until the time of test. On the other hand, there may be reasons for testing specimens at other water contents, including zero. In any case, the water content of the test specimen should be tailored to the problem at hand and reported in accordance with 10.1.6. If the water content of the specimen is to be determined, follow the procedures given in Test Method D 2216.

7.3 If water content is to be maintained, and the elevated temperature enclosure is not equipped with humidity control, seal the specimen using a flexible membrane or apply a plastic or silicone rubber coating to the specimen sides.

8. Procedure

8.1 Cement the metal caps to the test specimen to ensure alignment of the cap axes with the longitudinal axis of the specimen (see Note 2). The thickness of the cement layer should not exceed 1.5 mm ($\frac{1}{16}$ in.) at each end. The cement layer must be of uniform thickness to ensure parallelism between the top surfaces of the metal caps attached to both ends of the specimens. This should be checked before the cement is hardened (see Note 2) by measuring the length of the end-cap assembly at three locations 120° apart and near the edge. The maximum difference between these measurements should be less than 0.10 mm (0.005 in.) for each 25.0 mm (1.0 in.) of specimen diameter. After the cement has hardened sufficiently to exceed the tensile strength of the rock, place the specimen in the testing machine, making certain that the load transfer system is properly aligned.

NOTE 2—In cementing the metal caps to the test specimens, use jugs and fixtures of suitable design to hold the caps and specimens in proper alignment until the cement has hardened. The chucking arrangement of a machine lathe or drill press is also suitable. Epoxy resin formulations of rather stiff consistency and similar to those used as a patching and filling compound in automobile body repair work have been found to be a suitable cementing medium.

8.2 Apply the tensile load continuously and without shock to failure. Apply the load or deformation at an approximately constant rate such that failure will occur in not less than five nor more than 15 min. Note and record the maximum load carried by the specimen during the test.

NOTE 3—In this test arrangement failure often occurs near one of the capped ends. Discard the results for those tests in which failure occurs either partly or wholly within the cementing medium.

9. Calculation

9.1 Calculate the tensile strength of the rock by dividing the maximum load carried by the specimen during the test by the cross-sectional area; express the result to the nearest 35.0 kPa (5 psi).

10. Report

10.1 Report the following information:

10.1.1 Source of sample including project name and location, and if known, storage environment (often location is frequently specified in terms of the borehole number and depth of specimen from the collar of the hole),

10.1.2 Physical description of the sample including: rock type, location and orientation of apparent planes, bedding planes, and schistosity; and large inclusions or inhomogeneities, if any,

10.1.3 Date of sampling and testing,

10.1.4 Specimen length and diameter, also conformance with dimensional requirements,

10.1.5 Rate of loading or deformation rate,

10.1.6 General indication of water condition of sample at

time of test, such as, as-received, saturated, laboratory air dry, or oven dry (it is recommended that the moisture condition be more precisely determined when possible and reported as either water content or degree of saturation,

10.1.7 Direct tensile strength for each specimen as calculated, average direct tensile strength of all specimens, standard deviation, or coefficient of variation,

10.1.8 Type and location of failure (a sketch of the fractured specimen is recommended), and

10.1.9 Other available physical data.

NOTE 4—The number of specimens tested may depend upon the availability of specimens, but normally a minimum of ten is preferred. The number of specimens tested should be indicated. The statistical basis for relating the number of specimens to the variability of measurements is given in Practice E 122.

11. Precision and Bias

11.1 *Precision*—Due to the nature of the rock materials tested by this test method, it is, at this time, either not feasible

or too costly at this time to produce multiple specimens which have uniform mechanical properties. Therefore, since specimens which would yield the same test results cannot be tested, Subcommittee D18.12 cannot determine the variation between tests since any variation observed is just as likely to be due to specimen variation as to operator or laboratory testing variation. Subcommittee D18.12 welcomes proposals to resolve this problem that would allow for development of a valid precision statement.

11.2 *Bias*—There is no accepted reference value for this test method; therefore, bias cannot be determined.

12. Keywords

12.1 loading tests; rock; tension (tensile) properties/tests; tensile strength

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Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens¹

This standard is issued under the fixed designation D 2938; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method specifies the apparatus, instrumentation, and procedures for determining unconfined compressive strength of intact rock core specimens.

1.2 The values stated in inch-pound units are to be regarded as the standard. The SI values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock²

D 4543 Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances²

E 4 Practices for Load Verification of Testing Machines³

E 122 Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process⁴

3. Summary of Test Method

3.1 A rock core sample is cut to length and the ends are machined flat. The specimen is placed in a loading frame and, if required, heated to the desired test temperature. Axial load is continuously increased on the specimen until peak load and failure are obtained.

4. Significance and Use

4.1 Unconfined compressive strength of rock is used in many design formulas and is sometimes used as an index property to select the appropriate excavation technique.

4.2 The strength of rock cores measured in the laboratory usually do not accurately reflect large-scale *in situ* properties because the latter are strongly influenced by joints, faults, inhomogeneities, weakness planes, and other factors. Therefore, laboratory values for intact specimens must be employed with proper judgement in engineering applications.

5. Apparatus

5.1 *Loading Device*, of sufficient capacity to apply load at a rate conforming to the requirements set forth in 9.5. It shall be verified at suitable time intervals in accordance with the procedures given in Practices E 4, and comply with the requirements prescribed therein. The loading device may be equipped with a displacement transducer that can be used to advance the loading ram at a specified rate.

5.2 *Elevated-Temperature Enclosure*—The elevated temperature enclosure may be either an enclosure that fits in the loading apparatus or an external system encompassing the complete test apparatus. The enclosure may be equipped with humidity control for testing specimens in which the moisture content is to be controlled. For high temperatures, a system of heaters, insulation, and temperature measuring devices are normally required to maintain the specified temperature. Temperature shall be measured at three locations, with one sensor near the top, one at midheight, and one near the bottom of the specimen. The average specimen temperature based on the midheight sensor shall be maintained to within $\pm 1^{\circ}\text{C}$ of the required test temperature. The maximum temperature difference between the midheight sensor and either end sensor shall not exceed 3°C .

NOTE 1—An Alternative to measuring the temperature at three locations along the specimen during the test is to determine the temperature distribution in a dummy specimen that has temperature sensors located in drill holes at a minimum of six positions: along both the centerline and specimen periphery at midheight and each end of the specimen. The temperature controller set point shall be adjusted to obtain steady-state temperatures in the dummy specimen that meet the temperature requirements at each test temperature (the centerline temperature at midheight shall be within $\pm 1^{\circ}\text{C}$ of the required test temperature, and all other specimen temperatures shall not deviate from this temperatures by more than 3°C). The relationship between controller set point and dummy specimen temperature can be used to determine the specimen temperature during testing provided that the output of the temperature feedback sensor

¹ This method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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² Annual Book of ASTM Standards, Vol 04.08.

³ Annual Book of ASTM Standards, Vol 03.01.

⁴ Annual Book of ASTM Standards, Vol 14.02.

(or other fixed-location temperature sensor in the triaxial apparatus) is maintained constant within $\pm 1^\circ\text{C}$ of the required test temperature. The relationship between temperature controller set point and steady-state specimen temperature shall be verified periodically. The dummy specimen is used solely to determine the temperature distribution in a specimen in the elevated temperature enclosure—it is not to be used to determine compressive strength.

5.3 Temperature Measuring Device—Special limits-of-error thermocouples or platinum resistance thermometers (RTDs) having accuracies of at least $\pm 1^\circ\text{C}$ with a resolution of 0.1°C .

5.4 Platens—Two steel platens are used to transmit the axial load to the ends of the specimen. They shall have a hardness of not less than 58 HRC. The bearing faces shall not depart from a plane by more than 0.0125 mm when the platens are new and shall be maintained within a permissible variation of 0.025 mm. The platen diameter shall be at least as great as the specimen diameter, but shall not exceed 1.10 times the specimen diameter. The platen thickness shall be at least one-half the specimen diameter.

5.4.1 Spherical Seating—One of the platens should be spherically seated and the other a plain rigid platen. The diameter of the spherical seat shall be at least as large as that of the test specimen, but shall not exceed twice the diameter of the test specimen. The center of the sphere in the spherical seat shall coincide with the center of the loaded end of the specimen. The spherical seat shall be lubricated to ensure free movement. The movable portion of the platen shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated and tilted through small angles in any direction.

5.4.2 Rigid Seating—If a spherical seat is not used, the bearing faces of the platens shall be parallel to 0.0005 mm/mm of platen diameter. This criterion shall be met when the platens are in the loading device and separated by approximately the height of the test specimen.

6. Safety Precautions

6.1 Many rock types fail in a violent manner when loaded to failure in compression. A protective shield should be placed around the test specimen to prevent injury from flying rock fragments. Elevated temperatures increase the risks of electrical shorts and fire.

7. Sampling

7.1 The specimen shall be selected from the cores to represent a valid average of the type of rock under consideration. This can be achieved by visual observations of mineral constituents, grain sizes and shape, partings and defects such as pores and fissures, or by other methods such as ultrasonic velocity measurements.

8. Test Specimens

8.1 Prepare test specimens in accordance with Practice D 4543.

8.2 The moisture condition of the specimen at time of test can have a significant effect upon the deformation of the rock. Good practice generally dictates that laboratory tests be made upon specimens representative of field conditions. Thus, it follows that the field moisture condition of the specimen

should be preserved until time of test. On the other hand, there may be reasons for testing specimens at other moisture contents including zero. In any case, tailor the moisture content of the test specimen to the problem at hand and report it in accordance with 11.1.3. If the moisture content of the specimen is to be determined, follow the procedures in Test Method D 2216.

8.3 If moisture condition is to be maintained, and the elevated temperature enclosure is not equipped with humidity control, seal the specimen using a flexible membrane or apply a plastic or silicone rubber coating to the specimen sides.

9. Procedure

9.1 Check the ability of the spherical seat to rotate freely in its socket before each test.

9.2 Place the lower platen on the base or actuator rod of the loading device. Wipe clean the bearing faces of the upper and lower platens and of the test specimen, and place the test specimen on the lower platen. Place the upper platen on the specimen and align properly. A small axial load, approximately 100 N, may be applied to the specimen by means of the loading device to properly seat the bearing parts of the apparatus.

9.3 When appropriate, install elevated-temperature enclosure.

9.4 If testing at elevated temperature, raise the temperature at a rate not exceeding $2^\circ\text{C}/\text{min}$ until the required temperature is reached (Note 2). The test specimen shall be considered to have reached temperature equilibrium when all temperature measuring device outputs are stable for at least three readings taken at equal intervals over a period of no less than 30 min (3 min for tests performed at room temperature). Stability is defined as a constant reading showing only the effects of normal instrument and heater unit fluctuations.

NOTE 2—It has been observed that for some rock types microcracking will occur for heating rates above $1^\circ\text{C}/\text{min}$. The operator is cautioned to select a heating rate that microcracking is not significant.

9.5 Apply the axial load continuously and without shock until the load becomes constant, reduces, or a predetermined amount of strain is achieved. Apply the load in such a manner as to produce either a stress rate or a strain rate as constant as feasible throughout the test. Do not permit the stress rate or strain rate at any given time to deviate by more than 10 percent from that selected. The stress rate or strain rate selected should be that which will produce failure in a test time between 2 and 15 min. The selected stress rate or strain rate for a given type shall be adhered to for all tests in a given series of investigation (Note 3). Record the maximum load sustained by the specimen.

NOTE 3—Results of tests by other investigators have shown that strain rates within this range will provide strength values that are reasonably free from rapid loading effects and reproducible within acceptable tolerances. Lower strain rates are permissible, if required by the investigation.

10. Calculation

10.1 Calculate the compressive strength in the test specimen from the maximum compressive load on the specimen and the initial computed cross-sectional area as follows:

$$\sigma = \frac{P}{A} \quad (1)$$

where:

σ = Compressive strength
 P = Maximum load
 A = Cross sectional area.

NOTE 4—Tensile stresses are used as being positive. A consistent application of a compression-positive sign convention may be employed if desired. The sign convention adopted needs to be stated explicitly in the report. The formulas given are for engineering stresses. True stresses may be used, if desired, provided that specimen diameter at the time of peak load is known.

11. Report

11.1 The report shall include the following:

11.1.1 Source of sample including project name and location (often the location is specified in terms of the drill hole number and depth of specimen from the collar of the hole).

11.1.2 Lithologic description of the rock, formation name, and load direction with respect to lithology.

11.1.3 Moisture condition of specimen before test.

11.1.4 Specimen diameter and height, conformance with dimensional requirements.

11.1.5 Temperature at which test was performed.

11.1.6 Rate of loading or deformation rate.

11.1.7 Unconfined compressive strength.

NOTE 5—If failure is ductile, with the load on the specimen still increasing when the test is terminated, the strain at which the compressive strength was calculated shall be reported.

11.1.8 Type and location of failure. A sketch of the fractured specimen is recommended.

11.1.9 If the actual equipment or procedure has varied from the requirements contained in this test method, each variation and the reasons for it shall be discussed.

12. Precision and Bias

12.1 Data are being evaluated via an interlaboratory test program for rock properties to determine the precision of this test method.

12.2 Bias cannot be determined since there is no standard value of compressive strength that can be used to compare with values determined using this method.

13. Keywords

13.1 compression testing; compressive strength; loading tests; rock

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Standard Test Method for Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression¹

This standard is issued under the fixed designation D 3148; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 This test method covers the determination of elastic moduli of intact rock core specimens in uniaxial compression. It specifies the apparatus, instrumentation, and procedures for determining the stress-axial strain and the stress-lateral strain curves, as well as Young's modulus, E , and Poisson's ratio, ν .

NOTE 1—This test method does not include the procedures necessary to obtain a stress-strain curve beyond the ultimate strength.

1.2 For an isotropic material, the relation between the shear and bulk moduli and Young's modulus and Poisson's ratio are:

$$G = \frac{E}{2(1 + \nu)} \quad (1)$$

$$K = \frac{E}{3(1 - 2\nu)} \quad (2)$$

where:

G = shear modulus,

K = bulk modulus,

E = Young's modulus, and

ν = Poisson's ratio.

The engineering applicability of these equations is decreased if the rock is anisotropic. When possible, it is desirable to conduct tests in the plane of foliation, bedding, etc., and at right angles to it to determine the degree of anisotropy. It is noted that equations developed for isotropic materials may give only approximate calculated results if the difference in elastic moduli in any two directions is greater than 10 % for a given stress level.

NOTE 2—Elastic moduli measured by sonic methods may often be employed as preliminary measures of anisotropy.

1.3 The test method given for determining the elastic constants does not apply to rocks that undergo significant inelastic strains during the test, such as potash and salt. The elastic moduli for such rocks should be determined from unload-reload cycles, which is not covered by this test method.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the*

responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids²

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock²

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock Used in Engineering Design and Construction²

D 4543 Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances²

E 4 Practices for Load Verification of Testing Machines³

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method⁴

3. Terminology

3.1 *Definitions:* See Terminology D 653 for general definitions.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *bulk modulus, K [FL^{-2}]*—average normal stress divided by the change in volume per original volume.

3.2.2 *shear modulus, G [FL^{-2}]*—ratio of the shear stress to the corresponding shear strain below the proportional limit.

4. Summary of Test Method

4.1 A rock core sample is cut to length, and the ends are machined flat. The specimen is placed in a loading frame and, if required, heated to the desired test temperature. Axial load is continuously increased on the specimen, and deformation is monitored as a function of load.

5. Significance and Use

5.1 The elastic constants are used to calculate the stress and deformation in rock structures.

5.2 The deformation and strength properties of rock cores measured in the laboratory usually do not accurately reflect

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² Annual Book of ASTM Standards, Vol 04.08.

³ Annual Book of ASTM Standards, Vol 03.01.

⁴ Annual Book of ASTM Standards, Vol 14.02.

large-scale *in situ* properties, because the latter are strongly influenced by joints, faults, inhomogeneities, weakness planes, and other factors. Therefore, laboratory values for intact specimens must be employed with proper judgment in engineering applications.

NOTE 3—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 D 3740 are generally considered capable of competent and objective testing/sampling/inspection/ and the like. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Loading Device*—The loading device shall be of sufficient capacity to apply load at a rate conforming to the requirements specified in 10.5. It shall be verified at suitable time intervals in accordance with the procedures given in Practices E 4 and comply with the requirements prescribed therein. The loading device may be equipped with a displacement transducer than can be used to advance the loading ram at a specified rate.

6.2 *Elevated-Temperature Enclosure*—The elevated temperature enclosure may be either an enclosure that fits in the loading apparatus or an external system encompassing the complete test apparatus. The enclosure may be equipped with humidity control for testing specimens in which the moisture content is to be controlled. For high temperatures, a system of heaters, insulation, and temperature measuring devices are normally required to maintain the specified temperature. Temperature shall be measured at three locations, with one sensor near the top, one at midheight, and one near the bottom of the specimen. The average specimen temperature based on the midheight sensor shall be maintained to within $\pm 1^\circ\text{C}$ of the required test temperature. The maximum temperature difference between the midheight sensor and either end sensor shall not exceed 3°C .

NOTE 4—An alternative to measuring the temperature at three locations along the specimen during the test is to determine the temperature distribution in a dummy specimen that has temperature sensors located in drill holes at a minimum of six positions: along both the centerline and specimen periphery at midheight and at each end of the specimen. The temperature controller set point shall be adjusted to obtain steady-state temperatures in the dummy specimen that meet the temperature requirements at each test temperature (the centerline temperature at midheight shall be within $\pm 1^\circ\text{C}$ of the required test temperature, and all other specimen temperatures shall not deviate from this temperature by more than 3°C). The relationship between controller set point and dummy specimen temperature can be used to determine the specimen temperature during testing provided that the output of the temperature feedback sensor (or other fixed-location temperature sensor in the triaxial apparatus) is maintained constant within $\pm 1^\circ\text{C}$ of the required test temperature. The relationship between temperature controller set point and steady-state specimen temperature shall be verified periodically. The dummy specimen is used solely to determine the temperature distribution in a specimen in the triaxial apparatus; it is not to be used to determine elastic constants.

6.3 *Temperature Measuring Device*—Special limits-of-error thermocouples or platinum resistance thermometers (RTDs) having accuracies of at least $\pm 1^\circ\text{C}$ with a resolution of 0.1°C .

6.4 *Platens*—Two steel platens are used to transmit the axial

load to the ends of the specimen. They shall have a hardness of not less than 58 HRC. One of the platens should be spherically seated and the other on a plain rigid platen. The bearing faces shall not depart from a plane by more than 0.015 mm when the platens are new and shall be maintained within a permissible variation of 0.025 mm. The diameter of the spherical seat shall be at least as large as that of the test specimen but shall not exceed twice the diameter of the test specimen. The center of the sphere in the spherical seat shall coincide with that of the bearing face of the specimen. The spherical seat shall be properly lubricated to ensure free movement. The movable portion of the platen shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated and tilted through small angles in any direction. If a spherical seat is not used, the bearing faces of the platens shall be parallel to 0.0005 mm/mm of platen diameter. The platen diameter shall be at least as great as the specimen but shall not exceed the specimen diameter by more than 1.50 mm. This platen diameter shall be retained for a length of at least one-half the specimen diameter.

6.5 *Strain/Deformation Measuring Devices*—The strain/deformation measuring system shall measure the strain with a resolution of at least 25×10^{-6} strain and an accuracy within 2 % of the value of readings above 250×10^{-6} strain and accuracy and resolution within 5×10^{-6} for readings lower than 250×10^{-6} strain, including errors introduced by excitation and readout equipment. The system shall be free from noncharacterizable long-term instability (drift) that results in an apparent strain of $10^{-8}/\text{s}$.

NOTE 5—The user is cautioned about the influence of temperature on the output of strain and deformation sensors located within the heated environment.

6.5.1 *Axial Strain Determination*—The axial deformations or strains may be determined from data obtained by electrical resistance strain gages, compressometers, linear variable differential transformers (LVDTs), or other suitable means. The design of the measuring device shall be such that the average of at least two axial strain measurements can be determined. Measuring positions shall be equally spaced around the circumference of the specimen close to midheight. The gage length over which the axial strains are determined shall be at least 10 grain diameters in magnitude.

6.5.2 *Lateral Strain Determination*—The lateral deformations or strains may be measured by any of the methods mentioned in 6.5.1. Either circumferential or diametric deformations (or strains) may be measured. A single transducer that wraps around the specimen can be used to measure the change in circumference. At least two diametric deformation sensors shall be used if diametric deformations are measured. These sensors shall be equally spaced around the circumference of the specimen, close to midheight. The average deformation (or strain) from the diametric sensors shall be recorded.

NOTE 6—The use of strain gage adhesives requiring cure temperatures above 65°C is not allowed unless it is known that microfractures do not develop at the cure temperature.

7. Safety Precautions

7.1 Many rock types fail in a violent manner when loaded to

failure in compression. A protective shield should be placed around the test specimen to prevent injury from flying rock fragments. Elevated temperatures increase the risks of electrical shorts and fire.

8. Sampling

8.1 The specimen shall be selected from the cores to represent a valid average of the type of rock under consideration. This can be achieved by visual observations of mineral constituents, grain sizes and shape, partings and defects such as pores and fissures, or by other methods, such as ultrasonic velocity measurements.

9. Test Specimens

9.1 *Preparation*—Prepare test specimens in accordance with Practice D 4543.

9.2 Moisture condition of the specimen at the time of test can have a significant effect upon the deformation of the rock. Good practice generally dictates that laboratory tests be made upon specimens representative of field conditions. Thus, it follows that the field moisture condition of the specimen should be preserved until the time of test. On the other hand, there may be reasons for testing specimens at other moisture contents including zero. In any case, the moisture content of the test specimen should be tailored to the problem at hand and reported in accordance with 12.1.3. If the moisture content of the specimen is to be determined, follow the procedures given in Test Method D 2216.

9.3 If moisture content is to be maintained, and the elevated temperature enclosure is not equipped with humidity control, seal the specimen using a flexible membrane or apply a plastic or silicone rubber coating to the specimen sides.

10. Procedure

10.1 Check the ability of the spherical seat to rotate freely in its socket before each test.

10.2 Place the lower platen on the base or actuator rod of the loading device. Wipe clean the bearing faces of the upper and lower platens and of the test specimen, and place the test specimen on the lower platen. Place the upper platen on the specimen and align properly. A small axial load, approximately 100 N, may be applied to the specimen by means of the loading device to properly seat the bearing parts of the apparatus.

10.3 When appropriate, install elevated-temperature enclosure and deformation transducers for the apparatus and sensors used.

10.4 If testing at elevated temperature, raise the temperature at a rate not exceeding 2°C/min until the required temperature is reached (Note 7). The test specimen shall be considered to have reached temperature equilibrium when all deformation transducer outputs are stable for at least three readings taken at equal intervals over a period of no less than 30 min (3 min for tests performed at room temperature). Stability is defined as a constant reading showing only the effects of normal instrument and heater unit fluctuations. Record the initial deformation readings. Consider this to be the zero for the test.

NOTE 7—It has been observed that for some rock types microcracking will occur for heating rates above 1°C/min. The operator is cautioned to select a heating rate such that microcracking is not significant.

10.5 Apply the axial load continuously and without shock until the load becomes constant, reduces, or a predetermined amount of strain is achieved. Apply the load in such a manner as to produce either a stress rate or a strain rate as constant as feasible throughout the test. Do not permit the stress rate or strain rate at any given time to deviate by more than 10 % from that selected. The stress rate or strain rate selected should be that which will produce failure of a similar test specimen in unconfined compression in a test time between 2 and 15 min. The selected stress rate or strain rate for a given rock type shall be adhered to for all tests in a given series of investigation (Note 8). Observe and record readings of deformation at a minimum of 10 load levels that are evenly spaced over the load range. Continuous data recording is permitted, provided that the recording system meets the precision and accuracy requirements of 6.5.

NOTE 8—Results of tests by other investigators have shown that strain rates within this range will provide strength and moduli values that are reasonably free from rapid loading effects and reproducible within acceptable tolerances. Lower strain rates are permissible, if required by the investigation. The drift of the strain measuring system (see 6.5) shall be more stringent, corresponding to the longer duration of the test.

NOTE 9—Loading a high-strength specimen to failure in a loading frame that is not stiff will often result in violent failure, which will tend to damage the strain/deformation measuring devices.

11. Calculation

11.1 The axial strain, ϵ_a , and lateral strain, ϵ_l , may be obtained directly from strain-indicating equipment, or may be calculated from deformation readings, depending on the type of apparatus or instrumentation employed.

11.1.1 Calculate the axial strain, ϵ_a , as follows:

$$\epsilon_a = \frac{\Delta L}{L} \quad (3)$$

where:

L = original undeformed axial gage length, and

ΔL = change in measured axial length (negative for a decrease in length).

NOTE 10—Tensile stresses and strains are used as being positive. A consistent application of a compression-positive sign convention may be employed if desired. The sign convention adopted needs to be stated explicitly in the report. The formulas given are for engineering stresses and strains. True stresses and strains may be used if desired.

NOTE 11—If the deformation recorded during the test includes deformation of the apparatus, suitable calibration for apparatus deformation must be made. This may be accomplished by inserting into the apparatus a steel cylinder having known elastic properties and observing differences in deformation between the assembly and steel cylinder throughout the loading range. The apparatus deformation is then subtracted from the total deformation at each increment of load to arrive at specimen deformation from which the axial strain of the specimen is computed. The accuracy of this correction should be verified by measuring the elastic deformation of a cylinder of material having known elastic properties (other than steel) and comparing the measured and computed deformations.

11.1.2 Calculate the lateral strain, ϵ_l , as follows:

$$\epsilon_l = \frac{\Delta D}{D} \quad (4)$$

where:

D = original undeformed diameter, and

ΔD = change in diameter (positive for increased in diameter).

NOTE 12—Many circumferential transducers measure change in chord length and not change in arc length (circumference). The geometrically nonlinear relationship between change in chord length and change in diameter must be used to obtain accurate values of lateral strain.

11.2 Calculate the compressive stress in the test specimen from the compressive load on the specimen and the initial computed cross-sectional area as follows:

$$\sigma = \frac{P}{A} \quad (5)$$

where:

σ = stress,

P = load, and

A = area.

11.3 Plot the stress-versus-strain curve for the axial and lateral direction (Fig. 1). The complete curve gives the best description of the deformation behavior of rocks having nonlinear stress-strain relationships at low and high stress levels.

11.4 The axial Young's modulus, E , may be calculated using any of several methods employed in engineering practice. The most common methods, described in Fig. 2, are as follows:

11.4.1 Tangent modulus at a stress level that is some fixed percentage (usually 50 %) of the maximum strength.

11.4.2 Average slope of the more-or-less straight-line portion of the stress-strain curve. The average slope may be calculated either by dividing the change in stress by the change in strain or by making a linear least squares fit to the stress-strain data in the straight-line portion of the curve.

11.4.3 Secant modulus, usually from zero stress to some fixed percentage of maximum strength.

11.5 The value of Poisson's ratio, ν , is greatly affected by nonlinearities at low stress levels in the axial and lateral stress-strain curves. It is suggested that Poisson's ratio be calculated from the equation:

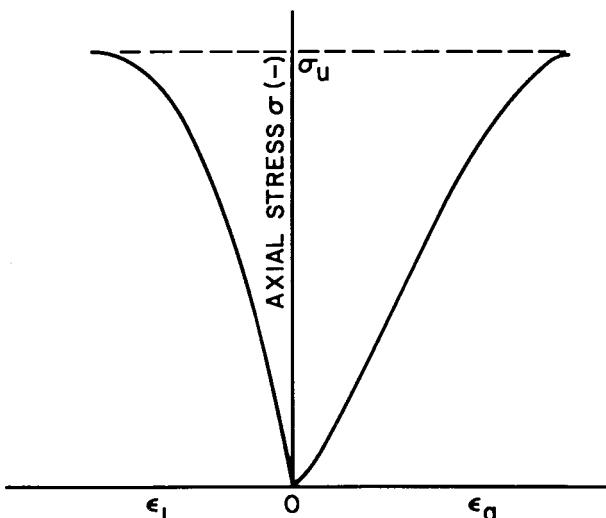


FIG. 1 Format for Graphical Presentation of Data

$$\nu = -\frac{\text{slope of axial curve}}{\text{slope of lateral curve}} = -\frac{E}{\text{slope of lateral curve}} \quad (6)$$

where the slope of the lateral curve is determined in the same manner as was done in 11.4 for Young's modulus, E .

NOTE 13—The denominator in the equation in 11.5 will have a negative value if the sign convention is applied properly.

12. Report

12.1 The report shall include the following:

12.1.1 Source of sample, including project name and location (often the location is specified in terms of the drill hole number and depth of specimen from collar of hole).

12.1.2 Lithologic description of the rock, formation name, and load direction with respect to lithology.

12.1.3 Moisture condition of specimen before test.

12.1.4 Specimen diameter and height, conformance with dimensional requirements.

12.1.5 Temperature at which test was performed.

12.1.6 Rate of loading or deformation rate.

12.1.7 Plot of the stress-versus-strain curves (Fig. 1).

12.1.8 Young's modulus, E , method of determination as given in Fig. 2, and at what stress level or levels determined.

12.1.9 Poisson's ratio, ν , method of determination in 11.5, and at what stress level or levels determined.

12.1.10 A description of physical appearance of specimen after test, including visible end effects such as cracking, spalling, or shearing at the platen-specimen interfaces.

12.1.11 If the actual equipment or procedure has varied from the requirements contained in this test method, each variation and the reasons for it shall be discussed.

13. Precision and Bias

13.1 An interlaboratory study was conducted in which eight laboratories each tested five specimens of four different rocks. The specimens were cored by a single laboratory from a common set of samples and randomly distributed to the testing laboratories for grinding of the ends and testing. The study was carried out in accordance with Practice E 691. Values of the elastic modulus were determined using the tangent modulus method at stress levels equal to 25, 50, and 75 % of the compressive strength. Details of the study are given in ISR Research Report No. PS #D18.12-R01, 1992. Table 1, Table 2, and Table 3 give the repeatability (within a laboratory) and reproducibility (between laboratories) for the method. At each level of determination, both the repeatability and reproducibility limits increase with the values of the elastic modulus.

13.1.1 The probability is approximately 95 % that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit. Likewise, the probability is approximately 95 % that two test results obtained in different laboratories on the same material will not differ by more than the reproducibility limit.

13.1.2 The repeatability and reproducibility standard deviation is equal to the limit values given divided by $2.83 (2\sqrt{2})$.

13.2 Bias cannot be determined since there is no standard value of each of the elastic constants that can be used to compare with values determined using this test method.

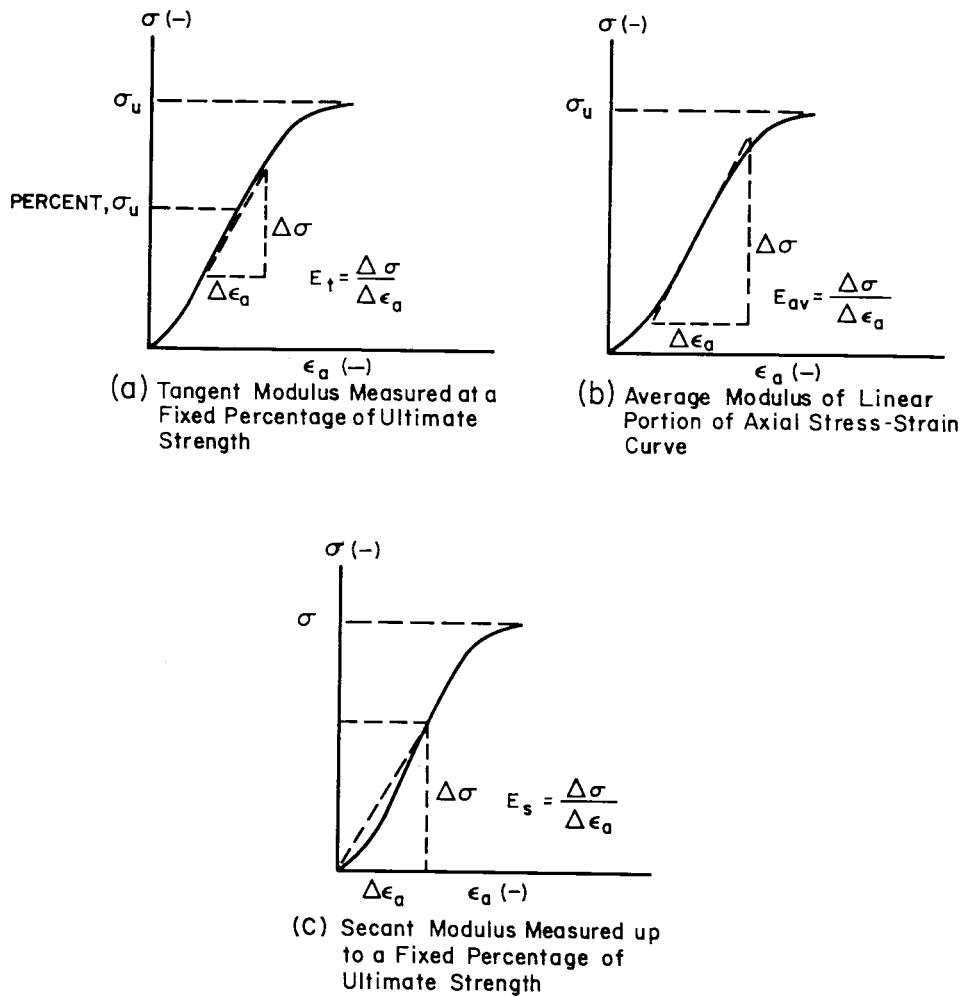


FIG. 2 Methods for Calculating Young's Modulus From Axial Stress-Axial Strain Curve

TABLE 1 Elastic Modulus (GPa) @ 25 %

	Berea Sandstone	Salem Limestone	Tennessee Marble	Barre Granite
Average Value	12.44	32.88	76.31	46.90
Repeatability Limit (d25)	3.37	10.50	14.85	6.12
Reproducibility Limit (d25)	4.17	12.54	17.17	6.45

TABLE 3 Elastic Modulus (GPa) @ 75 %

	Berea Sandstone	Salem Limestone	Tennessee Marble	Barre Granite
Average Value	17.15	27.27	65.57	53.11
Repeatability Limit (d25)	4.48	3.29	13.60	7.99
Reproducibility Limit (d25)	4.84	6.26	13.60	8.47

TABLE 2 Elastic Modulus (GPa) @ 50 %

	Berea Sandstone	Salem Limestone	Tennessee Marble	Barre Granite
Average Value	16.74	32.00	74.19	54.21
Repeatability Limit (d25)	4.15	4.21	10.13	6.75
Reproducibility Limit (d25)	5.19	5.47	12.33	7.77

14. Keywords

14.1 compression testing; loading tests; modulus of elasticity; modulus-Young's; rock

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition that may impact the use of this standard.

- (1) Standards D 653 and D 3740 were added to Section 2. added because they are not in D 653.
- (2) Terminology Section was added. (4) Required caveat for D 3740 was added.
- (3) Definitions for bulk modulus and shear modulus were

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Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens¹

This standard is issued under the fixed designation D 3967; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers testing apparatus, specimen preparation, and testing procedures for determining the splitting tensile strength of rock by diametral line compression of a disk.

NOTE 1—The tensile strength of rock determined by tests other than the straight pull test is designated as the “indirect” tensile strength and, specifically, the value obtained in Section 8 of this test is termed the “splitting” tensile strength.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

E 4 Practices for Force Verification of Testing Machines²
E 691–92 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method³

3. Significance and Use

3.1 By definition the tensile strength is obtained by the direct uniaxial tensile test. But the tensile test is difficult and expensive for routine application. The splitting tensile test appears to offer a desirable alternative, because it is much simpler and inexpensive. Furthermore, engineers involved in rock mechanics design usually deal with complicated stress fields, including various combinations of compressive and tensile stress fields. Under such conditions, the tensile strength should be obtained with the presence of compressive stresses to be representative of the field conditions. The splitting tensile strength test is one of the simplest tests in which such stress fields occur. Since it is widely used in practice, a uniform test method is needed for data to be comparable. A uniform test is also needed to insure positively that the disk specimens break diametrically due to tensile pulling along the loading diameter.

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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² Annual Book of ASTM Standards, Vol 03.01.

³ Annual Book of ASTM Standards, Vol 14.02.

4. Apparatus

4.1 *Loading Device*, to apply and measure axial load on the specimen, of sufficient capacity to apply the load at a rate conforming to the requirements in 7.3. It shall be verified at suitable time intervals in accordance with Practices E 4 and shall comply with the requirements prescribed therein.

4.2 *Bearing Surfaces*—The testing machine shall be equipped with two steel bearing blocks having a Rockwell hardness of not less than 58 HRC (see Note 2).

NOTE 2—False platens, with bearing faces conforming to the requirements of this standard, may be used. These shall be oil hardened to more than 58 HRC, and surface ground. With abrasive rocks these platens tend to roughen after a number of specimens have been tested, and hence need to be surfaced from time to time.

4.2.1 *Flat Bearing Blocks*—During testing the specimen can be placed in direct contact with the machine bearing plates (or false platens, if used) (see Fig. 1). The bearing faces shall not depart from a plane by more than 0.0125 mm when the platens are new and shall be maintained within a permissible variation of 0.025 mm. The bearing block diameter shall be at least as great as the specimen thickness.

4.2.2 *Curved Bearing Blocks*, may be used to reduce the contact stresses. The radius of curvature of the supplementary bearing plates shall be so designed that their arc of contact with the specimen will in no case exceed 15° or that the width of contact is less than $D/6$, where D is the diameter of the specimen.

NOTE 3—Since the equation used in 8.1 for splitting tensile strength is derived based on a line load, the applied load shall be confined to a very narrow strip if the splitting tensile strength test is to be valid. But a line load creates extremely high contact stresses which cause premature cracking. A wider contact strip can reduce the problems significantly. Investigations show that an arc of contact smaller than 15° causes no more than 2 % of error in principal tensile stress while reducing the incidence of premature cracking greatly.

4.2.3 *Spherical Seating*—One of the bearing surfaces should be spherically seated and the other a plain rigid block. The diameter of the spherical seat shall be at least as large as that of the test specimen, but shall not exceed twice the diameter of the test specimen. The center of the sphere in the spherical seat shall coincide with the center of the loaded side of the specimen. The spherical seat shall be lubricated to assure free movement. The movable portion of the platen shall be held closely in the spherical seat, but the design shall be such that



FIG. 1 One of the Proposed Testing Setup for Splitting Tensile Strength

the bearing face can be rotated and tilted through small angles in any direction.

4.2.4 Rigid Seating—If a spherical seat is not used, the faces of the bearing blocks shall be parallel to 0.0005 mm/mm of the block diameter. This criterion shall be met when the blocks are in the loading device and separated by approximately the diameter of the test specimen.

4.3 Bearing Strips (0.01 D thick cardboard cushion, where D is the specimen diameter; or up to 0.25 in. thick plywood cushion are recommended to place between the machine bearing surfaces (or supplementary bearing plates; if used) and the specimen to reduce high stress concentration.

NOTE 4—Experiences have indicated that test results using the curved supplementary bearing plates and bearing strips, as specified in 4.2.2 and 4.3, respectively, do not significantly differ from each other, but there may be some consistent difference from the results of tests in which direct contact between the specimen and the machine platen is used.

5. Sampling

5.1 The specimen shall be selected from the core to represent a true average of the type of rock under consideration. This can be achieved by visual observations of mineral constituents, grain sizes and shape, partings, and defects such as pores and fissures.

6. Test Specimens

6.1 Dimensions—The test specimen shall be a circular disk

with a thickness-to-diameter ratio (t/D) between 0.2 and 0.75. The diameter of the specimen shall be at least 10 times greater than the largest mineral grain constituent. A diameter of 50 mm (1 $\frac{15}{16}$ in.) (NX wireline core) will generally satisfy this criterion.

NOTE 5—When cores smaller than the specified minimum must be tested because of the unavailability of material, notation of the fact shall be made in the test report.

NOTE 6—If the specimen shows apparent anisotropic features such as bedding or schistosity, care shall be exercised in preparing the specimen so that the orientation of the loading diameter relative to anisotropic features can be determined precisely.

6.2 Number of specimens—At least ten specimens shall be tested to obtain a meaningful average value. If the reproducibility of the test results is good (coefficient of variation less than 5 %), a smaller number of specimens is acceptable.

6.3 The circumferential surface of the specimen shall be smooth and straight to 0.50 mm (0.020 in.).

6.4 Cut the ends of the specimen parallel to each other and at right angles to the longitudinal axis. The ends of the specimen shall not deviate from perpendicular to the core axis by more than 0.5°. This requirement can be generally met by cutting the specimen with a precision diamond saw.

6.5 Determine the diameter of the specimen to the nearest 0.25 mm (0.01 in.) by taking the average of at least three measurements, one of which shall be along the loading diameter.

6.6 Determine the thickness of the specimen to the nearest 0.25 mm (0.01 in.) by taking the average of at least three measurements, one of which shall be at the center of the disk.

6.7 The moisture conditions of the specimen at the time of test can have a significant effect upon the indicated strength of the rock. The field moisture condition for the specimen shall be preserved until the time of test. On the other hand, there may be reasons for testing specimens at other moisture contents, including zero, and preconditioning of specimen when moisture control is needed. In any case, tailor the moisture content of the test specimen to the problem at hand and report it in accordance with 9.1.6.

7. Procedure

7.1 Marking—The desired vertical orientation of the specimen shall be indicated by marking a diametral line on each end of the specimen. These lines shall be used in centering the specimen in the testing machine to ensure proper orientation, and they are also used as the reference lines for thickness and diameter measurements.

NOTE 7—If the specimen is anisotropic, take care to ensure that the marked lines in each specimen refer to the same orientation.

7.2 Positioning—Position the test specimen to ensure that the diametral plane of the two lines marked on the ends of the specimen lines up with the center of thrust of the spherically seated bearing surface to within 1.25 mm (0.05 in.).

NOTE 8—A good line loading can often be attained by rotating the specimen about its axis until there is no light visible between the specimen and the loading platens. Back lighting helps in making this observation.

7.3 Loading—Apply a continuously increasing compressive load to produce an approximately constant rate of loading or

deformation such that failure will occur within 1 to 10 min of loading, which should fall between 0.05 and 0.35 MPa/s (500 and 3000 psi/min) of loading rate, depending on the rock type.

NOTE 9—Results of tests by several investigators indicate that rates of loading at this range are reasonably free from rapid loading effects.

8. Calculation

8.1 The splitting tensile strength of the specimen shall be calculated as follows:

$$\sigma_t = 2P/\pi LD \quad (1)$$

and the result shall be expressed to the appropriate number of significant figures (usually 3),

where:

σ_t = splitting tensile strength, MPa (psi),
 P = maximum applied load indicated by the testing machine, N (or lbf),
 L = thickness of the specimen, mm (or in.), and
 D = diameter of the specimen, mm (or in.).

9. Report

9.1 The report shall include as much of the following as possible:

9.1.1 Sources of the specimen including project name and location, and if known, storage environment. The location is frequently specified in terms of the borehole number and depth of specimen from collar of hole.

9.1.2 Physical description of the specimen including rock type; location and orientation of apparent weakness planes, bedding planes, and schistosity; large inclusions or inhomogeneities, if any.

9.1.3 Dates of sampling and testing.

9.1.4 Specimen diameter and length, conformance with dimensional requirements, direction of loading if anisotropy exists. Type of contact between the specimen and the loading platens.

9.1.5 Rate of loading or deformation rate.

9.1.6 General indication of moisture condition of the specimen at time of test such as as-received, saturated, laboratory air dry, or oven dry. It is recommended that the moisture condition

be more precisely determined when possible and reported as either water content or degree of saturation.

9.1.7 Splitting tensile strength of each specimen as calculated, average splitting tensile strength of all specimens, standard deviation or coefficient of variation.

9.1.8 Type and location of failure. A sketch of the fractured specimen is recommended.

10. Precision and Bias

10.1 An interlaboratory study was conducted in which seven laboratories each tested five specimens of four different rocks. The specimens were cored by a single laboratory from a common set of samples and randomly distributed to the testing laboratories for testing. The study was carried out in accordance with Practice E 691. Details of the study are given in ISR Research Report No. PS #D18.12-R01, 1992, and its Addendum, 1994. The table below gives the repeatability limit (within a laboratory) and reproducibility limit (between laboratories) for the method.

10.1.1 The probability is approximately 95 % that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit. Likewise, the probability is approximately 95 % that two test results obtained in different laboratories on the same material will not differ by more than reproducibility limit.

TABLE Splitting Tensile Strength (MPa)

	Berea Sandstone	Salem Limestone	Tennessee Marble	Barre Granite
Average Value	3.85	4.92	9.39	13.66
Repeatability Limit	1.24	1.56	3.63	4.31
Reproducibility Limit	1.37	1.74	5.38	4.98

10.2 The variability of rock and resultant inability to determine a true reference value prevent development of a meaningful statement of bias.

11. Keywords

11.1 compression testing; indirect tensile strength; loading tests; rock; splitting tensile strength; tension (tensile) properties/tests

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Standard Practices for Preserving and Transporting Soil Samples¹

This standard is issued under the fixed designation D 4220; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 These practices cover procedures for preserving soil samples immediately after they are obtained in the field and accompanying procedures for transporting and handling the samples.

1.2 *Limitations*—These practices are not intended to address requirements applicable to transporting of soil samples known or suspected to contain hazardous materials.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* See Section 7.

2. Referenced Documents

2.1 ASTM Standards:

D 420 Guide to Site Characterization for Engineering, Design, and Construction Purposes²

D 653 Terminology Relating to Soil, Rock, and Contained Fluids²

D 1452 Practice for Soil Investigation and Sampling by Auger Borings²

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils²

D 1587 Practice for Thin-Walled Tube Sampling of Soils²

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)²

D 3550 Practice for Ring-Lined Barrel Sampling of Soils²

D 4564 Test Method for Density of Soil in Place by the Sleeve Method²

D 4700 Guide for Soil Sampling from the Vadose Zone²

3. Terminology

3.1 Terminology in these practices is in accordance with Terminology D 653.

4. Summary of Practices

4.1 The various procedures are given under four groupings as follows:

¹ These practices are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

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² Annual Book of ASTM Standards, Vol 04.08.

4.1.1 *Group A*—Samples for which only general visual identification is necessary.

4.1.2 *Group B*—Samples for which only water content and classification tests, proctor and 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.

4.1.3 *Group C*—Intact, naturally formed or field fabricated, samples for density determinations; 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.

4.1.4 *Group D*—Samples that are fragile or highly sensitive for which tests in Group C are required.

4.2 The procedure(s) to be used should be included in the project specifications or defined by the designated responsible person.

5. Significance and Use

5.1 Use of the various procedures recommended in these practices is dependent on the type of samples obtained (Practice D 420), the type of testing and engineering properties required, the fragility and sensitivity of the soil, and the climatic conditions. In all cases, the primary purpose is to preserve the desired inherent conditions.

5.2 The procedures presented in these practices were primarily developed for soil samples that are to be tested for engineering properties, however, they may be applicable for samples of soil and other materials obtained for other purposes.

6. Apparatus

6.1 The type of materials and containers needed depend upon the conditions and requirements listed under the four groupings A to D in Section 4, and also on the climate and transporting mode and distance.

6.1.1 *Sealing Wax*, includes microcrystalline wax, paraffin, beeswax, ceresine, carnaubawax, or combinations thereof.

6.1.2 *Metal Disks*, about $\frac{1}{16}$ in. (about 2 mm) thick and having a diameter slightly less than the inside diameter of the tube, liner, or ring and to be used in union with wax or caps and tape, or both.

6.1.3 *Wood Disks*, prewaxed, 1 in. (25 mm) thick and having a diameter slightly less than the inside diameter of the liner or tube.

6.1.4 *Tape*, either waterproof plastic, adhesive friction, or duct tape.

6.1.5 *Cheesecloth*, to be used in union with wax in alternative layers.

6.1.6 *Caps*, either plastic, rubber or metal, to be placed over the end of thin-walled tubes (Practice D 1587), liners and rings (Practice D 3550), in union with tape or wax.

6.1.7 *O'ring (Sealing End Caps)*, used to seal the ends of samples within thin-walled tubes, by mechanically expanding an O'ring against the tube wall.

NOTE 1—Plastic expandable end caps are preferred. Metal expandable end caps seal equally well; however, long-term storage may cause corrosion problems.

6.1.8 *Jars*, wide mouthed, with rubber-ringed lids or lids lined with a coated paper seal and of a size to comfortably receive the sample, commonly $\frac{1}{2}$ pt (250 mL), 1 pt (500 mL) and quart-sized (1000 mL).

6.1.9 *Bag*, either plastic, burlap with liner, burlap or cloth type (Practice D 1452).

6.1.10 *Packing Material*, to protect against vibration and shock.

6.1.11 *Insulation*, either granule (bead), sheet or foam type, to resist temperature change of soil or to prevent freezing.

6.1.12 *Sample Cube Boxes*, for transporting cube (block) samples. Constructed with $\frac{1}{2}$ to $\frac{3}{4}$ in. (13 to 19 mm) thick plywood (marine type).

6.1.13 *Cylindrical Sample Containers*, somewhat larger in dimension than the thin-walled tube or liner samples, such as cylindrical frozen food cartons.

6.1.14 *Shipping Containers*, either box or cylindrical type and of proper construction to protect against vibration, shock, and the elements, to the degree required.

NOTE 2—The length, girth and weight restrictions for commercial transportation must be considered.

6.1.15 *Identification Material*—This includes the necessary writing pens, tags, and labels to properly identify the sample(s).

7. Precautions

7.1 Special instructions, descriptions, and marking of containers must accompany any sample that may include radioactive, chemical, toxic, or other contaminant material.

7.2 Interstate transportation containment, storage, and disposal of soil samples obtained from certain areas within the United States and the transportation of foreign soils into or through the United States are subject to regulations established by the U.S. Department of Agriculture, Animal, and Plant Health Service, Plant Protection and Quarantine Programs, and possibly to regulations of other federal, state, or local agencies.

7.2.1 Samples shipped by way of common carrier or U.S. Postal Service must comply with the Department of Transportation Hazardous Materials Regulation, 49CRF Part 172.

7.3 Sample traceability records (see Fig. 1) are encouraged and should be required for suspected contaminated samples.

7.3.1 The possession of all samples must be traceable, from collection to shipment to laboratory to disposition, and should be handled by as few persons as possible.

7.3.2 The sample collector(s) should be responsible for

initiating the sample traceability record; recording the project, sample identification and location, sample type, date, and the number and types of containers.

7.3.3 A separate traceability record shall accompany each shipment.

7.3.4 When transferring the possession of samples the person(s) relinquishing and receiving the samples shall sign, date, record the time, and check for completeness of the traceability record.

8. Procedure

8.1 *All Samples*—Properly identify samples with tags, labels, and markings prior to transporting them as follows:

8.1.1 Job name or number, or both,

8.1.2 Sampling date,

8.1.3 Sample/boring number and location,

8.1.4 Depth or elevation, or both,

8.1.5 Sample orientation,

8.1.6 Special shipping or laboratory handling instructions, or both, including sampling orientation, and

8.1.7 Penetration test data, if applicable (Test Method D 1586).

8.1.8 Subdivided samples must be identified while maintaining association to the original sample.

8.1.9 If required, sample traceability record.

8.2 *Group A*—Transport samples in any type of container by way of available transportation. If transported commercially, the container need only meet the minimum requirements of the transporting agency and any other requirements necessary to assure against sample loss.

8.3 *Group B*:

8.3.1 Preserve and transport these samples in sealed, moistureproof containers. All containers shall be of sufficient thickness and strength to ensure against breakage and moisture loss. The container types include: plastic bags or pails, glass or plastic (provided they are waterproof) jars, thin walled tubes, liners, and rings. Wrap cylindrical and cube samples in suitable plastic film or aluminum foil, or both, (Note 3) and coat with several layers of wax, or seal in several layers of cheesecloth and wax.

8.3.2 Transport these samples by any available transportation. Ship these samples as prepared or placed in larger shipping containers, including bags, cardboard, or wooden boxes or barrels.

NOTE 3—Some soils may cause holes to develop in aluminum foil, due to corrosion. Avoid direct contact where adverse affects to sample composition are a concern.

8.3.3 *Plastic Bags*—Place the plastic bags as tightly as possible around the sample, squeezing out as much air as possible. They shall be 3 mil or thicker to prevent leakage.

8.3.4 *Glass-Plastic Jars*—If the jar lids are not rubber ringed or lined with new waxed paper seals, seal the lids with wax.

8.3.5 *Plastic Pails*—If the plastic pail lids are not air tight, seal them with wax or tape.

8.3.6 *Thin-Walled Tubes*:

8.3.6.1 *Expandable Packers*—The preferred method of

Sample Identification/Traceability Record (Controlled Document)

Project: _____
Shipped by: _____
Shipped to: _____
Comments: _____

W.O.

Attention of:
Hazardous materials suspected?
(yes/no)

Sampler(s) (signature) _____

Field ID	Relinquished by: (signature)	Date/Time	Received by: (signature)	Date/Time	Comments

Shipment prepared by: (signature) _____ Date/Time _____ Shipment method: _____

Received for Lab by: (signature) _____ Date/Time _____ Comments _____

Receiving Laboratory: Please return original form after signing for receipt of samples.

FIG. 1 Example Layout of Record Form

sealing sample ends within tubes is with plastic, expandable packers.

8.3.6.2 *Wax With Disks*—For short-term sealing, paraffin wax is acceptable. For long term sealing (in excess of 3 days) use microcrystalline waxes or combine with up to 15 % beeswax or resin, for better adherence to the wall of the tube and to reduce shrinkage. Several thin layers of wax are preferred over one thick layer. The minimum final thickness shall be 0.4 in. (10 mm).

8.3.6.3 End Caps—Seal metal, rubber, or plastic end caps with tape. For long term storage (longer than 3 days), also dip them in wax, applying two or more layers of wax.

8.3.6.4 *Cheesecloth and Wax*—Use alternating layers (a minimum of two each) of cheesecloth and wax to seal each end of the tube and stabilize the sample.

NOTE 4—Where necessary, spacers or appropriate packing materials, or both, must be placed prior to sealing the tube ends to provide proper confinement. Packing material must be nonabsorbent and must maintain its properties to provide the same degree of continued sample support.

8.3.7 *Liners and Rings*—Refer to 8.3.6.3 or 8.3.6.4.

8.3.8 Exposed Samples:

8.3.8.1 Cylindrical, Cubical or Other Samples Wrapped in

Plastic, such as polyethylene and polypropylene, or foil should be further protected with a minimum of three coats of wax.

8.3.8.2 *Cylindrical and Cube Samples Wrapped in Cheesecloth and Wax*, shall be sealed with a minimum of three layers of each, placed alternatively.

8.3.8.3 *Carton Samples (Frozen Food Cartons)*—Samples placed in these containers must be situated so that wax can be poured completely around the sample. The wax should fill the void between the sample and container wall. The wax should be sufficiently warm to flow, but not so hot that it penetrates the pores of the soil. Generally, the samples should be wrapped in plastic or foil before being surrounded with wax.

8.4 Group C:

8.4.1 Preserve and seal these samples in containers as covered in 8.3. In addition, they must be protected against vibration and shock, and protected from extreme heat or cold.

8.4.2 Samples transported by the sampling or testing agency personnel on seats of automobiles and trucks need only be placed in cardboard boxes, or similar containers into which the sealed samples fit snugly, preventing bumping, rolling, dropping, etc.

8.4.3 For all other methods of transporting samples, including automobile trunk, bus, parcel services, truck, boat, air, etc., place the sealed samples in wood, metal, or other type of suitable shipping containers that provide cushioning or insulation, or both, for each sample and container. Avoid transporting by any agency whose handling of containers is suspect.

8.4.4 The cushioning material (sawdust, rubber, polystyrene, urethane foam, or material with similar resiliency) should completely encase each sample. The cushioning between the samples and walls of the shipping containers should have a minimum thickness of 1 in. (25 mm). A minimum thickness of 2 in. (50 mm) shall be provided on the container floor.

8.4.5 When required, the samples should be shipped in the same orientation in which they were sampled. Otherwise, special conditions shall be provided such as freezing, controlled drainage, or sufficient confinement, or a combination thereof, to maintain sample integrity.

8.5 Group D:

8.5.1 The requirements of 8.4 must be met, in addition to the following:

8.5.1.1 Samples should be handled in the same orientation in which they were sampled, including during transportation or shipping, with appropriate markings on the shipping container.

8.5.1.2 For all modes of private or commercial transportation, the loading, transporting and unloading of the shipment containers should be supervised as much as possible by a qualified person.

NOTE 5—A qualified person may be an engineer, geologist, soil scientist, soils technician or responsible person designated by the project manager.

8.6 *Shipping Containers* (see Figs. 2-7 for typical containers):

8.6.1 The following features should be included in the design of the shipping container for Groups C and D.

8.6.1.1 It should be reuseable,

8.6.1.2 It should be constructed so that the samples can be maintained, at all times, in the same position as when sampled or packed, or both,

8.6.1.3 It should include sufficient packing material to

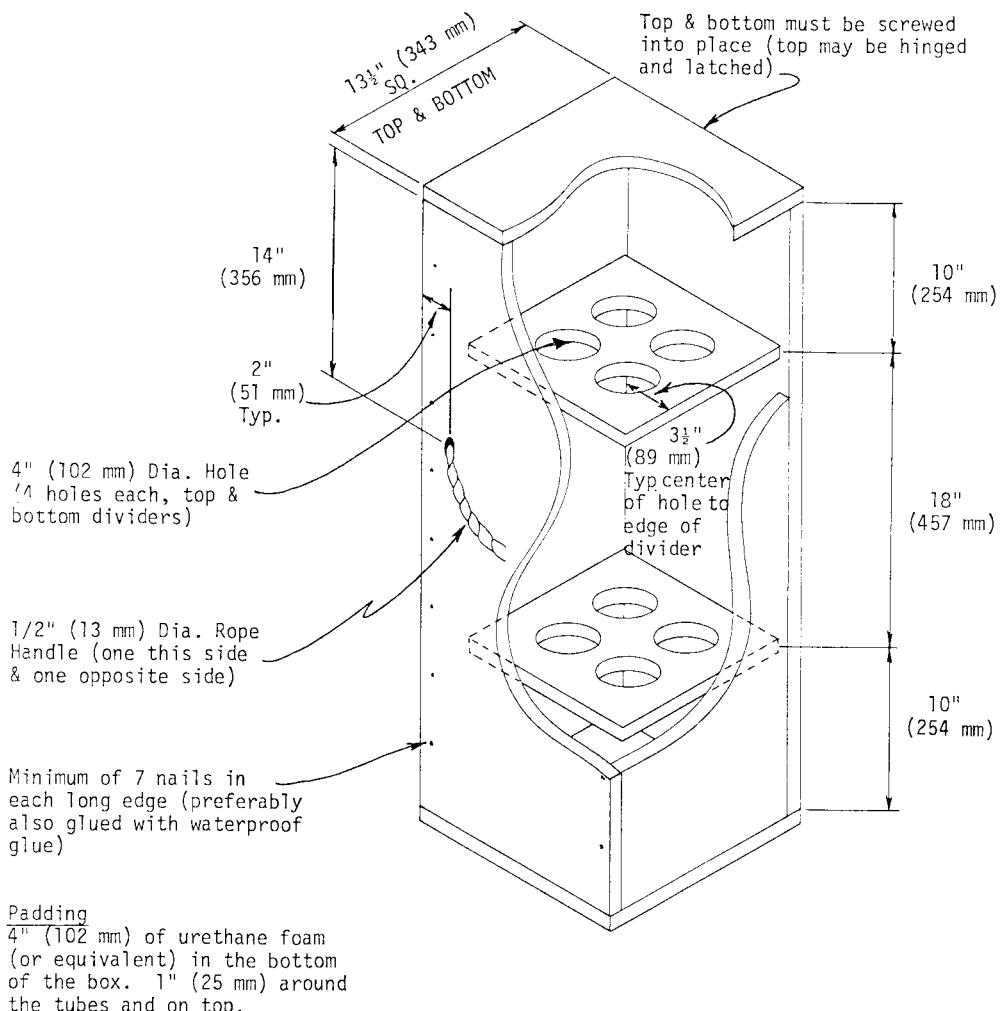
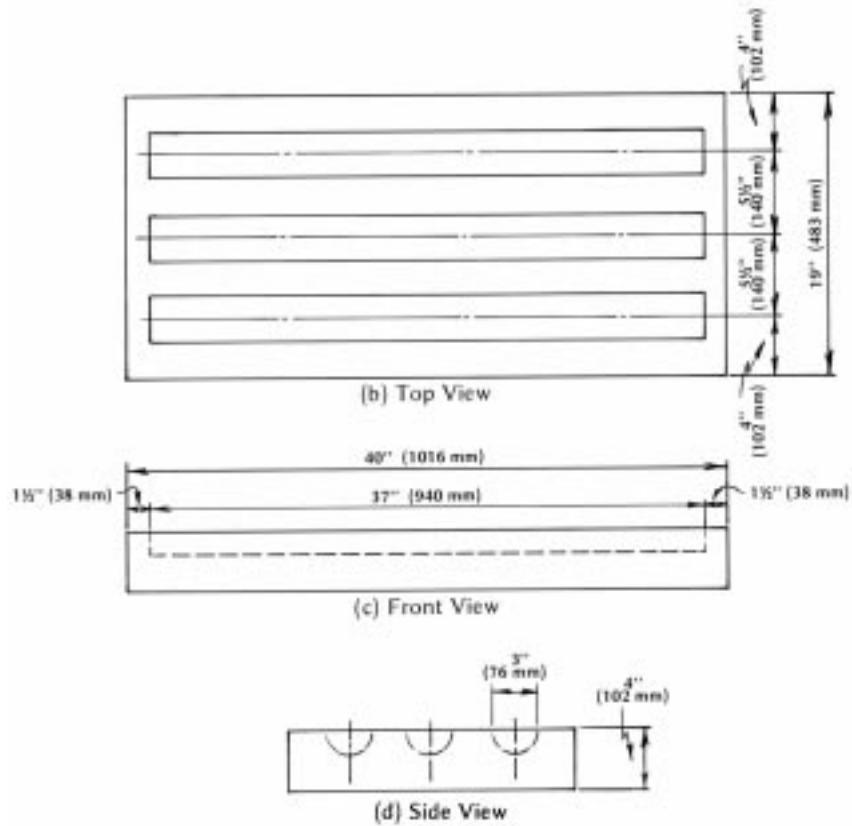


FIG. 2 Shipping Box for 3-in. (76-mm) Thin-Walled Tubes



(a) Photo of Open Box For 5" (127 mm) Tubes



NOTE 1—Top and bottom halves are identical.

FIG. 3 Styrene Shipping Container for 3-in. (76-mm) Thin-Walled Tubes

to cushion or isolate, or both, the tubes from the adverse effect of vibration and shock, and

8.6.1.4 It should include sufficient insulating material to prevent freezing, sublimation and thawing, or undesirable temperature changes.

8.6.2 Wood Shipping Containers:

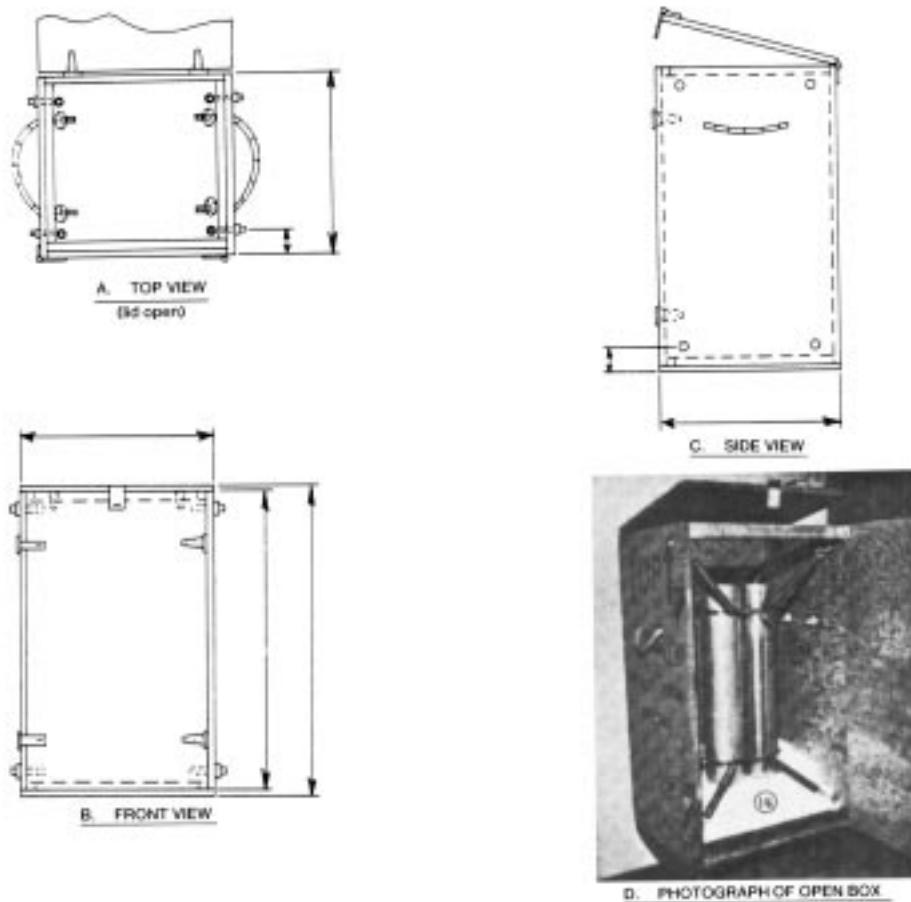
8.6.2.1 Wood is preferred over metal. Outdoor (marine) plywood having a thickness of $1/2$ and $3/4$ in. (13 to 19 mm) may

be used. The top (cover) should be hinged and latched, or fastened with screws.

8.6.2.2 The cushioning requirements are given in 8.4.4.

8.6.2.3 For protection against freezing or extreme temperature variation, the entire shipping container should be lined with a minimum insulation thickness of 2 in. (50 mm).

8.6.3 *Metal Shipping Containers*—The metal shipping containers must incorporate cushioning and insulation material to



BILL OF MATERIALS

Item No.	Description of Item	Quantity	Item No.	Description of Item	Quantity	
1	Plywood, 4 ft by 8 ft by $\frac{3}{4}$ in. (1220 mm by 2440 mm by 19.1 mm) exterior, Grade AC	1 Sheet	13	Rope, nylon, $\frac{1}{2}$ -in. (12.7-mm) diameter, solid braided	5 ft (1524 mm)	
2	Hinge, strap, 4 in. (102 mm), heavy duty with screws	4 Each	14	Cushioning Material, expanded polystyrene foam	10 ft ³ (0.28 m ³)	
3	Hasp, hinged, $\frac{1}{2}$ in. (114 mm), with screws	3 Each	Notes—			
4	Screw, Wood, Steel, Flathead, No. 10 by $1\frac{1}{4}$ in. (44.5 mm)	72 Each	(a) All wooden components can be sawed from one sheet of plywood.			
5	Bolt, Machine, $\frac{3}{8}$ in. (9.5 mm), with nut to secure hasps	3 Each	(b) This shipping box will accommodate approximately three 3-in. (76-mm) diameter tubes or two 5-in (127-mm) diameter tubes up to 30 in. (762 mm) in length. For longer tubes the inside height of the box must be a minimum of 6-in. (152 mm) greater than the length of the tube.			
6	Washer, flat, $\frac{3}{8}$ in. (9.5 mm)	3 Each	(c) All joints to be glued and fastened with screws.			
7	Eye Bolt, $\frac{1}{2}$ by 2 in. (6.4 mm by 51 mm), zinc-plated, with nut	8 Each	(d) Stencil all sides as follows (See Views B and C).			
8	Washer, flat, $\frac{1}{4}$ in. (6.4 mm), for hasp bolt	8 Each	(e) After suspending samples as indicated above, all void space must be filled with a suitable resilient packing material.			
9	S Hooks, 2 in. (51 mm), open, zinc-plated	8 Each	TO PROTECT FROM FREEZING			
10	Clamp, adjustable, hose, steel, worm screw adjustment	2 Each				
11	Spring, expansion	8 Each				
12	Adhesive, woodworking	1 lb (454 g)				

FIG. 4 Suspension System Container for Thin-Walled Tubes

minimum thicknesses in accordance with 8.6.2, although slightly greater thicknesses would be appropriate. Alternatively, the cushion effect could be achieved with a spring suspension system, or any other means that would provide similar protection.

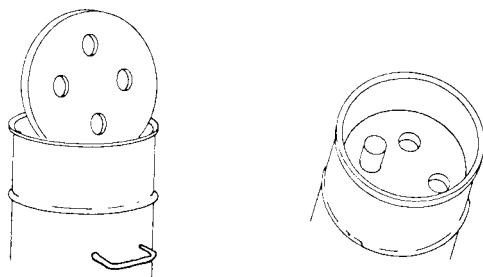
8.6.4 Styrene Shipping Containers—Bulk styrene with slots cut to the dimensions of the sample tube or liner. A protective outer box of plywood or reinforced cardboard is recommended.

8.6.5 Other Containers—Containers constructed with laminated fiberboard, plastic or reinforced cardboard outer walls, and properly lined, may also be used.

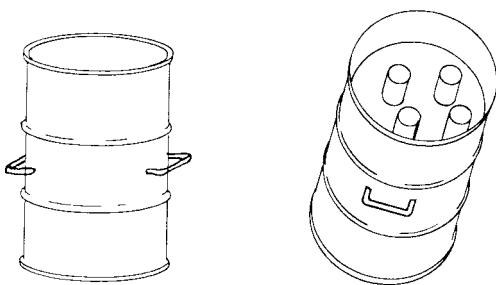
9. Reporting

9.1 The data obtained in the field shall be recorded and should include the following:

- 9.1.1 Job name or number, or both,
- 9.1.2 Sampling date(s),
- 9.1.3 Sample/boring number(s) and location(s),
- 9.1.4 Depth(s) or elevation(s), or both,
- 9.1.5 Sample orientation,
- 9.1.6 Groundwater observation, if any,
- 9.1.7 Method of sampling, and penetration test data, if applicable,



(a) 55-gallon (0.21 m^3) oil barrels with sections of styrofoam insulation; welded handles on each side.



(b) Same as (a) showing barrel ready for shipment. Steel lids bolted on to provide tight seal.

NOTE 1—Two in. (51 mm) of foam rubber covers 2 in. of styrofoam at the base. One in. (25 mm) of foam rubber overlays the top of the tubes, and the remaining space to the lid is filled with styrofoam.

FIG. 5 Shipping Barrel for Thin-Walled Tubes

9.1.8 Sample dimensions,
9.1.9 Soil description (Practice D 2488),

9.1.10 Names of technician/crewman, engineer, project chief, etc.,

9.1.11 Comments regarding contaminated or possible contaminated samples,

9.1.12 If used, a copy of traceability records,

9.1.13 Weather conditions, and

9.1.14 General remarks.

10. Precision and Bias

10.1 This practice provides qualitative and general information only. Therefore, a precision and bias statement is not applicable.

11. Keywords

11.1 preservation; soil samples; transportation

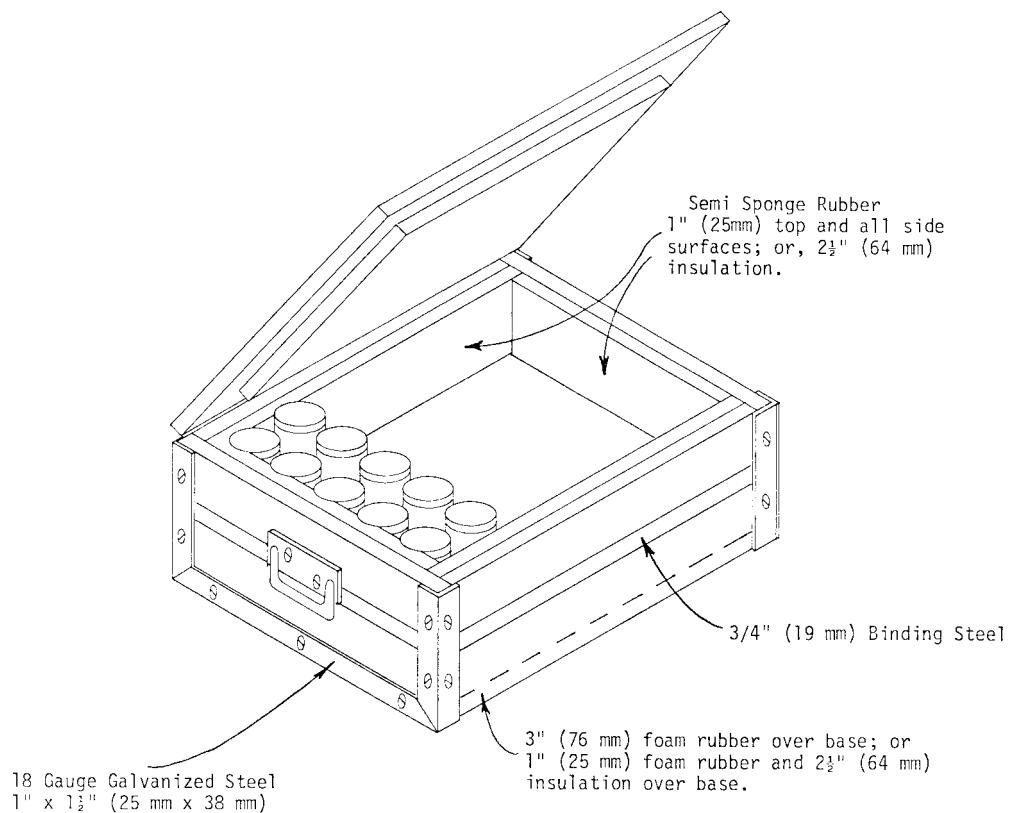
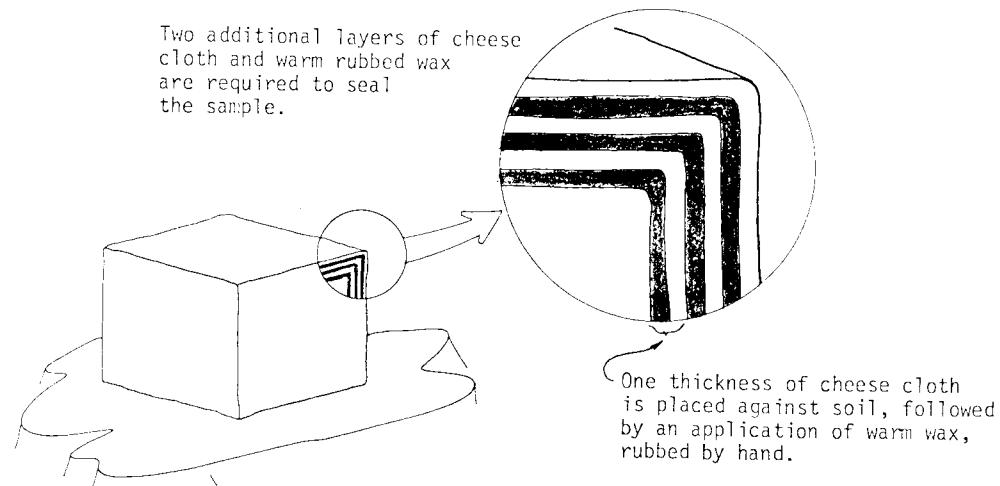
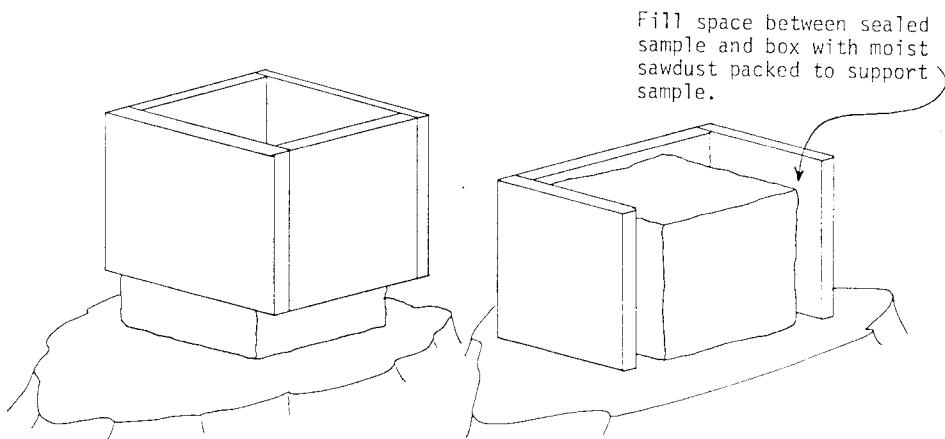


FIG. 6 Shipping Box for Liner (Short Tube) or Ring Samples



A. METHOD FOR SEALING HAND-CUT UNDISTURBED SAMPLES



B. ENCASE EASILY DISTURBED SAMPLES IN BOX PRIOR TO CUTTING

Box constructed with 1/2"-3/4" (13 - 19 mm) exterior plywood.

FIG. 7 Preparing and Packaging a Block Sample

SUMMARY OF CHANGES

This section identifies the location of changes to these practices that have been incorporated since the last issue. Committee D-18 has highlighted those changes that affect the technical interpretation or use of these practices.

- (1) Section 11 was added since the last revision.
- (2) Section 2 was expanded since the last revision.

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Standard Practices for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances¹

This standard is issued under the fixed designation D 4543; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice specifies procedures for determining the length and diameter of rock core specimens and the conformance of the dimensions with established standards.

1.2 Rock is a complex engineering material which can vary greatly as a function of lithology, stress history, weathering, and other natural geologic processes. As such, it is not always possible to obtain or prepare rock core specimens which satisfy the desirable criteria given in this practice. Most commonly, this situation presents itself with weaker, more porous, and poorly cemented rock types and rock types containing significant structural features. For these and other rock types which are difficult to prepare, all reasonable efforts shall be made to prepare a sample in accordance with this practice. However, when it has been determined by trial that this is not possible, prepare the rock specimen to the highest standard practicable and consider this to be the best effort and report it as such, with all appropriate size and dimensional measurements reported as in Section 6.

1.3 This practice also prescribes tolerance checks on the straightness of the elements on the cylindrical surface, the flatness of the end bearing surfaces, and the perpendicularity of the end surfaces with the axis of the core.

1.4 The requirement for specifying the moisture condition of the test specimen at the time of the test is also stated.

1.5 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses are for information only.

1.6 *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.*

1.7 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgement. Not all aspects of this practice 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.

2. Referenced Documents

2.1 ASTM Standards:

- C 617 Practice for Capping Cylindrical Concrete Specimens²
- D 2113 Practice for Rock Core Drilling and Sampling of Rock for Site Investigation³
- D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass³
- D 2664 Test Method for Triaxial Compressive Strength of Undrained Rock Core Specimens without Pore Pressure Measurements³
- D 2936 Test Method for Direct Tensile Strength of Intact Rock Core Specimens³
- D 2938 Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens³
- D 3148 Test Method for Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression³
- D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
- D 4341 Test Method for Creep of Cylindrical Hard Rock Core Specimens in Uniaxial Compression³
- D 4405 Test Method for Creep of Cylindrical Soft Rock Core Specimens in Uniaxial Compression³
- D 4406 Test Method for Creep of Cylindrical Rock Core Specimens in Triaxial Compression³

3. Significance and Use

3.1 The dimensional, shape, and surface tolerances of rock core specimens are important for determining rock properties of intact specimens. Dimensional and surface tolerance checks are required in the test methods listed in 2.1. To simplify test

¹ This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved June 10, 2001. Published November 2001. Originally published as D 4543-85. Last previous edition D 4543-85 (Reapproved 1991).

² Annual Book of ASTM Standards, Vol 04.02.

³ Annual Book of ASTM Standards, Vol 04.08.

procedures in laboratories, the parts of those procedures that are common to the test methods are given in this standard.

4. Specimens

4.1 Test specimens shall be right circular cylinders within the tolerances specified herein.

4.2 The specimen shall have a length-to-diameter ratio (L/D) of 2.0 to 2.5 and a diameter of not less than 1 $\frac{1}{8}$ in. (47 mm).

NOTE 1—It is desirable that the diameter of rock test specimens be at least ten times the diameter of the largest mineral grain. For weak rock types which behave more like soil (for example, weakly cemented sandstone), the specimen diameter should be at least six times the maximum particle diameter. It is considered that the specified minimum specimen diameter of approximately 1 $\frac{1}{8}$ in. (47 mm) will satisfy this criterion in the majority of cases. When cores of diameter smaller than the specified minimum must be tested because of the unavailability of larger diameter core, as is often the case in the mining industry, suitable notation of this fact shall be made in the report.

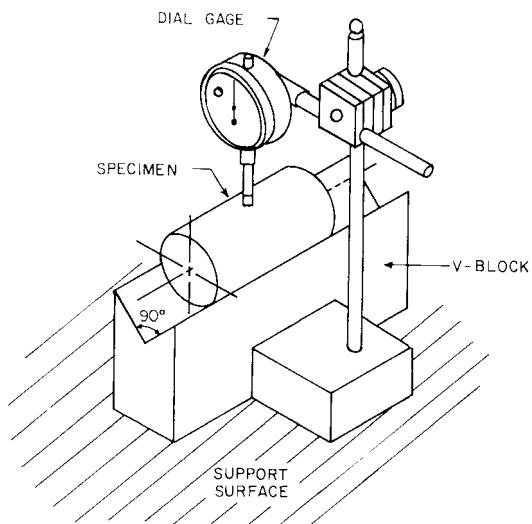


FIG. 1 Assembly for Determining the Straightness of Elements on the Cylindrical Surface—Procedure B

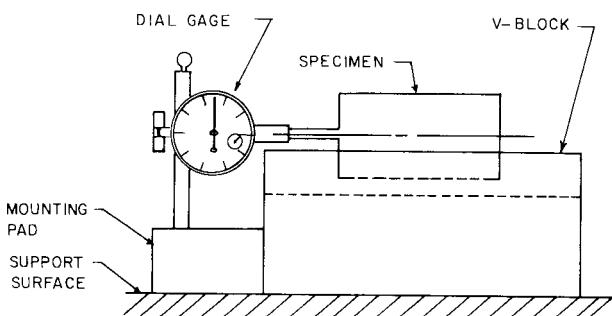


FIG. 2 Assembly for Determining the Flatness and Perpendicularity of End Surfaces to the Specimen Axis—Procedure B

4.3 The sides of the specimen shall be generally smooth and free of abrupt irregularities, with all the elements straight to within 0.020 in. (0.50 mm) over the full length of the specimen, as determined by 5.1.

4.4 The ends of the specimen shall be cut parallel to each other and at right angles to the longitudinal axis. The end surfaces shall be surface ground or lapped flat to a tolerance not to exceed 0.001 in. (25 μm), as determined by 5.2.⁴

5. Procedure

5.1 Determine the deviation from straightness of the elements by either Procedure A or Procedure B, as follows:

5.1.1 *Procedure A*—Roll the cylindrical specimen on a smooth, flat surface and measure the height of the maximum gap between the specimen and the flat surface with a feeler gage. If the maximum gap exceeds 0.020 in. (0.50 mm), the specimen does not meet the required tolerance for straightness of the elements. The flat test surface on which the specimen is rolled shall not depart from a plane by more than 0.0005 in. (13 μm).

5.1.2 *Procedure B*—Place the cylindrical surface of the specimen on a V-block that is laid flat on a support surface. The V-block shall be machinist quality with all bearing faces surface ground and with a 90° included angle. Maintain the support surface and all bearing surfaces on the V-block flat and smooth to within 0.0005 in. (13 μm). The length of the V-block shall be sufficient that the specimen will not project over its ends during movement.

5.1.2.1 Place a dial gage in contact with the top of the specimen, as shown in Fig. 1, and observe the dial reading as the specimen is moved from one end of the V-block to the other along a straight line, without rotation. The sensitivity of the dial gage shall be at least 0.001 in. (25 μm). The measurement contact tip of the dial gage shall be round in shape.

5.1.2.2 Record the maximum and minimum readings on the dial gage and calculate the difference, Δ_0 . If the dial gage traverses a natural cavity in the rock, readings in this region should not be included in the determination of Δ_0 . Repeat the same operations by rotating the specimen for every 120°, and obtain the differences Δ_{120} and Δ_{240} . The maximum value of these three differences shall be less than 0.020 in. (0.50 mm).

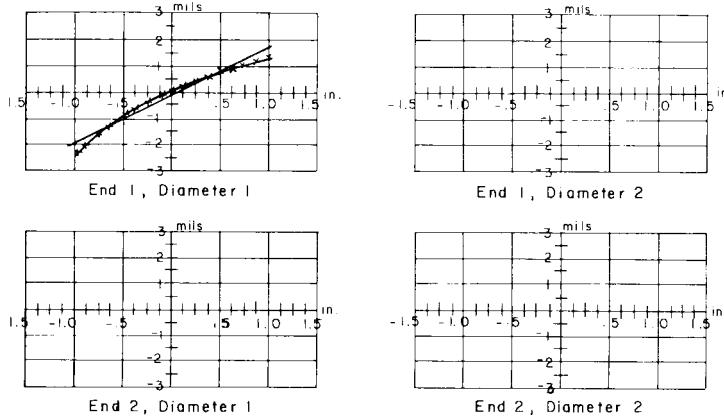
5.2 Check the end flatness tolerance by either Procedure A or Procedure B, as follows:

5.2.1 *Procedure A*—Place the specimen in a setup similar to that for the cylindrical surface (Fig. 2) except that the dial gage shall be mounted near the end of the V-block.

5.2.1.1 Move the mounting pad horizontally so that the dial gage measurement tip runs across a diameter of the specimen end surface. Make sure that the end of the mounting pad maintains intimate contact with the end surface of the V-block during movement. A dial gage readable to 0.0001 in. (2.5 μm) is required for measurements on the end surfaces.

5.2.1.2 Record the dial gage readings every $\frac{1}{8}$ in. (3 mm) across the diameter. These readings may be recorded in tabular form, or to simplify the procedure, they may be plotted directly on a graph as shown for End 1, Diameter 1, in Fig. 3. Data recording is simplified if the dial gage is set to zero when it is in contact with the center of the end face.

⁴ Hoskins, J. R., and Horino, F. G., "Effects of End Conditions on Determining Compressive Strength of Rock Samples," *Report of Investigations U.S. Bureau of Mines 7171*, 1968.



Difference between maximum and minimum readings for Diam 1, End 1 = Δ_1 = _____

Difference for Diam 2, End 1 = Δ_2 = _____

Difference for Diam 1, End 2 = Δ_1' = _____

Difference for Diam 2, End 2 = Δ_2' = _____

Use the largest of the four Δ , Δ_{\max} = _____

Perpendicularity tolerance is met when $\frac{\Delta_{\max}}{\text{diam}} \leq 0.0043$

FIG. 3 Suggested Format for Presenting Tolerance-Check Data

5.2.1.3 Plot the readings and draw a smooth curve through the points to represent the surface profile along the specified diametrical plane, as shown for End 1, Diameter 1, in Fig. 3. Do not plot dial gage readings taken when the gage tip drops into a natural cavity in the rock. The flatness tolerance is met when the smooth curve so determined does not depart from a visual best-fit straight line by more than 0.001 in. (25 μm).

5.2.1.4 Rotate the specimen 90° about its longitudinal axis and repeat the same operations and tolerance checks for the new diametrical plane. Turn the specimen end for end and repeat the same measurement procedures and tolerance checks for the other end surface.

5.2.2 *Procedure B*—Set the specimen upright on a smooth, flat surface that does not depart from plane by more than 0.0005 in (13 μm).

5.2.2.1 Place a dial gage measurement tip in contact with the top of the specimen. The readability of the dial gage shall be at least 0.0001 in (2.5 μm).

5.2.2.2 Move the dial gage measurement tip across the top of the specimen along at least three different diameters. Note the maximum and minimum dial gage readings. Do not include dial gage readings taken when the measurement tip drops into a natural cavity in the rock. Turn the specimen end-for-end and repeat.

5.2.2.3 The flatness tolerance is met if the difference between the maximum and minimum readings is less than 0.0015 in. (38 μm). This procedure also ensures that the ends of the specimen are parallel.

5.3 The ends of the specimen shall not depart from perpendicularity to the axis of the specimen by more than 0.25°, which is a slope of 1 part in 230.^{4,5} Check this tolerance using either Procedure A or Procedure B, as follows:

⁵ Podnieks, E. R., Chamberlain, P. G., and Thill, R. E., "Environmental Effects on Rock Properties," *Basic and Applied Rock Mechanics, Proceedings of Tenth Symposium on Rock Mechanics*, AIME, 1972, pp. 215-241.

5.3.1 *Procedure A*—Use the measurements taken in 5.2.1. Calculate the difference between the maximum and the minimum readings on the dial gage along Diameter 1. This difference is denoted as Δ_1 . Calculate the corresponding difference for Diameter 2, which is 90° from Diameter 1. Denote the difference for Diameter 2 as Δ_2 . Calculate the corresponding differences for the other end of the specimen, Δ_1' and Δ_2' . The perpendicularity tolerance will be considered to have been met when:

$$\frac{\Delta_i}{d} \text{ and } \frac{\Delta_i'}{d} \leq \frac{1}{230} = 0.0043 \quad (1)$$

where:

$i = 1$ or 2 , and

d = diameter.

5.3.2 *Procedure B*—Set the specimen upright on a smooth, flat surface that does not depart from plane by more than 0.0005 in. (13 μm).

5.3.2.1 Place the base of a true square on the test surface and in contact with the bottom of the specimen.

5.3.2.2 Rotate the specimen, keeping contact with the square, until the maximum gap between the square and the top of the specimen is found. Determine the width of the gap using a feeler gage.

5.3.2.3 The perpendicularity tolerance is met if the gap, Δ , divided by the specimen length, L , is less than 1 part in 230, i.e.,

$$\frac{\Delta}{L} \leq \frac{1}{230} = 0.0043 \quad (2)$$

5.3.2.4 Repeat for other end of specimen unless the specimen ends were checked for parallelism in 5.2.2.

5.4 The measurements described in 5.1.2, 5.2, and 5.3 are taken with a mechanical dial gage. An optical or electronic device with an equivalent or better readout sensitivity and accuracy may be used in place of the dial gage, if desired.

5.5 The measurements taken on the ends of the specimen in

5.2.1 and 5.3.1 may also be made with the specimen clamped upright in a machinist quality V-block. The measuring tip of the dial gage would then contact the upper end surface of the specimen. Either the V-block and specimen may be moved as a unit under a stationary dial gage, or the dial gage may be moved while the V-block and specimen remain stationary. Whatever configuration is assembled, it must be machinist quality so that readings may be reproduced within 0.0001 in. (2.5 μ m). The readings to be taken with such a vertical configuration are the same as those specified for the horizontal configuration in 5.2.1 and 5.3.1.

5.6 Determine the diameter of the test specimen to the nearest 0.01 in. (0.25 mm) by averaging two diameters measured at right angles to each other at about midheight of the specimen. Use this average diameter for calculating the cross-sectional area. Determine the length of the test specimen to the nearest 0.01 in. (0.25 mm) at the centers of the end faces.

5.7 The use of capping materials or end surface treatments other than the grinding and lapping specified herein is not permitted, except as noted in 5.8. Lubricants are not permitted on the specimen - platen interfaces.

5.8 There are some rock types with physical characteristics or low strengths which preclude preparing specimens to the flatness tolerance specified in 5.2, even with the best effort (Note 2). In these instances, first cut to length the core specimen and apply end caps to the end surfaces of the specimen.

5.8.1 The specifications for the capping compound, capping plates, and alignment devices and the procedure for capping weak rock core specimens shall be the same as those established for compression testing of concrete in Practice C 617; however, melted sulfur capping compounds are not permitted because of the possible detrimental effects of the high temperature on the rock.

NOTE 2—Best effort in surface preparation refers to the use of a well-maintained surface grinder by an experienced operator. Air-cooled grinding with a dust collector is recommended over water circulation for weak rocks and rocks that may react to fluids. A diamond grinding wheel may help if there are hard mineral grains in the rock, such as pyrite in shale.

5.9 The moisture condition of the specimen shall be determined using Test Method D 2216 and reported as required in 6.1.6.

NOTE 3—The moisture condition of the specimen at the time of the sample preparation can have a significant effect upon the strength and

deformation characteristics of the rock. Good practice generally dictates that laboratory tests be made upon specimens representative of field conditions. Thus, it follows that the field moisture condition of the specimen should be preserved until the time of the test. In some instances, however, there may be reasons for testing specimens at other moisture contents, from saturation to dry. In any case, the moisture content of the test specimen should be tailored to the problem at hand. Excess moisture will affect the adhesion of resistance strain gages, if used, and the accuracy of their performance. Adhesives used to bond the rock to steel end pieces in the direct tension test will also be affected adversely by excess moisture.

6. Report

6.1 Report the following along with other data required for the particular test (2.1) being performed:

6.1.1 Source of test specimen, including project name and location. Often the location is specified in terms of the drill hole number and depth of specimen from collar of hole.

6.1.2 Date test is performed.

6.1.3 Physical description of test specimen including: rock type such as sandstone, limestone, granite, etc.; location and orientation of inherent rock structural features and any discontinuities; and large inclusions or inhomogeneities, if any. A sketch of the test specimen is recommended for other than homogeneous rock types.

6.1.4 Specimen diameter and length, and conformance or best effort conformance with dimensional requirements (4.2 and 5.6).

6.1.5 Data to substantiate the following three tolerances:

6.1.5.1 Straightness of elements by either Procedure A (5.1.1) or Procedure B (5.1.2).

6.1.5.2 Flatness of end faces by either Procedure A (5.1.1) or Procedure B (5.1.2).

6.1.5.3 Perpendicularity of end faces by either Procedure A (5.3.1) or Procedure B (5.3.2).

6.1.6 General indication of the moisture condition of the sample at the time of the test, such as as-received, saturated, laboratory air-dry, or oven dry. It is recommended that the moisture conditions be more precisely determined when possible and reported as either water content or degree of saturation.

7. Keywords

7.1 conformance; core; diameter; dimensional tolerances; dimensions; length; rock; specimen preparation (for testing); specimen shape; specimen size

SUMMARY OF CHANGES

- (1) In title, "Practice" was changed to "Practices."
- (2) In the Scope, added caveat required for practices.
- (3) In Referenced Documents, added D 2216 Method for Determination of Water (Moisture) Content of Soil and Rock
- (4) In Referenced Documents, added D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
- (5) In Referenced Documents, deleted D 3967 Test Method for Splitting Tensile Strength of Intact Rock Core Specimens
- (6) In Procedure, minor corrections were made to some of the metric conversions.
- (7) In Procedure, a procedure B was added to sections 5.2 and 5.3, which dealt with end flatness and perpendicularity. This

was to include a procedure, which has been historically used by a large number of test laboratories where one end of the cylindrical surface is placed on a flat surface while the other end is checked with a dial gage, or similar device.

(8) In Procedure, An ASTM test method for determining water content, which did not previously exist, was added to the procedure. The reference to a International Society for Rock Mechanics Suggested Method, which had been used to cover the previous deficiency, was removed since it was no longer needed.

(9) In Keywords, deleted: surface analysis and tolerances.

(10) In Keywords, added: core, specimen shape, specimen size, and dimensional tolerances.

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Standard Test Method for Determination of the Point Load Strength Index of Rock¹

This standard is issued under the fixed designation D 5731; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 This test method covers the guidelines, requirements, and procedures for determining the point load strength index of rock. Specimens in the form of rock cores, blocks, or irregular lumps can be tested by this test method. This test method can be performed in the field or laboratory because the testing machine is portable. This is an index test and is intended to be used to classify and characterize rock.

1.2 This test method applies to hard rock (compressive strength over 15 MPa (2200 psi)).

1.3 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.3.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.4 The values stated in the SI units are to be regarded as standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids²

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock²

D 2938 Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens²

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock

as Used in Engineering Design and Construction²
D 5079 Practices for Preserving and Transporting Rock Core Samples²
D 6026 Practice for Using Significant Digits in Geotechnical Data³
E 18 Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials⁴
2.2 *ISRM Standard:*
Suggested Methods for Determining Point Load Strength⁵

3. Terminology

3.1 For definitions of terms used in this test method refer to Terminology D 653.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *point load strength index*—an indicator of strength (see 9.1) obtained by subjecting a rock specimen to an increasingly concentrated point load, applied through a pair of truncated, conical platens, until failure occurs.⁵

4. Summary of Test Method

4.1 This index test is performed by subjecting a rock specimen to an increasingly concentrated load until failure occurs by splitting the specimen. The concentrated load is applied through coaxial, truncated conical platens. The failure load is used to calculate the point load strength index and to estimate the uniaxial compressive strength.

5. Significance and Use

5.1 The uniaxial compression test (see Test Method D 2938) is used to determine compressive strength of rock specimens, but it is a time-consuming and expensive test that requires specimen preparation. When extensive testing is required for preliminary and reconnaissance information, alternative tests such as the point load test can be used in the field to reduce the time and cost of compressive strength tests.

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved Nov. 10, 2002. Published January 2003. Originally approved in 1995. Last previous edition approved in 1995 as D 5731–95.

² Annual Book of ASTM Standards, Vol 04.08.

³ Annual Book of ASTM Standards, Vol 04.09.

⁴ Annual Book of ASTM Standards, Vol 03.01.

⁵ “Suggested Methods for Determining Point Load Strength”, International Society for Rock Mechanics Commission on Testing Methods, *Int. J. Rock. Mech. Min. Sci. and Geomechanical Abstr.*, Vol 22, No. 2, 1985, pp. 51–60.

5.2 The point load strength test is used as an index test for strength classification of rock materials. The test results should not be used for design or analytical purposes.

5.3 This test method is performed to determine the point load strength index ($I_s(50)$) of rock specimens, and the point load strength anisotropy index ($I_a(50)$) that is the ratio of point load strengths on different axes that result in the greatest and least values.

5.4 Rock specimens in the form of either core (the diametral and axial tests), cut blocks (the block test), or irregular lumps (the irregular lump test) are tested by application of concentrated load through a pair of truncated, conical platens. Little or no specimen preparation is required. However, the results can be highly influenced by how the specimen is treated from the time it is obtained until the time it is tested. Therefore, it may be necessary to handle specimens in accordance with Practice D 5079.

NOTE 1—The quality of the result produced by this standard is dependent upon the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing and sampling. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *General*—A point load tester (see Fig. 1) consists of a loading system typically comprised of a loading frame, platens, a measuring system for indicating load, P , (required to break the specimen), and a means for measuring the distance, D , between the two platen contact points. The equipment shall be resistant to shock and vibration so that the accuracy of readings is not adversely affected by repeated testing.

6.2 Loading System:

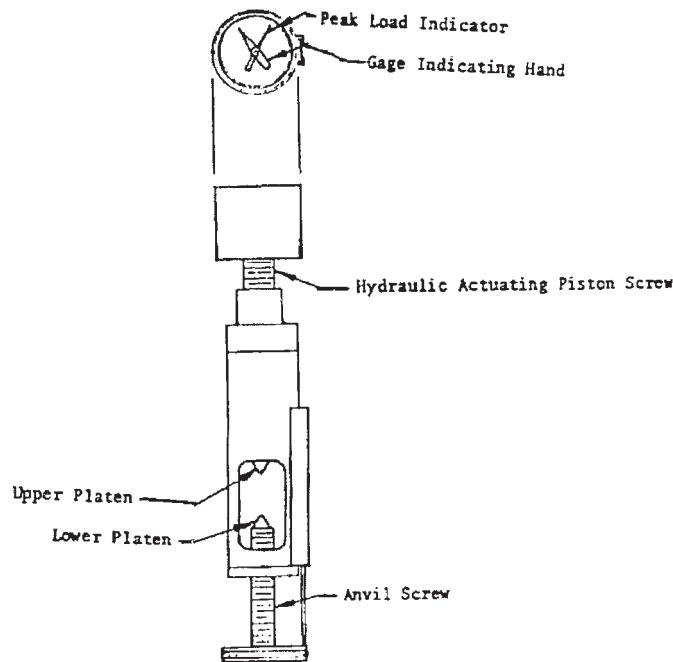


FIG. 1 An Example of a Loading System

6.2.1 The loading system shall have a loading frame with a platen-to-platen clearance that allows testing of rock specimens in the required size range. Typically, this range is within 30 to 85 mm so that an adjustable distance is available to accommodate both small and large specimens.

6.2.2 The loading capacity shall be sufficient to break the largest and strongest specimens to be tested.

6.2.3 The test machine shall be designed and constructed so that it does not permanently distort during repeated applications of the maximum test load, and so that the platens remain coaxial within ± 0.2 mm throughout testing. No spherical seat or other nonrigid component is permitted in the loading system. Loading system rigidity is essential to avoid slippage when specimens of irregular geometry are tested.

6.2.4 Truncated, conical platens, as shown on Fig. 2, are to be used. The 60° cone and 5-mm radius spherical platen tip shall meet tangentially. The platens shall be of hard material (Rockwell 58 HRC, as explained in Test Method E 18) such as tungsten carbide or hardened steel so they remain undamaged during testing.

6.3 Load Measuring System:

6.3.1 A load measuring system, for example a load cell or a hydraulic pressure gage, that will indicate failure load, P , required to break specimen. The system should conform to the requirements of 6.3.2-6.3.4.

6.3.2 Measurements of failure load, P , shall be to a precision of $\pm 5\%$ or better of full-scale load-measuring system, irrespective of the size and strength of specimen that is tested.

6.3.3 Failure is often sudden and a peak load indicator is required so the failure load can be recorded after each test.

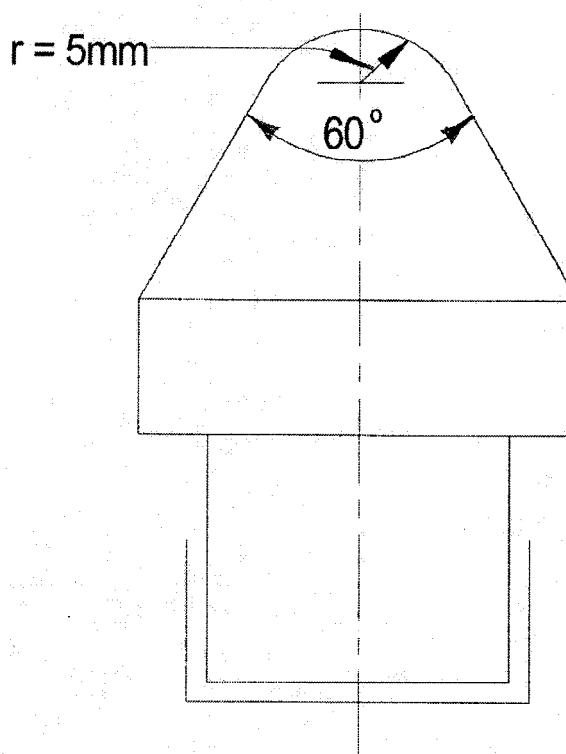


FIG. 2 Platen Dimensions

6.3.4 The system should be capable of using interchangeable measuring devices in order to be consistent with the estimated strength of rock (point load strength of rock is usually an order of magnitude lower than the compressive strength of rock).

6.4 Distance Measuring System:

6.4.1 The distance measuring system, a vernier direct reading scale, should connect to the loading frame for measuring the distance, D , between specimen-platen contact points and conform to requirements 6.4.2 and 6.4.3.

6.4.2 Measurements of D shall be to an accuracy of $\pm 2\%$ or better of distance between contact points, irrespective of the size and strength of specimen that is tested.

6.4.3 The measuring system shall allow a check of the "zero displacement" value when the two platens are in contact and should include a zero adjustment.

6.4.4 An instrument such as a caliper or a steel rule is required to measure the width, W , (with an accuracy of $\pm 5\%$) of specimens for all but the diametral test.

6.5 *Miscellaneous Items*—Diamond saw, chisels, towels, marking pens, and plotting paper.

7. Test Specimens

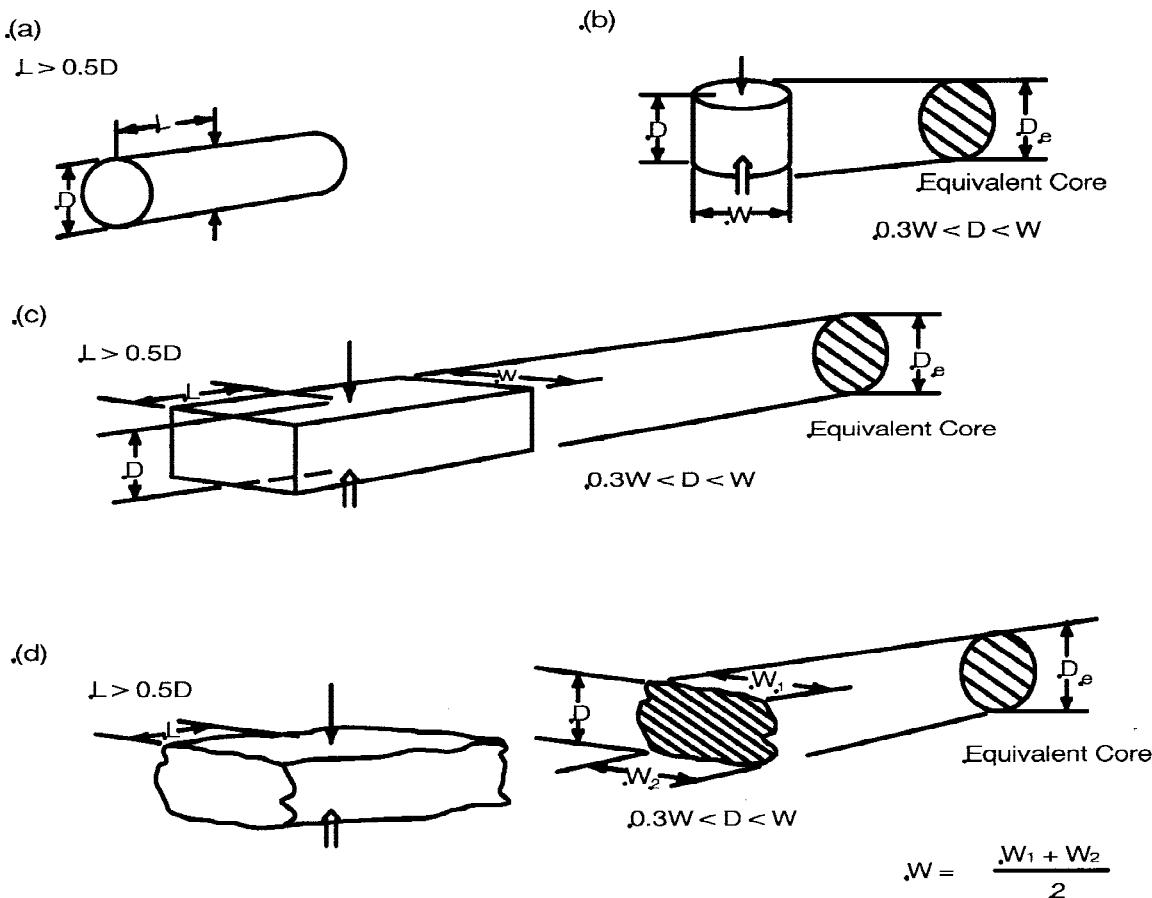
7.1 *Sampling*—Rock samples are grouped on the basis of both rock type and estimated strength. When testing core or block specimens at least ten specimens are selected. When testing irregular-shaped specimens obtained by other means at least 20 specimens are selected. Specimens in the form of core are preferred for a more precise classification.

7.2 *Dimensions*—The specimen's external dimensions shall not be less than 30 mm and not more than 85 mm with the preferred dimension about 50 mm.

7.3 *Size and Shape*—The size and shape requirements for diametral, axial, block, or irregular lump testing shall conform with the recommendations shown on Fig. 3. The sides of the specimens shall be free from abrupt irregularities that can generate stress concentrations. No specimen preparation is required.

7.4 *Water Content*—Using Test Method D 2216, determine the water content of each specimen after testing since it can affect the value of the point load strength.

7.5 *Marking and Measuring Specimens*—The specimens shall be properly marked and measured.



NOTE 1—Legend: L = length, W = width, D = depth or diameter, and D_e = equivalent core diameter (see 9.1).

FIG. 3 Load Configurations and Specimen Shape Requirement for (a) the Diametral Test, (b) the Axial Test, (c) the Block Test, and (d) the Irregular Lump Test⁵

7.5.1 Marking—The desired test orientation of the specimen shall be indicated by marking lines on the specimen. These lines are used for centering the specimen in the testing machine, and to ensure proper orientation during testing. These lines may also be used as reference lines for measuring thickness and diameter.

7.5.2 Measuring—Measure each dimension of a specimen at three different places, and calculate the averages.

8. Procedure

8.1 Diametral Test:

8.1.1 Core specimens with length/diameter ratio greater than one are suitable for diametral testing.

8.1.2 Insert a specimen in the test device and close the platens to make contact along a core diameter. Ensure that the distance, L , between the contact points and the nearest free end is at least 0.5 times the core diameter (see Fig. 3(a)).

8.1.3 Determine and record the distances D and L (see Fig. 3).

8.1.4 Steadily increase the load such that failure occurs within 10 to 60 s, and record failure load, P . The test should be rejected if the fracture surface passes through only one platen loading point (see Fig. 4(d)).

8.1.5 The procedures in 8.1.2-8.1.4 are repeated for each specimen of the rock type.

8.2 Axial Test:

8.2.1 Core specimens with length/diameter ratio of $1/3$ to 1 are suitable for axial testing (see Fig. 3(b)). Suitable specimens can be obtained by saw-cutting or chisel-splitting.

8.2.2 Insert a specimen in the test machine and close the platens to make contact along a line perpendicular to the core end faces (in the case of isotropic rock, the core axis, but see 8.4 for anisotropic rock).

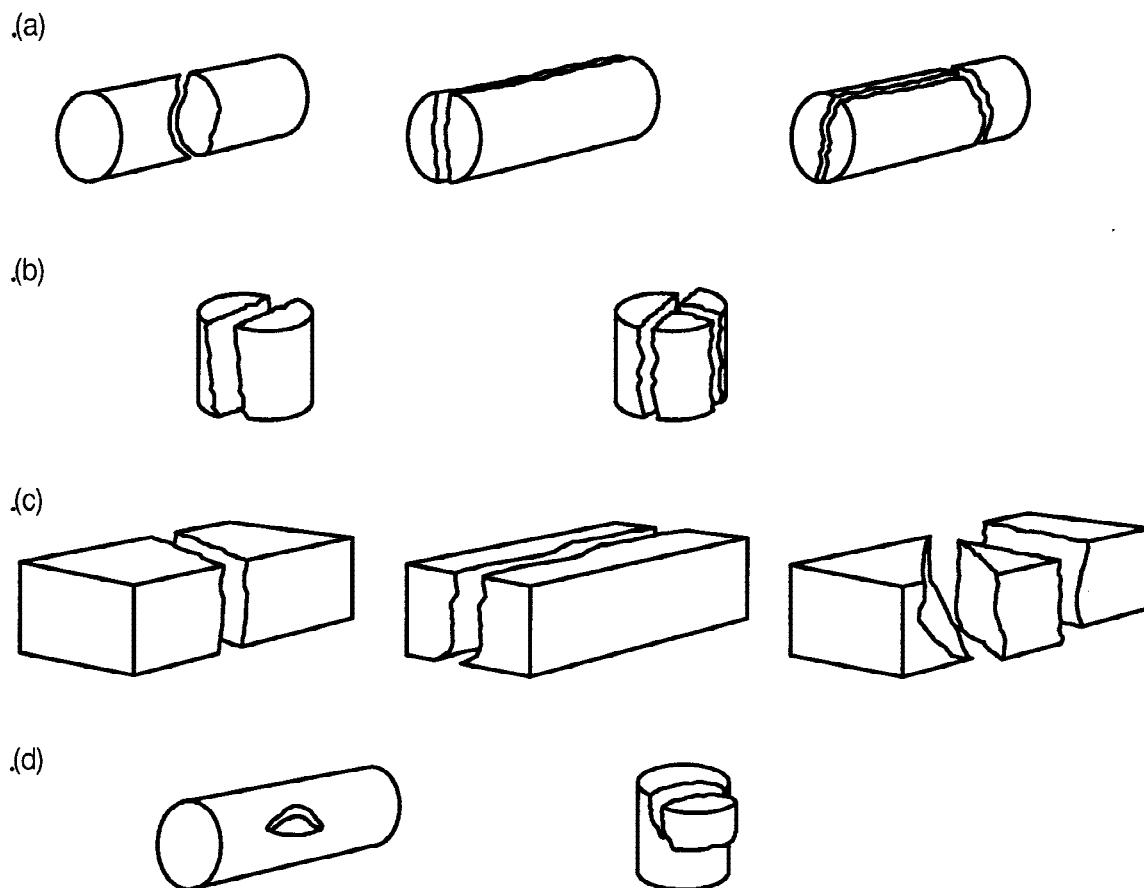
8.2.3 Record the distance, D , between platen contact points (see Fig. 3). Record the specimen width, W , perpendicular to the loading direction, with an accuracy of $\pm 5\%$.

8.2.4 Steadily increase the load such that failure occurs within 10 to 60 s, and record the failure load, P . The test should be rejected if the fracture surface passes through only one loading point (see Fig. 4(e)).

8.2.5 Procedures 8.2.2-8.2.4 are repeated for each test specimen of the rock type.

8.3 Block and Irregular Lump Tests:

8.3.1 Rock blocks or lumps, 30 to 85 mm, and of the shape shown in Fig. 3(c) and (d) are suitable for the block and the



NOTE 1—(a) Valid diametral tests; (b) valid axial tests; (c) valid block tests; (d) invalid core test; and (e) invalid axial test (point load strength index test).

FIG. 4 Typical Modes of Failure for Valid and Invalid Tests⁵

irregular lump tests. The ratio, D/W , should be between $1/3$ and 1 , preferably close to 1 . The distance L should be at least $0.5 W$.

8.3.2 Insert a specimen in the testing machine and close the platens to make contact with the smallest dimension of the lump or block, away from edges and corners (see Fig. 3(c) and (d)).

8.3.3 Record the distance D between platen contact points. Record the smallest specimen width, W , perpendicular to the loading direction. If the sides are not parallel, then calculate W as $(W_1 + W_2)/2$ as shown on Fig. 3. This width, W , is used in calculating point load strength index irrespective of the actual mode of failure (see Fig. 3 and Fig. 4).

8.3.4 Steadily increase the load such that failure occurs within 10 to 60 s, and record the failure load, P . The test should be rejected if the fracture surface passes through only one loading point (see examples for other shapes in Fig. 4(d) or (e)).

8.3.5 Procedures 8.3.2-8.3.4 are repeated for each test specimen in the sample.

8.4 Anisotropic Rock:

8.4.1 When a rock sample is shaly, bedded, schistose, or otherwise observably anisotropic, it should be tested in directions that will give the greatest and least strength values, in general, parallel and normal to the planes of anisotropy.

8.4.2 If the sample consists of core drilled through weakness planes, a set of diametral tests may be completed first, spaced at intervals that will yield pieces that can then be tested axially.

8.4.3 Strongest test results are obtained when the core axis is perpendicular to the planes of weakness; therefore, when possible, the core should be drilled in this direction. The angle between the core axis and the normal to the direction of least strength should preferably not exceed 30° .

8.4.4 For measurement of the point load strength index (I_s) value in the direction of least strength, ensure that load is applied along a single weakness plane. Similarly, when testing for the I_s value in the direction of greatest strength, ensure that the load is applied perpendicular to the direction of least strength.

8.4.5 If the sample consists of blocks or irregular lumps, it should be tested as two subsamples, with load first applied perpendicular to, then along the observable planes of weakness. Again, the required minimum strength value is obtained when the platens make contact and are loaded to failure along a single plane of weakness.

8.5 If significant platen penetration occurs, the dimension D to be used in calculating point load strength should be the value D' measured at the instant of failure, that will be smaller than the initial value suggested in 8.1.3, 8.2.3, and 8.3.3. The error in assuming D to be its initial value is negligible when the specimen is large or strong. The dimension at failure may always be used as an alternative to the initial value and is preferred.

8.6 *Water Content*—Follow Test Method D 2216 to determine the water content of each rock specimen and report the moisture condition (see Section 10).

9. Calculation

9.1 *Uncorrected Point Load Strength Index*—The uncorrected point load strength I_s is calculated as:

$$I_s = P/D_e^2, \text{ MPa} \quad (1)$$

where:

P = failure load, N,
 D_e = equivalent core diameter = D for diametral tests (see Fig. 3), m, and is given by:
 $D_e^2 = D^2$ for cores, mm^2 , or
 $D_e^2 = 4A/\pi$ for axial, block, and lump tests, mm^2 ;

where:

$A = WD =$ minimum cross-sectional area of a plane through the platen contact points (see Fig. 3).

NOTE 2—If significant platen penetration occurs in the test, such as when testing weak sandstones, the value of D should be the final value of the separation of the loading points, D' . Measurements of core diameter, D , or specimen width, W , made perpendicular to the line joining the loading points are not affected by this platen penetration and should be retained at the original values. The modified values of D_e can be calculated from:

$$D_e^2 = D \times D' \text{ for cores} = 4/\pi W \times D' \text{ for other shapes} \quad (2)$$

9.2 Size Correction Factor:

9.2.1 I_s varies as a function of D in the diametral test, and as a function of D_e in axial, block, and irregular lump tests, so that a size correction must be applied to obtain an unique point load strength value for the rock sample and one that can be used for purposes of rock strength classification.

9.2.2 The size-corrected point load strength index, $I_{s(50)}$, of a rock specimen is defined as the value of I_s that would have been measured by a diametral test with $D = 50$ mm.

9.2.3 When a precise rock classification is essential, the most reliable method of obtaining $I_{s(50)}$ is to conduct diametral tests at or close to $D = 50$ mm. Size correction is then unnecessary. For example, in case of diametral tests on NX, core diameter = 54 mm and size correction to $D = 50$ mm is not necessary. Most point load strength tests are in fact performed using other specimen sizes or shapes. In such cases, the size correction described in 9.2.4 or 9.2.5 must be applied.

9.2.4 The most reliable method of size correction is to test the specimen over a range of D or D_e values and to plot graphically the relation between P and D_e . If a log-log plot is used, the relation is a straight line (see Fig. 5). Points that deviate substantially from the straight line may be disregarded (although they should not be deleted). The value of $I_{s(50)}$ corresponding to $D_e^2 = 2500 \text{ mm}^2$ ($D_e = 50 \text{ mm}$) can be obtained by interpolation and use of the size-corrected point load strength index calculated as shown in 9.2.5.

9.2.5 When neither 9.2.3 nor 9.2.4 is practical (for example when testing single-sized core at a diameter other than 50 mm or if only a few small pieces are available), size correction may be accomplished using the formula:

$$I_{s(50)} = F \times I_s \quad (3)$$

The “Size Correction Factor F ” can be obtained from the chart in Fig. 6, or from the expression:

$$F = (D_e/50)^{0.45} \quad (4)$$

For tests near the standard 50-mm size, only slight error is introduced by using the approximate expression:

$$F = \sqrt{(D_e/50)} \quad (5)$$

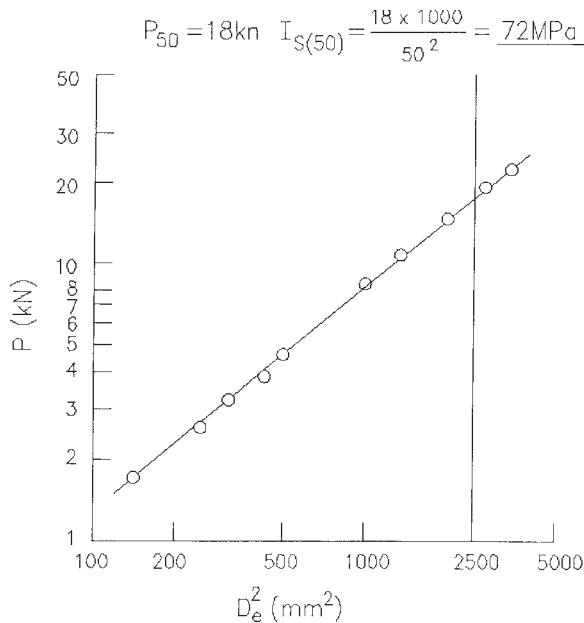


FIG. 5 Procedure for Graphical Determination of $I_{s(50)}$ from a Set of Results at D_e Values Other Than 50 mm⁵

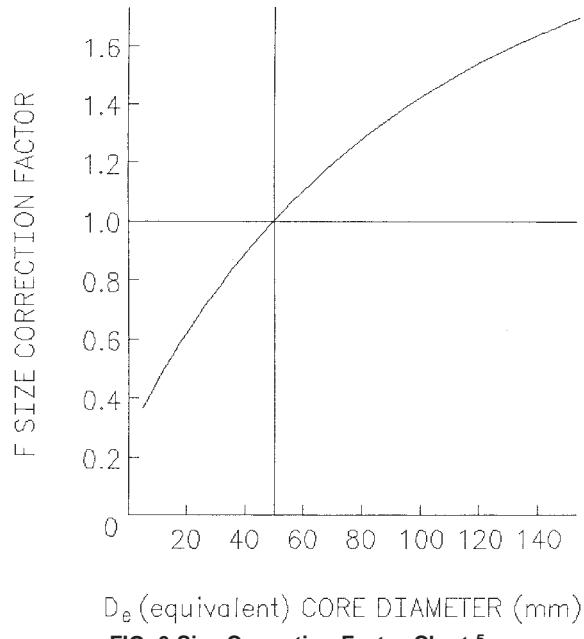


FIG. 6 Size Correction Factor Chart⁵

instead of using the procedure outlined on Fig. 5.

9.3 Mean Value Calculation:

9.3.1 Mean values of $I_{s(50)}$, as defined in 9.3.2, are to be used when classifying samples with regard to their point load strength and point load strength anisotropy indices.

9.3.2 The mean value of $I_{s(50)}$ is to be calculated by deleting the two highest and two lowest values from the ten, or more, valid tests, and calculating the mean of the remaining values. If significantly fewer specimens are tested, only the highest and lowest values are to be deleted and the mean calculated from those remaining.

9.4 Point Load Strength Anisotropy Index—The strength anisotropy index $I_{a(50)}$ is defined as the ratio of mean $I_{s(50)}$

values measured perpendicular and parallel to planes of weakness, that is, the ratio of greatest to least point load strength indices. See Fig. 7⁶.

9.5 Estimation of Compressive Strength—The estimated uniaxial compressive strength can be obtained by using Fig. 6 or using the following formula:

$$\delta_{uc} = C I_{s(50)} \quad (6)$$

where:

δ_{uc} = uniaxial compressive strength,
 C = factor that depends on site-specific correlation between δ_{uc} and $I_{s(50)}$, and
 $I_{s(50)}$ = corrected point load strength index.

9.5.1 If site-specific correlation factor "C" is not available, use the generalized value of "C" shown in Table 1.

TABLE 1 Generalized Value of "C"^A

Core Size, mm	Value of "C" (Generalized)
20	17.5
30	19
40	21
50	23
54	24
60	24.5

^A From ISRM Suggested Methods.⁵

9.5.2 If any specimen in a rock type gives a value 20 % under the average, it should be examined for defects.

10. Report

10.1 A typical report (example shown in Fig. 8) may include the following:

10.1.1 Source of sample including project name, location, and, if known, storage environment. The location may be specified in terms of borehole number and depth of specimen from the collar of the hole,

10.1.2 Physical description of sample including rock type and location and orientation of discontinuities, such as, apparent weakness planes, bedding planes, schistosity, or large inclusions, if any,

10.1.3 Date of sampling and testing,

10.1.4 General indication of the moisture condition of test specimens at the time of testing, such as, saturated, as received, laboratory air dry, or oven dry. In some cases, it may be necessary to report the actual water content as determined in accordance with Test Method D 2216,

10.1.5 Average thickness and average diameter of the test specimen,

10.1.6 The maximum applied load "P",

10.1.7 The distance "D" or D' , or both, if required,

10.1.8 Direction of loading (parallel to or normal to plane of weakness),

10.1.9 The number of specimens tested,

10.1.10 The calculated uncorrected (I_s) and corrected $I_{s(50)}$ point load strength index values,

⁶ D'Andrea, D.V., Fisher, R.L., and Fogelson, D.E., Prediction of Compressive Strength of Rock from Other Rock Properties, U.S. Bureau of Mines Rep. Invest., 6702, 1965.

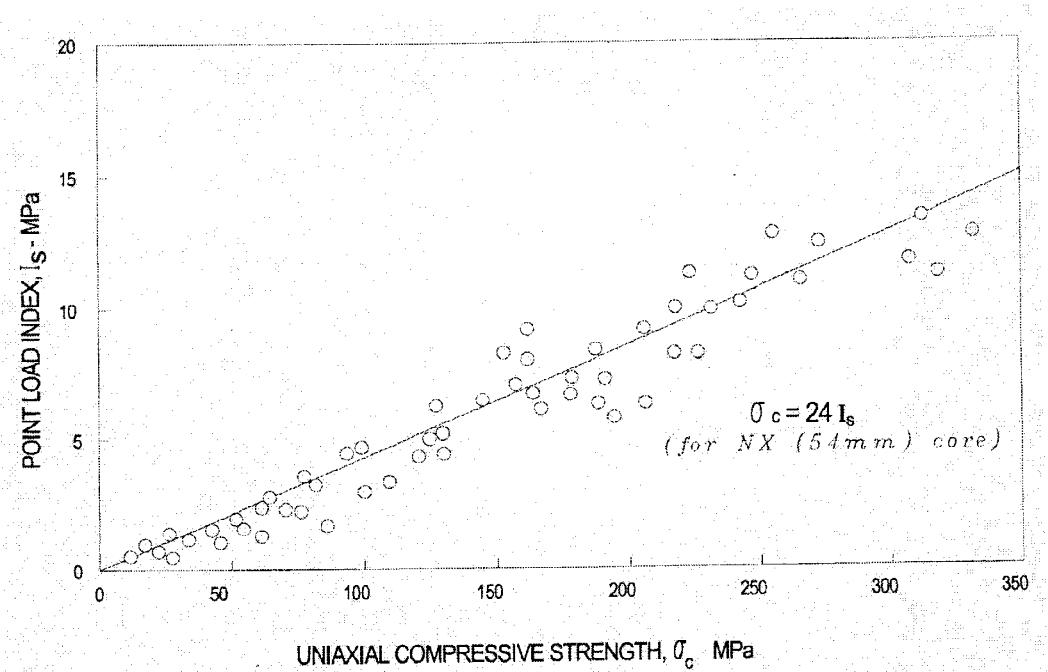


FIG. 7 Relationship Between Point Load Strength Index and Uniaxial Compressive Strength from 125 Tests On Sandstone, Quartzite, Marikana, Norite, and Belfast Norite⁶

10.1.11 The estimated value of uniaxial compressive strength (δ_{uc}),

10.1.12 The calculated value of strength anisotropy index ($I_{a(50)}$), and

10.1.13 Type and location of failure, including any photographs of the tested specimens before and after the test.

11. Precision and Bias

11.1 *Precision*—Due to the nature of rock materials tested by this test method, multiple specimens that have uniform physical properties have not been produced for testing. Since specimens that would yield the same test results have not been tested, Subcommittee D18.12 cannot determine the variation between tests since any variation observed is just as likely to be due to specimen variation as to operator or testing variation. Subcommittee D18.12 welcomes proposals to resolve this problem and would allow for development of a valid precision statement.

11.2 *Bias*—There is no accepted reference value for this test method; therefore, bias cannot be determined.

12. Keywords

12.1 compressive strength; index test; point load; rock

Sample Details

Point Load Test

Date 11/17/83

1 block sample from Gamblethorpe Opencast site.

Fine grained pale grey Coal Measures sandstone with numerous coaly streaks along horizontal bedding planes.

Specimens 1-6 chisel cut blocks, air-dried 2 weeks;
 7-10 sawn blocks, air-dried 2 weeks;
 11-15 cores, air-dried 2 weeks;
 16-20 cores, air-dried 2 weeks;
 - tested in laboratory.

No.	Type	W (mm)	D (mm)	P (kN)	D ² (mm ²)	D _a (mm)	I _a	F	I _{a(50)}
1	i \perp	30.4	17.2	2.687	666	25.8	4.03	0.75	
2	i \perp	16	8	0.977	163	12.8	5.99	0.54	3.24
3	i \perp	19.7	15.6	1.962	391	19.8	5.02	0.66	3.31
4	i \perp	35.8	18.1	3.641	825	28.7	4.41	0.765	3.46
5	i \perp	42.5	29	6.119	1569	39.6	3.90	0.875	3.49
6	i \perp	42	35	7.391	1872	43.3	3.95	0.935	
7	b \perp	44	21	4.600	1176	34.3	3.91	0.84	
8	b \perp	40	30	5.940	1528	39.1	3.88	0.89	
9	b \perp	19.5	15	2.040	372	19.3	5.48	0.655	
10	b \perp	33	16	2.87	672	25.9	4.27	0.75	
11	d //	-	49.93	5.107	-	-	-	-	
12	d //	-	49.88	4.615	-	-	-	-	
13	d //	-	49.82	5.682	-	-	-	-	
14	d //	-	49.82	4.139	-	-	-	-	
15	d //	-	49.86	4.546	-	-	-	-	1.83
16	d //	-	25.23	1.837	-	-	2.89	0.74	2.14
17	d //	-	25.00	1.891	-	-	3.02	0.735	2.22
18	d //	-	25.07	2.118	-	-	3.37	0.735	
19	d //	-	25.06	1.454	-	-	2.32	0.735	
20	d //	-	25.04	1.540	-	-	2.46	0.735	1.81

d = diametral;
 a = axial;
 b = block;
 i = irregular lump test;
 \perp = perpendicular;
 // = parallel to planes of weakness.

Mean I _{a(50)} \perp	3.38
Mean I _{a(50)} //	1.98
I _{a(50)}	1.71

FIG. 8 Test Record⁵

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (1995) that may impact the use of this standard.

- (1) Add Practice D 3740, Practice D , and Test Method E 18 to Referenced Document section.
- (2) Added Section 2.2, ISRM standard.
- (3) Added Section 3.1 referencing Terminology D 653 and renumbered subsections accordingly.
- (4) In Section 5, added a new Note 1 which references Practice D 3740 and renumbered subsequent notes.
- (5) Deleted parenthetical statement from title of Figures 1, 2, 5, and 6.
- (6) Corrected spelling of equivalent in Figures 3b, 3c, and 3d.
- (7) Corrected labeling of Figures 3c and 3d.
- (8) Added footnote 3 to Figure 3
- (9) In Section 8.4.1 corrected spelling of shaly
- (10) Redrafted Figures 4a, 4b, 4c, and 4d.
- (11) In Section 9.5.1 deleted exact from first sentence
- (12) Added missing outline numbering , 9.5.2, for last sentence in Section 9.5.1.
- (13) In Section 10.1.2, changed sentence to read"....schistosity, or large inclusions, if any."
- (14) Deleted Note 1 from Figure 6
- (15) Corrected number in Figure 7 from 42 to 24, expanded title, deleted note, and added reference.

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Standard Test Method for Determination of Rock Hardness by Rebound Hammer Method¹

This standard is issued under the fixed designation D 5873; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 This test method covers the testing apparatus, sampling, test specimen preparation, and testing procedures for determining the rebound hardness number of rock material using a spring-driven steel hammer, referred to variously as a rebound hammer, impact test hammer, or concrete test hammer.

1.2 This test method is best suited for rock material with uniaxial compressive strengths (see Test Method D 2938) ranging between approximately 1 and 100 MPa.

1.3 The portable testing apparatus may be used in the laboratory or field to provide a means of rapid assessment of rock hardness or to serve as an indicator of rock hardness.

1.4 The values stated in SI units are to be regarded as the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

C 805 Test Method for Rebound Number of Hardened Concrete²

D 420 Guide to Site Characterization for Engineering, Design, and Construction Purposes³

D 653 Terminology Relating to Rock, Soil, and Contained Fluids³

D 2938 Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens³

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction³

D 4543 Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances³

D 4879 Guide for Geotechnical Mapping of Large Underground Openings in Rock³

2.2 ISRM Standards:

Suggested Method for Determination of Schmidt Rebound Hardness⁴

Suggested Method for Quantitative Description of Discontinuities in Rock Masses⁴

3. Terminology

3.1 For common definitions of terms in this standard, refer to Terminology D 653.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *rebound hammer*—a portable, spring loaded, piston-type, steel hammer used to classify the hardness of rock in the field or laboratory.

3.2.2 *rebound hardness number*— H_R , a dimensionless number representing empirically determined, relative hardness of rock material or other hard substance by use of a rebound hammer.

4. Significance and Use

4.1 The rebound hardness method provides a means for rapid classification of the hardness of rock during site characterization for engineering, design, and construction purposes (see Guide D 420), geotechnical mapping of large underground openings in rock (see Guide D 4879), or reporting the physical description of rock core (see Practice D 4543). The rebound hardness number, H_R , can serve in a variety of engineering applications that require characterization of rock material. These applications include, for examples, the prediction of penetration rates for tunnel boring machines, determination of rock quality for construction purposes, and prediction of hydraulic erodibility of rock.

4.2 This test method is of limited use on very soft rock or very hard rock (unconfined compressive strengths less than approximately 1 MPa or greater than 100 MPa).

4.3 The results of this test method are not intended for conversion to strength data suitable for design.

NOTE 1—Several types of rebound hammers are commercially available to accommodate testing of various sizes and types of concrete construction (See Test Method C 805) and rock material.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved June 10, 2000. Published September 2000. Originally published as D 5873 – 95. Last previous edition D 5873 – 95.

² Annual Book of ASTM Standards, Vol 04.02.

³ Annual Book of ASTM Standards, Vol 04.08.

⁴ Brown, E. T., ed., *Suggested Methods: Rock Characterization, Testing, and Monitoring*, International Society of Rock Mechanics: Pergamon Press, London, 1981.

suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing and sampling. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *Rebound Hammer*, consisting of a spring-loaded piston, or hammer, which is projected against a metal anvil in contact with the rock surface. The hammer must travel with a fixed and reproducible velocity. The rebound distance of the piston from the steel plunger is measured in a linear scale attached to the frame of the instrument and is taken as an empirical measure of rock hardness.

5.2 *Steel Base*—A steel base of minimum mass of 20 kg to which specimens are securely fastened. Rock core specimens may be tested in a steel cradle with a semicylindrical machined slot of the same radius as the core, or firmly seated in a steel V-block.

5.3 *Calibration Anvil*—The standard calibration block used to calibrate the rebound hammer.

5.4 *Abrasive Stone*—A medium-grained texture silicon carbide or equivalent material.

6. Sampling

6.1 Drill core specimens shall be NX or larger core art at least 15 cm in length. Block specimens shall have edge lengths of at least 15 cm. Rock surfaces tested in place, including natural outcrops or prepared surfaces such as tunnel walls or floors, shall have a smooth, flat test area at least 15 cm in diameter.

6.2 Samples shall be representative of the rock to be studied. Obtain samples by direct sampling of subsurface rock units with core borings or by sampling blocks of rock material from outcrops that correlate with the subsurface rock unit of interest. At surface outcrops, avoid sampling and testing rock material weakened by weathering or alteration or is otherwise unrepresentative of the rock material of interest.

6.3 The rebound hammer is generally unsuitable for very soft or very hard rock. Conduct simple field tests to quickly assess a rock material's suitability for the rebound hammer test method. Scratch very soft rock with a fingernail and peel with a pocket knife. An intact specimen of very hard rock breaks only by repeated, heavy blows with a geological hammer and cannot be scratched with a common 20d steel nail.

7. Specimen Preparation

7.1 For a block or core specimen, determine its length by taking the average of four lengths measured at four equally spaced points on the circumference and record to the nearest 5 mm.

7.2 For a block or core specimen, determine its diameter by taking the average of two diameters measured at right angles to each other approximately midway along the length of the specimen and record to the nearest 5 mm.

7.3 Report the moisture condition of the block or specimen.

7.4 The test surface of all specimens, either in the laboratory or in the field, shall be smooth to the touch and free of joints, fractures, or other obvious localized discontinuities to a depth

of at least 6 cm. In situ rock shall be flat and free of surface grit over the area covered by the plunger. If the surface of the test area is heavily textured, grind it smooth with the abrasive stone described in 5.4.

8. Calibration

8.1 Prior to each testing sequence, calibrate the hammer using a calibration test anvil supplied by the manufacturer for that purpose.

8.1.1 Place the calibration anvil in the core holder and conduct ten readings on the anvil.

8.1.2 Calculate the correction factor by dividing the manufacturer's standard hardness value for the anvil by the average of the ten readings taken on the anvil.

NOTE 3—If the instrument reads lower than the manufacturer's standard hardness value, the correction factor will be greater than unity. If the readings are higher, the correction factor will be less than unity.

NOTE 4—Operation of the rebound hammer is satisfactory if the calibration readings fall within the range provided by the manufacturer. If the calibration readings fall outside this range, the instrument must be cleaned, adjusted, or returned to the manufacturer for correction.

NOTE 5—Rebound hammers require periodic servicing and verification to provide reliable results.

9. Procedure

9.1 Place the steel base on a flat, level surface that provides firm, rigid support, such as a concrete floor.

9.2 Securely clamp rock core specimens in a steel cradle with a semicylindrical machined slot of the same radius as the core, or firmly seat into a steel V-shaped block. Securely clamp block specimens to the rigid steel base in such a manner as to prevent vibration and movement of the specimen during the test.

9.3 For tests conducted on specimens in the laboratory, orient the instrument within 5° of vertical with the bottom of the piston at right angles to and in firm contact with the surface of the test specimen. A guide may be used to ensure the rebound hammer is positioned for optimum performance. Position the hammer not less than one diameter from the edge of the specimen.

9.4 For tests conducted in situ on a rock mass, the rebound hammer can be used at any desired orientation provided the plunger strikes perpendicular to the surface tested. The results are corrected to a horizontal or vertical position using the correction curves provided by the manufacturer.

9.5 Before conducting the tests, ensure the hammer is at the same temperature as the test specimens by exposing it to the ambient environmental conditions of the test area (indoors or outdoors) for at least 2 h.

9.6 Compress the hammer spring by gradually depressing the plunger until the hammer is triggered and impact occurs.

9.7 Read and record the height of the plunger rebound to the nearest whole number, as measured on an arbitrary scale of 10 to 100 divisions located on the side of the hammer, before restoring the piston to its original extension. Repeat this procedure at ten representative locations on the specimen. Test locations shall be separated by at least the diameter of the piston and only one test may be taken at any one point.

9.8 If a specimen breaks during rebound testing, energy is absorbed during breakage and, consequently, the rebound

reading will be lower than had it not broken. Any individual impact test that causes cracking or any other visible failure shall cause that test and the specimen to be rejected.

9.9 Some factors that may affect the results of the test include:

9.9.1 Rock at 0° C or less may exhibit very high rebound values.

9.9.2 Temperature of the rebound hammer itself may affect the rebound number. The hammer and materials to be tested should be at the same temperature.

9.9.3 For readings to be compared, the direction of impact, horizontal, upward, downward, and so forth, must be the same.

9.9.4 Different hammers of the same nominal design may give rebound numbers differing from one to three units and therefore, tests should be made with the same hammer in order to compare results. If more than one hammer is to be used, a sufficient number of tests must be made on typical rock surfaces to determine the magnitude of the differences to be expected.

10. Calculation

10.1 Using the data from the ten readings obtained in 9.7, discard readings differing from the average of ten readings by more than seven units and determine the average of the remaining readings. To calculate the rebound hardness number (H_R) of the tested rock material, multiply this average by the correction factor determined in 8.1.2 and record the results to the nearest whole number.

11. Report

11.1 Report the following minimum information for each specimen or test area:

11.1.1 Source of samples, including geographic location; boring number, depth, orientation, and stationing; and rock type,

11.1.2 Weathering and alteration condition of samples, particularly when sampling a surface outcrop,

11.1.3 Type of specimen (core, block, or in situ); size and shape of specimen; and, if block type, whether cut or blasted,

11.1.4 Date of sampling and date of testing,

11.1.5 Storage conditions of samples (for example, exposure to temperature extremes, air drying, and moisture changes),

11.1.6 Type and model number of hammer,

11.1.7 Orientation of the plunger axis during the test,

11.1.8 Method of securing the sample (for example, V-block, or clamps),

11.1.9 Number of tests conducted,

11.1.10 Temperature of site at time of test, and

11.1.11 The individual and average values of hammer rebound, the value of the correction factor, and the rebound hardness number, H_R (obtained in 10.1).

12. Precision and Bias

12.1 *Precision*—No data exist to determine the precision of this test method in determining rock hardness.

12.2 *Bias*—There is no accepted standard value for H_R for any material, therefore bias cannot be determined.

13. Keywords

13.1 core; hardness; rock mass; rock; unconfined compressive strength

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (1995) that may impact the use of the standard.

- (1) Added in section 2.1, D 653 and D 3740 to list of ASTM referenced documents.
- (2) Added section 3.1, reference to definitions of terms in Terminology D 653 and changed numbering in section 3 accordingly.
- (3) Added the symbol H_R to the definition of rebound hardness number in 3.2.
- (4) Added Note 2 caveat regarding use of D 3740 to section 4 on Significance and Use.

(5) Added “record the results to the nearest whole number” to sections 9.7 and 10.1.

(6) Changed wording of section 12.2, Bias, to read, “There is no accepted standard value for H_R for any material, therefore bias cannot be determined.

(7) Changed key words “cores” to “core”, “rocks” to “rock”, and “test” to “strength”.

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Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Core¹

This standard is issued under the fixed designation D 6032; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope *

1.1 This test method covers the determination of the rock quality designation (RQD) as a standard parameter in drill core logging.

1.2 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.2.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.3 The values stated in SI units are to be regarded as the standard. The values stated in inch-pound units are approximate.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

D 653 Terminology Relating to Soil, Rock, and Contained Fluids²

D 2113 Practice for Diamond Core Drilling for Site Investigation²

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction²

D 5079 Practices for Preserving and Transporting Rock Core Samples²

D 6026 Practice for Using Significant Digits in Geotechnical Data³

E 691 Practice for Conducting an Interlaboratory Study to

Determine the Precision of a Test Method⁴

3. Terminology

3.1 For terminology used in this test method, refer to Terminology D 653.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *core run*—in the most basic usage, the length of the interval measured from the depth each core sample was started to the depth at which drilling stopped and the sample was recovered from the core barrel. If required, the core run can also be defined to cover a specific length or lithology in the core samples.

3.2.2 *drill break*—any mechanical or man-made break in the core that is not natural occurring.

3.2.3 *intact core*—any segment of core between two open, natural discontinuities.

3.2.4 *rock quality designation (RQD)*—a modified core recovery percentage in which all pieces of sound core over 100 mm are counted as recovery.

3.2.5 *sound core*—any core which is fresh to moderately weather and which has sufficient strength to resist hand breakage.

4. Summary of Test Method

4.1 The RQD denotes the percentage of intact and sound rock retrieved from a borehole of any orientation. All pieces of intact and sound rock core equal to or greater than 100 mm (4 in.) long are summed and divided by the total length of the core run, as shown in Fig. 1. Rock mechanics judgement may be necessary to determine if a piece of core qualifies as being intact and sound.

5. Significance and Use

5.1 The RQD was first introduced in the mid 1960's to provide a simple and inexpensive general indication of rock mass quality to predict tunneling conditions and support requirements. The recording of RQD has since become virtually standard practice in drill core logging for a wide variety of geotechnical investigations.

5.2 The RQD values provide a basis for making preliminary design decisions involving estimation of required depths of

¹ This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Ground Water and Vadose Zone Investigations.

Current edition approved Nov. 10, 2002. Published January 2003. Originally approved in 1996. Last previous edition approved in 1996 as D 6032–96.

² Annual Book of ASTM Standards, Vol 04.08.

³ Annual Book of ASTM Standards, Vol 04.09.

⁴ Annual Book of ASTM Standards, Vol 14.02.

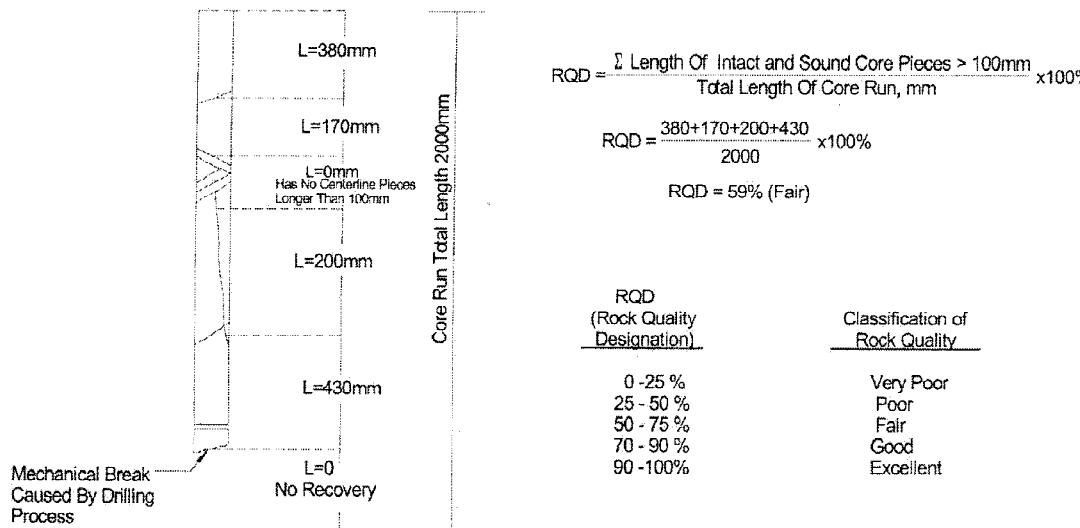


FIG. 1 RQD Logging Center Line Method⁵

excavation for foundations of structures. The RQD values also can serve to identify potential problems related to bearing capacity, settlement, erosion, or sliding in rock foundations. The RQD can provide an indication of rock quality in quarries for concrete aggregate, rockfill, or large riprap.

5.3 The RQD has been widely used as a warning indicator of low-quality rock zones that may need greater scrutiny or require additional borings or other investigational work.

5.4 The RQD is a basic component of many rock mass classification systems for engineering purposes.

5.5 Used alone, RQD is not sufficient to provide an adequate description of rock mass quality. The RQD does not account for joint orientation, tightness, continuity, and gouge material. The RQD must be used in combination with other geological and geotechnical input.

5.6 The RQD is sensitive to the orientation of joint sets with respect to the orientation of the core. That is, a joint set parallel to the core axis will not intersect the core, unless the drill hole happens to run along the joint. A joint set perpendicular to the core axis will intersect the core axis at intervals equal to the joint spacing. For intermediate orientations, the spacing of joint intersections with the core will be a cosine function of angle between joints and the core axis.

5.7 Core sizes from BQ to PQ with core diameters of 36.5 mm (1.44 in.) and 85 mm (3.35 in.), respectively, are normally acceptable for measuring RQD as long as proper drilling techniques are used that do not cause excess core breakage or poor recovery, or both. The NX-size (54.7 mm [2.16 in.]) and NQ-size (47.5 mm [1.87 in.]) are the optimal core sizes for measuring RQD. The RQD is also useful for large core diameters provided the core diameter is clearly stated. The RQD calculated for core smaller than BQ may not be representative of the true quality of the rock mass.

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 D 3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Procedure

6.1 Drilling of the rock core should be done in accordance with Practice D 2113. It is important that proper drilling techniques and equipment are used to minimize core breakage or poor core recovery, or both.

6.2 There are several ways to define a core run for calculating RQD. Three of these are: (1) a core run is equal to a drill run; (2) a change in formation or rock type could constitute an end of a core run; and (3) a core run can be a selected zone of concern. In determining a core run it is important to be consistent throughout a drill hole and to document how the core run was defined.

6.3 Retrieval, preservation, transportation, storage, and cataloging of the rock core should be done in accordance with Practices D 5079. The RQD should be logged on site when the core is retrieved because some rocks can disintegrate, due to poor curatorial handling, slaking, desiccation, stress relief, or swelling, with time. For these rocks it is recommended that the RQD be measured again after 24 h to assist in determining durability.

6.4 Close visual examination of core pieces is required for assessing the type of fracture (that is, natural or drill break). Pieces of core that are moderately or intensely weathered, contain numerous pores, or are friable, or combination thereof, should not be included in the summation of pieces greater than 100 mm (4 in.) for the determination of the RQD. Any rejected piece of core is still included as part of the total length of core run and should be noted in the report.

6.5 Measure all core piece lengths that are intact and greater than 100 mm (4 in.) to the nearest 1 mm (0.04 in.) and record

on a RQD data sheet (Fig. 2). Measure such pieces along the centerline of the core as illustrated in Fig. 1⁵

NOTE 2—Centerline measurements ensure that the RQD value resulting from the measurements is not dependent on the core diameter. Centerline measurements also avoid unduly penalizing resulting RQD values for cases where fractures parallel the core axis. Any other method used for accounting for fractures parallel to the core axis, while not advocated by this test method and in the literature, must be clearly stated.^{6,7}

6.6 Only those pieces of rock formed by natural fractures (that is, joints, shear zones, bedding planes, or cleavage planes that result in surfaces of separation) shall be considered for RQD purposes. The core pieces on either side of core breaks caused by the drilling process shall be fitted together and counted as one piece. Drilling breaks are usually evident by rough fresh surfaces. In some cases it may be difficult to differentiate between natural fractures and drilling breaks. When in doubt, count a fracture as a natural fracture. If for some reason there is not 100 % core recovery for a drill run, the length of core left in the borehole should be taken into account by adding it to the run in which it was cored rather than the run in which it was retrieved.

6.7 Record the top and bottom depths of each core run.

6.8 Sketch core features such as natural fractures, drilling breaks, lost core, highly weathered pieces, and so forth (see Fig. 1).

6.9 Include remarks concerning judgement decisions such as whether a break in a core is a natural fracture or a drilling break or why a piece of core longer than 100 mm (4 in.) was not considered to be intact.

6.10 Record the sum of intact core pieces longer than 100 mm (4 in.) long, and calculate the RQD value for the core run being evaluated.

6.11 Indicate the rock quality description for the core run using the rock quality table in Fig. 1.

7. Calculation

7.1 Calculate as a percentage, the RQD of a core run as follows:

$$RQD = \frac{[\text{length of intact and sound pieces} > 100 \text{ mm (4 in.)}] \times 100 \%}{\text{total core run length, mm}} \quad (1)$$

In accordance with Practice D 6026, record the result to the nearest one percent.

8. Report

8.1 A typical report may include the following:

⁵ Deere, D. U., and Deere, D. W., "The Rock Quality Designation (RQD) After Twenty Years," *Rock Classification Systems for Engineering Purposes, ASTM STP 984*, 1988, pp. 91–101.

⁶ Deere, D. U., and Deere, D. W., "Rock Quality Designation (RQD) Index in Practice," *Contract Report GI-89-1*, Department of the Army Corps of Engineers, 1989.

⁷ Bieniawski, Z.T., "Exploration for Rock Engineering" *Proceeding of the Symposium on Exploration for Rock Engineering*, November 1976, Johannesburg, A.A., Balkema, Rotterdam.

8.1.1 Source of sample including project name, location, and, if known, storage environment. The location may be specified in terms of borehole number and depth of core runs from the collar of the hole.

8.1.2 Description of drilling equipment, method, personnel, and hole orientation.

8.1.3 Physical description of core runs including diameter, rock type and location and orientation of discontinuities, such as, apparent weakness planes, bedding planes, schistosity, and large inclusions or inhomogeneities, if any.

8.1.4 Date of RQD calculations and sketches and/or photographs of core runs.

8.1.5 General indication of any conditions, observations, and assumptions relevant to the RQD values or calculations.

8.1.6 Include a table of RQD values and/or copies of any RQD data forms or sketches.

8.1.7 Report the rock quality classification for the core run using the table in Fig. 1.

9. Precision and Bias

9.1 *Precision*—A round-robin study of the RQD index of cores of four selected types of sedimentary rock (anhydrite/calcite, calcareous shale, limestone, and anhydrite) with four replications per rock type was conducted in accordance with Practice E 691 by eight experienced participants.⁸ The repeatability and reproducibility statistics reported in Table 1 refer to within-participant and between-participant precision, respectively. The probability is approximately 95 % that two results obtained by the same participant on the same material will not differ by more than the repeatability limit r . Likewise, the probability is approximately 95 % that two results obtained by different participants on the same material will not differ by more than the reproducibility limit R . The precision statistics are calculated from the following equation:

$$r = 2(\sqrt{2})s_r \quad (2)$$

where s_r = repeatability standard deviation, and

$$R = 2(\sqrt{2})s_R \quad (3)$$

where s_R = reproducibility standard deviation.

NOTE 3—Some combinations of the means and r and R can result in KQD limits that exceed 100 % because the RQD values have been assumed to be normally distributed which may not reflect the actual underlying distribution of the RQD values.

9.2 *Bias*—There is no accepted reference value for this test method; therefore, bias cannot be determined.

10. Keywords

10.1 classification; index; logging; quality; rock; rock core

⁸ Pincus, H. J., and Clift, S. J., *Interlaboratory Testing Program for Rock Properties: Repeatability and Reproducibility of RQD Values for Selected Sedimentary Rocks*, PCN: 33-000011-38, ASTM Institute of Standards Research, 1994.

RQD DATA SHEET			
Project:		Date:	
Core Box I.D. no.:		Recorder(s):	
Total Length of Core Run, mm (in):		Checker(s):	
Core Diameter, mm (in):		Date Checked:	
Depth, m (ft)	Sketch or Photographic Image of Core	Length of Each Sound Piece of Core > 100 mm (4-inch)	Remarks
<ul style="list-style-type: none"> Lengths of Sound Pieces of Core > 100 mm (4-in): <ul style="list-style-type: none"> Lengths of Sound Pieces of Core > 100 mm (4-in) * 100% 			
$RQD (\%) = \frac{\text{Lengths of Sound Pieces of Core > 100 mm (4-in) * 100\%}}{\text{Total Length of Core Run, mm (in)}}$			
RQD (%) =		Rock Classification:	
Page _____ of _____			

FIG. 2 RQD Data Sheet

TABLE 1 RQD Index of Cores of Sedimentary Rock

Material (Rock Type)	Mean RQD, \bar{x} , %	Repeatability, r , % ^A	Reproducibility, R , % ^A
Anhydrite/calcite	86	28	28
Calcareous shale	60	32	40
Limestone	92	14	14
Anhydrite	86	20	20

^A The numbers in the r and R columns are not to be taken as percentages of the means, but are applied as plus or minus terms to the respective means.

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (1996) that may impact the use of this standard.

- (1) Added to Section 1 required statement about significant figures and Practice D 6026.
- (2) Added Terminology D 653, Practices D 3740, and D 6026
- (3) Added Terminology Section , and renumbered subsequent sections.
- (4) Added Note 1 in Significance and Use Section, referencing Practice D 3740, and renumbered subsequent notes.
- (5) In Section 4.1 defined method as applicable to drill holes in any orientation and added the word “sound” between “intact rock”. Changed “Engineering judgement” to Rock mechanics judgement” so that both the engineering and geological considerations were included.
- (6) In Calculation Section, added the sentence: “In accordance with Practice D 6026, record the result to the nearest one percent.
- (7) In Calculation Section, Note 2, corrected typographical error in a symbol and the abbreviation for RQD. Took out confusing discussion of vertical fractures since it pertains to any fracture that parallels the core axis and added references used to support this section.
- (8) In Section 6.1 added words “and equipment” with “proper drilling techniques.”
- (9) In Section 6.3 added the influence of curatorial handling.
- (10) Added Report Section and renumbered accordingly.
- (11) Figure 1 — Added “Centerline Method” to title, added “intact and sound” to the formula and changed “Description of Rock Quality” to “Rock Quality Classification.”
- (12) Figure 2 — Fixed heading to include more relevant background data, added the words “intact and sound” to the formula, changed meters to millimeters, and added place to put the rock quality classification.

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