INTERNATIONAL

Designation: D1586/D1586M – $18^{\varepsilon 1}$

Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils[1]

This standard is issued under the fixed designation D1586/D1586M; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

ε[1] NOTE—Reference (14) was editorially corrected in April 2022.

1. Scope*

1.1 This test method describes the procedure, generally known as the Standard Penetration Test (SPT), for driving a split-barrel sampler with a 140 lb [63.5 kg] hammer dropped 30 in. [750 mm] to obtain a soil sample for identification purposes, and measure the resistance of the soil to penetration of the standard 2 in. [50 mm] diameter sampler. The SPT "*N*" value is the number of hammer blows required to drive the sampler over the depth interval of 0.5 to 1.5 ft [0.15 to 0.45 m] of a 1.5 ft [0.45 m] drive interval.

1.2 Test Method D4633 is generally necessary to measure the drill rod energy of a given drop hammer system and using the measured drill rod energy, *N* values can be corrected to a standard energy level. Practice D6066 uses Test Methods D1586 and D4633 and has additional requirements for hammers, hammer energy, and drilling methods to determine energy corrected penetration resistance of loose sands for liquefaction evaluation.

1.3 Practice D3550/D3550M is a similar procedure using a larger diameter split barrel sampler driven with a hammer system that may allow for a different hammer mass. The penetration resistance values from Practice D3550/D3550M do not comply with this standard.

1.4 Test results and identification information are used in subsurface exploration for a wide range of applications such as geotechnical, geologic, geoenvironmental, or geohydrological explorations. When detailed lithology is required for geohydrological investigations, use of continuous sampling methods (D6282/D6282M, D6151/D6151M, D6914/D6914M) are recommended when the incremental SPT *N* value is not needed for design purposes (see 4.1.1).

1.5 Penetration resistance testing is typically performed at 5 ft [1.5 m] depth intervals or when a significant change of materials is observed during drilling, unless otherwise specified.

1.6 This test method is limited to use in nonlithified soils and soils whose maximum particle size is approximately less than one-half of the sampler diameter.

1.7 This test method involves use of rotary drilling equipment (Guide D5783, Practice D6151/D6151M). Other drilling and sampling procedures (Guides D6286 and D6169/D6169M) are available and may be more appropriate. Considerations for hand driving or shallow sampling without boreholes are not addressed. Subsurface investigations should be recorded in accordance with Practice D5434. Samples should be preserved and transported in accordance with Practice D4220/D4220M using Group B. Soil samples should be identified by group name and symbol in accordance with Practice D2488.

1.8 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.8.1 The procedures used to specify how data are collected/recorded and calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering data.

1.9 *Units*—The values stated in either inch-pound or SI units [presented in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. Reporting of test results in units other than inch-pound shall not be regarded as

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Evaluations.

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

nonconformance with this practice. SI equivalent units shown herein are in general conformance with existing international standards.

1.10 Penetration resistance measurements often will involve safety planning, administration, and documentation. This test method does not purport to address all aspects of exploration and site safety.

1.11 Performance of the test usually involves use of a drill rig; therefore, safety requirements as outlined in applicable safety standards (for example, OSHA regulations,[2] NDA Drilling Safety Guide,[3] drilling safety manuals, and other applicable local agency regulations) must be observed.

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

1.13 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[4]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1452/D1452M Practice for Soil Exploration and Sampling by Auger Borings
D1587/D1587M Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)
D2573/D2573M Test Method for Field Vane Shear Test in Saturated Fine-Grained Soils
D3550/D3550M Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220/D4220M Practices for Preserving and Transporting Soil Samples
D4633 Test Method for Energy Measurement for Dynamic Penetrometers
D5088 Practice for Decontamination of Field Equipment Used at Waste Sites
D5092 Practice for Design and Installation of Groundwater Monitoring Wells
D5299 Guide for Decommissioning of Groundwater Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities
D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock (Withdrawn 2021)[5]
D5778 Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils
D5782 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5783 Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
D5784/D5784M Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water Quality Monitoring Devices
D5872/D5872M Guide for Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water Quality Monitoring Devices
D6026 Practice for Using Significant Digits and Data Records in Geotechnical Data
D6066 Practice for Determining the Normalized Penetration Resistance of Sands for Evaluation of Liquefaction Potential (Withdrawn 2020)[5]
D6151/D6151M Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling
D6169/D6169M Guide for Selection of Subsurface Soil and Rock Sampling Devices for Environmental and Geotechnical Investigations
D6282/D6282M Guide for Direct Push Soil Sampling for Environmental Site Characterizations
D6286 Guide for Selection of Drilling and Direct Push Methods for Geotechnical and Environmental Subsurface Site Characterization
D6913/D6913M Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
D6914/D6914M Practice for Sonic Drilling for Site Characterization and the Installation of Subsurface Monitoring Devices

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms in this standard refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *anvil, n—in drilling*, that portion of the drive-weight assembly which the hammer strikes and through which the hammer energy passes into the drill rods.

[2] Available from Occupational Safety and Health Administration (OSHA), 200 Constitution Ave., NW, Washington, DC 20210, http://www.osha.gov.

[3] Available from the National Drilling Association, 3511 Center Rd., Suite 8, Brunswick, OH 44212, http://www.nda4u.com.

[4] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

3.2.2 *cathead, n—in drilling*, the rotating drum or windlass in the rope-cathead lift system around which the operator wraps a rope to lift and drop the hammer by successively tightening and loosening the rope turns around the drum.

3.2.3 *drill rods, n—in drilling*, rods used to transmit downward force and torque to the drill bit while drilling a borehole and also connect sampler to the hammer system for testing.

3.2.4 *hammer, n—in drilling*, that portion of the hammer drop system consisting of the 140 ± 2 lbm [63.5 ± 0.5 kg] impact mass which is successively lifted and dropped to provide the impact energy to drill rods that accomplishes the sampling and penetration.

3.2.5 *hammer drop system, n—in drilling*, the equipment that includes the 140 lbm [63.5 kg] hammer, lifting and dropping assembly, and guide tube (if used) which the operator or automatic system accomplishes the lifting and dropping of the hammer to produce the blow.

3.2.6 *hammer fall guide, n—in drilling*, that part of the hammer drop system used to guide the fall of the hammer.

3.2.7 *number of rope turns, n—in drilling*, the total contact angle between the rope and the cathead at the beginning of the operator's rope slackening to drop the hammer, divided by 360° (see Fig. 1).

3.2.8 *sampling rods, n—in drilling*, rods that connect the drive-weight assembly to the sampler. Drill rods are often used for this purpose.

3.2.9 *standard penetration test (SPT), n—in drilling*, a test process in the bottom of a borehole in which a split-barrel sampler (see 5.3) with an outside diameter of 2 in. [50 mm] is driven a prescribed distance of 1.0 ft [0.3 m] after a seating interval of 0.5 ft [0.15 m] using a 140 lbm [63.5 kg] hammer falling 30 in. [750 mm] for each hammer blow to compute the *N*-value.

3.2.10 *test interval, n—in drilling*, the depth interval for the SPT test consists of an 0.5 ft [0.15 m] seating interval followed by the 1.0 ft [0.3 m] test interval.

3.3 *Definitions from D6066 Pertinent to This Standard:*

3.3.1 *cleanout depth, n*—depth that the bottom of the cleanout tool (end of drill bit or cutter teeth) reaches before termination of cleanout procedures.

3.3.2 *cleanout interval, n*—interval between successive penetration resistance tests from which material must be removed using conventional drilling methods.

3.3.2.1 *Discussion*—During the clean-out process, the previous penetration test interval (1.5 ft [450 mm]) is drilled through and an additional distance is cleaned past the end depth of the previous test to assure minimal disturbance of the next test interval. The term cleanout interval in this practice refers to the additional distance past the previous test termination depth.

3.4 *Symbols Specific to This Standard:*

3.4.1 *N-value, n*—reported in blows per foot, equals the sum of the number of blows (*N*) required to drive the sampler over the depth interval of 0.5 to 1.5 ft [0.15 to 0.45 m] below the base of the boring (see 8.3).

3.4.2 N_{60}, *n*—standard penetration resistance adjusted to a 60 % drill rod energy transfer ratio (Test Method D4633, Practice D6066).

3.5 *Symbols Specifc to This Standard and Pertinent to This Standard from Test Method D4633:*

3.5.1 *EFV, n*—the energy transmitted to the drill rod from the hammer during the impact event.

3.5.2 *ETR, n*—ratio (*EFV / PE*) of the measured energy transferred to the drill rods to the theoretical potential energy (PE).

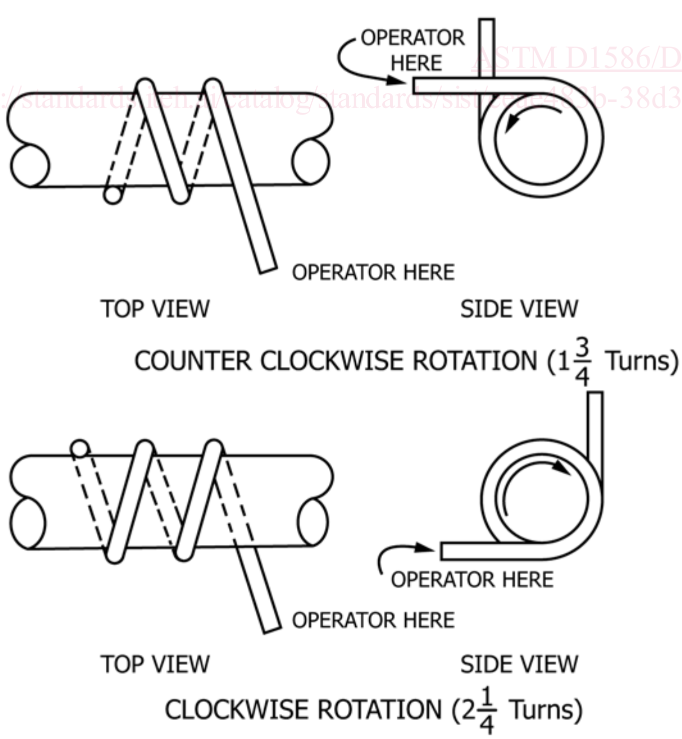


FIG. 1 Definitions of the Number of Rope Turns and the Angle for (*a*) Counterclockwise Rotation and (*b*) Clockwise Rotation of the Cathead

4. Significance and Use

4.1 This test is the most frequently used subsurface exploration drilling test performed worldwide. Numerous international and national standards are available for the SPT which are in general conformance with this standard.[6] The test provides samples for identification purposes and provides a measure of penetration resistance which can be used for geotechnical design purposes. Many local and widely published international correlations which relate blow count, or *N*-value, to the engineering properties of soils are available for geotechnical engineering purposes.

4.1.1 Incremental SPT sampling is not a preferred method of soil sampling for environmental or geohydrological exploration unless the SPT *N*-value is needed for design purposes. Continuous sampling methods such as Direct Push Soil Sampling (Guide D6282/D6282M), or continuous coring using

[6] "Geotechnical Investigation and testing – Field testing- Part 3: Standard Penetration Test (ISO 22476-3:2004)," EN ISO 22476-3, European Standard, European Committee for Standardization, Brussels Belgium.

Hollow-Stem Augers (Practice D6151/D6151M) or Sonic Drills (Practice D6914/D6914M) provide the best continuous record of lithology. Continuous sampling can be performed with SPT samplers, but it is slow compared to other methods, and *N* values may unreliable (see 4.6.1). Sampling for detailed lithology can be reduced by using screening tests such as geophysics and Direct Push profiling tests such as Cone Penetrometers (Test Method D5778), Dynamic Cone Penetrometer, or electrical resistivity probe.

4.2 SPT *N* values are affected by many variables allowed in the design and execution of the test (see Appendix X1). Investigations of energy transmission in SPT testing began in the 1970's and showed that differing drop hammer systems provide different energies to the sampler at depth. There are so many different hammer designs that it is important to obtain the energy transfer ratio (ETR) for the hammer system being used according to Test Method D4633. ETR of various hammer systems has shown to vary between 45 to 95 % of maximum Potential Energy (PE). Since the *N*-value is inversely proportional to the energy delivered, resulting *N* values from different systems are far from standard. It is now common practice to correct *N* values to an energy level of 60 % of total (PE), or N_{60} values as presented here and in Practice D6066. In this standard it is not required to report ETR or N_{60} but strongly advised to be noted and reported if available. If ETR of the hammer/anvil/rod system is known, the hammer PE can still vary after calibration, thus it is essential that hammer drop heights/rates be monitored to confirm consistent performance. Report any occurrence of hammer drop heights that do not meet the required value of 30 in. [750 mm] during testing. Using previous ETR data for a hammer system does not assure that it will perform the same on the current project. If onsite ETR is not obtained, be sure to check hammer drop height/ rates to assure the hammer is operating the same as when previously checked.

4.2.1 Other mechanical variables and drilling errors can also adversely affect the *N* value as discussed in X1.4. Drilling methods can have a major effect on testing (see 4.5). While the SPT hammer system is standardized knowing ETR, drilling methods are not, and a variety of drilling methods can be used.

4.3 SPT is applicable to a wide range of soils. For nomenclature on soil in terms of *N*-value refer to Appendix X2 for consistency of clays (cohesive soils) and relative density of sands (cohesionless soils) as proposed by Terzaghi and Peck and used commonly in geotechnical practice. SPT drilling can be performed easily using a variety of drilling methods in denser soils but has some difficulty in softer and looser soils. This test method is limited to non-lithified or un-cemented soils and soils whose maximum particle size is approximately one-half of the sampler diameter or smaller. Large particles result in higher blow counts and may make the data unsuitable for empirical correlations with finer soils. For example, chamber tests on clean sands have shown coarse sands have higher blow counts than medium fine sands (see X1.6). In gravelly soils, with less than 20 % gravel, liquefaction investigations may require recording of penetration per blow in an attempt to extrapolate the results to sand blow counts (see X1.7). Soil deposits containing gravels, cobbles, or boulders typically result in penetration refusal, damage to the equipment, and unreliable *N* values if gravel plugs the sampler.

4.3.1 *Sands*—SPT is widely used to determine the engineering properties of drained clean sands during penetration. Obtaining "intact" soil samples of clean sands for laboratory testing is difficult and expensive (see thin walled tube, Practice D1587/D1587M), so engineers use penetration results in sands for predicting engineering properties (Appendix X1). Appendix X2 and X1.6 provides some estimated properties of sands. There are problems with SPT in loose sands below the water table since they are unstable during drilling. Practice D6066 provides restricted drilling methods for SPT in loose sands for evaluating earthquake liquefaction potential. Practice D6066 method relies on mud rotary drilling, casing advancers, and fluid filled hollow-stem augers.

4.3.2 *Clays*—SPT is easy to perform in clays of medium to stiff consistency and higher using a variety of drilling methods. SPT is unreliable in soft to very soft clays because the clay, yields or "fails" under the static weight of the rods alone, or weight of rods and hammer before the test is started. This problem is accentuated by the heavier weights of automatic hammer assemblies (see X1.3.1.4) but can be alleviated with automatic hammers which are designed to float over the anvil (see 5.4.2.1). There is such a large variation in possible *N* values in soft clays it is well accepted that SPT is a poor predictor of the undrained shear strength of clay. It is recommended to evaluate soft clays with more appropriate methods such as CPT (Test Method D5778), vane shear (Test Method D2573/D2573M), and/or Thin-Wall Tube sampling (Practice D1587/D1587M) and laboratory testing.

4.4 *Hammer Drop System*—SPT can be performed with a wide variety of hammer drop systems. Typical hammer systems are listed below in order of preference of use:

(1) Hydraulic automatic chain cam/mechanical grip-release hammers

(2) Mechanical trip donut hammers

(3) Rope and cathead operated safety hammers

(4) Rope and cathead operated donut hammers

4.4.1 Automatic and trip hammers are preferred for consistent energy during the test. Automatic chain cam hammers are also the safest because the hammer is enclosed, and the operators can stand away from the equipment. If the rope and cathead method is used, the enclosed safety hammer is safer than donut hammer because the impact anvil is enclosed. For more information on hammer systems, consult X1.3.

4.5 *Drilling Methods*—The predominant drilling methods used for SPT are open hole fluid rotary drilling (Guide D5783) and hollow-stem auger drilling (Practice D6151/D6151M). Limited research has been done comparing these methods and their effects on SPT *N* values (see X1.5.1.1).

4.5.1 Research shows that open hole bentonite fluid rotary drilling is the most reliable method for most soils below the water table. Hollow-stem augers had problems with saturated loose sands since they must be kept full of fluid. The research also showed that driven casing using water as the drilling fluid, can adversely influence the SPT if the casing is driven close to the test depth interval. Use of casing combined with allowing a fluid imbalance also causes disturbances in sands below the water table. Fluid filled rotary casing advancers (Guide D6286) are included as an allowable drilling method for loose sands in Practice D6066.

4.5.2 SPT is used with other drilling methods including reverse circulation, sonic drilling, and direct push methods practices. There are concerns, undocumented by research, with direct push (Guide D6282/D6282M), sonic drilling (Practice D6914/D6914M), and reverse circulation methods using heavy casing drive hammers (Guide D6286), that the extreme dynamic loading and vibrations could disturb some soils such as sands and soft clays past the seating interval. The professional responsible for the investigation should evaluate SPT under these conditions and if drilling disturbance is suspected, then *N* values can be checked against other drilling methods in section 4.5 or deploy the alternate drilling method through and ahead of the casings.

4.5.3 SPT is also performed at shallow depths above the groundwater table using solid stem flight augers (Practice D1452/D1452M), but below the water table borings may be subject to caving sands. Solid stem borings have been drilled to depths of 100 ft or more in stable material.

4.5.4 SPT is rarely performed in cable tool or air rotary drilling.

4.6 *Planning, Execution, and Layout*—When SPT borings are used, often there are requirements for other companion borings or test holes to be located near or around the SPT boring. In general, borings should be no closer than 10 ft [3 m] at the surface for depths of up to 100 ft [30 m]. A minimum would be as close as 5 ft [2 m], but at this spacing, boreholes may meet if there is significant vertical deviation.

4.6.1 *Test Depth Increments*—Test intervals and locations are normally stipulated by the project engineer or geologist. Typical practice is to test at 5 ft [1.5 m] intervals or less in homogeneous strata. If a different soil type in the substratum is encountered, then a test is conducted as soon as the change is noted. It is recommended to clean out the borehole a minimum cleanout interval of at least 1 ft [0.25 m] past the termination point of the previous test depth between tests to assure test isolation and to check drill hole condition for the next test. Therefore, the closest spacing for typical practice of SPT is 2.5 ft [0.75 m]. The cleanout between test intervals can be adjusted by the user depending on borehole conditions and design data needs such as hard soils or thin strata. The practice of performing continuous SPT for *N*-value determination is not recommended but can be done with careful cleanout before testing. The borehole must be cleaned out between tests (see 6.5). At continuous spacing, with no additional cleanout depth, *N* values may be adversely affected by disturbance of previous sample driving especially in softer soils but the effect his not known. Some practitioners like to overdrive the sampler an additional 0.5 ft [0.15 m] to gain additional soil sample for a total drive interval of 2.0 [0.6 m]. This is acceptable if the *N*-value remains the sum of the 0.5 to 1.0 ft [0.15 to 0.3 m] intervals of the drive interval and reasonable cleanout is performed between tests.

4.7 This test method provides a Class A and B soil samples according to Practice D4220/D4220M which is suitable for soil identification and classification (Practices D2487 and D2488), water content (Test Methods D2216), and specific gravity tests (Test Methods D854). The soil can be reconstituted for some advanced laboratory tests. The small-diameter, thick wall, drive sampler will not obtain a sample suitable for advanced laboratory tests such as those used for strength or compressibility from the core. Consult Guide D6169/D6169M for samplers that provide laboratory grade intact samples.

NOTE 1—The reliability of data and interpretations generated by this practice is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 generally are considered capable of competent testing. Users of this practice are cautioned that compliance with Practice D3740 does not assure reliable testing. Reliable testing depends on several factors and Practice D3740 provides a means of evaluating some of these factors.

Practice D3740 was developed for agencies engaged in the testing, inspection, or both, of soils and rock. As such, it is not totally applicable to agencies performing this field test. Users of this test method should recognize that the framework of Practice D3740 is appropriate for evaluating the quality of an agency performing this test method. Currently, there is no known qualifying national authority that inspects agencies that perform this test method.

5. Apparatus

5.1 *Drilling Equipment*—Any drilling equipment that provides at the time of sampling a suitable borehole before insertion of the sampler and ensures that the penetration test is performed on intact soil shall be acceptable. A suitable borehole is one in which the drilling indicates stable conditions at the base of the boring (see 6.2). In general the boring should have an diameter of 3 to 6 in. [75 to 150 mm] diameter. Borings greater than 6 in. [150 mm] inside diameter may result in lower blow counts and require a correction factor (see X1.5.4).

5.1.1 *Fluid Rotary Drilling Drill Bits*—Use side discharge or baffled bottom discharge bits to avoid jetting fluid disturbance in the base of the boring. The tricone roller bit baffles produce some downward discharge. If the deposit is fine grained, it is preferred to use a fishtail or drag bit with baffled discharge points to advance the boring. Wash boring chopping bits should not be used near the test zone.

5.1.2 *Hollow-Stem Augers*—The boring can be advanced either using a pilot bit or an interior sampling tube. When drilling below the water table in unstable sands, add water when retrieving the cleanout string and sampler to maintain water at or above the groundwater table depth. Two types of hollow-stem auger systems are used, either center rod or wireline type. The wireline system suffers from several problems when unstable soil such as sand gets inside the augers and the pilot bit will not latch. If the bit does not latch, the sand must be cleared, but often drillers will pull back the outer augers instead of cleaning causing further disturbance. For that reason, rod type systems are preferred in unstable soils.

5.2 *Sampling Rods*—Flush-joint steel drill rod shall be used to connect the split-barrel sampler to the drive-weight assembly. Drill rod mass per foot ranges from 4 lbm/ft [6 kg/m] to 8 lbm/ft [12 kg/m]. See X1.4.3 for effects on energy in drill rods. If drill rods are longer than 100 ft [30 m], an energy correction may be needed to account for energy loss in long drill strings. *N* series drill rods are the maximum size allowed for the test (see Note 2 and X1.4.3).

NOTE 2—In North America, drill rods specifications commonly used are those from the Diamond Drill Core Manufacturers Association.[7] The most common drill rods used are A series rods (A, AW, AWJ) of 1.75 in. [45 mm] outside diameter weighing about 4 lbm/ft [6 kg/m]. For depths greater than 75 ft [20 m] some publications recommend going to stiffer B or N size rod. Some agencies drill solely with N series rod which are about 2.63 in. [67 mm] O.D. and weigh about 8 lb/ft [11 kg/m].

5.3 *Split-Barrel Sampler*—The standard sampler dimensions are shown in Fig. 2. Samplers are made from steel and in most cases are hardened for durability. The split-barrel sampler must be equipped with a ball check and vent. The sampler has an outside diameter of 2.00 in. [51 mm]. The inside diameter of the shoe is 1.375 in. [35 mm]. The inside diameter of the split-barrel (dimension D in Fig. 2) can be either 1.5 in. [38 mm] or 1.375 in. [35 mm]. The upset portion of the split barrel may be equipped with liners making the inside diameter 1.375 in. [35 mm]. The length of the sampler should be at least 2 ft [0.6 m] such that it can accommodate the drive interval of 1.5 ft [0.45 m] plus 0.5 ft [0.15 m] of additional length of material. This split barrel sampler is also in conformance with Practice D3550/D3550M split barrel sampler specifications as shown in Appendix X1, X1.4.2.1, and Fig. X1.6.

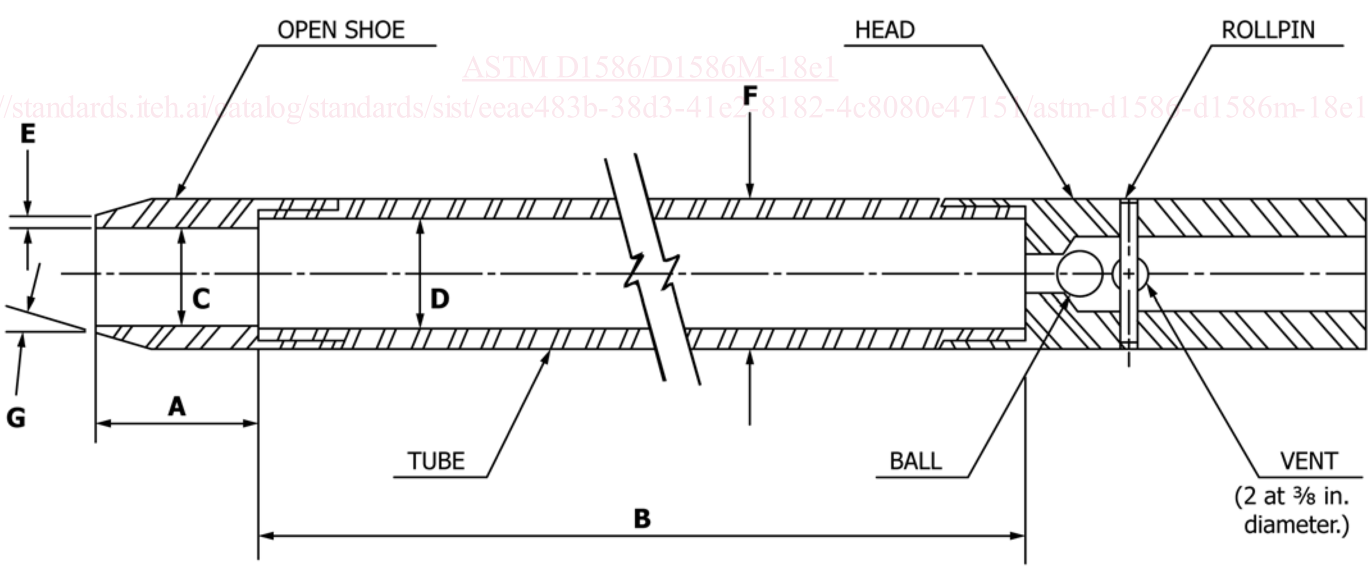
5.3.1 *Liners*—Typical practice in the North America has been to use the upset wall sampler. The use of an upset wall improves recovery of the sample but has been shown to reduce friction especially in denser soils. International practice favors the original use of a constant inside diameter sampler. Limited research suggests that *N*-values may differ as much as 10 to 30 % between a constant inside diameter sampler which provides higher *N* values than the upset wall sampler and recommends that a correction may be required for soils with blow counts exceeding $N > 10$ (see X1.4.1). For liquefaction evaluations it is common practice to correct upset wall data to constant diameter using the procedures in X1.4.1.1. Report the type of sampler used, e.g., Liner or no Liners. Liners are usually steel, brass, or plastic and may be sectional and supplied with end caps for sealing. Report the type of liner used.

5.3.2 *Drive Shoe*—Drive shoes are made of steel and should be hardened for durability. The drive shoe shown on Fig. 2 is the standard for use in finer soils without gravels. Manufacturers do supply thicker more durable shoes for denser soils and where coarser soils are encountered (see X1.4.4). The thicker shoes are not in conformance with this standard. There is no research on the effect of shoe size/dimensions on *N* values. If thicker shoes are used, they should be noted.

5.3.3 *Retainers*—Various types of retainers are used for sandy soils which may be difficult to recover. These retainers cause a restriction to sample entrance and may affect the *N*-value. There is no available research on the effect of use of retainers on blow counts. If retainers are used, they should be reported.

5.3.4 *Sampler Maintenance*—The sampler must be clean at the beginning of each test and should be smooth and free of scars, indentations, and distortions. The driving shoe should be repaired and restored to specifications tolerances or replaced when it becomes dented, cracked, or distorted. Plugging of the vent ports and ball check system of the sampler results in

[7] DCDMA Technical Manual, National Drilling Association, 6089 Frantz Rd. Suite 101, Dublin, Ohio 43017, 1991.



A = 1.0 to 2.0 in. (25 to 50 mm)
B = 18.0 to 30.0 in. (0.457 to 0.762 m)
C = 1.375± 0.005 in. (34.93 ± 0.13 mm)
D = 1.50 ± 0.05 – 0.00 in. (38.1 ± 1.3 – 0.0 mm)
E = 0.10 ± 0.02 in. (2.54 ± 0.25 mm)
F = 2.00 ± 0.05 – 0.00 in. (50.8 ± 1.3 – 0.0 mm)
G = 16.0° to 23.0°

FIG. 2 Split-Barrel Sampler

unreliable penetration resistance values. Instances of vent port plugging must be noted on daily data sheets and reported in the boring log.

5.4 *Hammer, Anvil, and Hammer Drop System:*

5.4.1 *Hammer and Anvil*—The hammer shall weigh 140 ± 2 lbm [63.5 kg ± 0.5 kg] and shall be a rigid metallic mass. The hammer shall strike the anvil and make steel on steel contact when it is dropped. The hammer drop system is to be designed to permit a constant and unimpeded vertical hammer fall of 30 in. [750 mm] on the impact anvil which is firmly connected by threaded connection to the top drill rods. The anvil acts as an energy damper, such that the transmitted energy through the drill rods is attenuated; therefore, the larger the anvil the lower the energy transmission. Special precautions should be taken to ensure that the energy of the falling mass is not significantly reduced by friction between the drive weight and guide system. Periodic inspection and maintenance (cleaning and lubrication) should be performed to avoid friction buildup and to check the hammer and assembly mass.

5.4.2 *Hammer Drop Systems*—Any hammer assembly that meets the requirements of 5.4.1 may be used for SPT. Various hammer assemblies as listed here and in section 4.4 may be used in order of preference. At a minimum, report the type and details of the hammer system being used. Many hammer systems have published information on their respective energy transfer or ETR. However, these should not be relied upon as manufacturers can change components during their production life. It is desirable that that actual hammer being used be tested for ETR within some reasonable time frame. If available, report the ETR or onsite measured ETR using Test Method D4633. Report any operational problems when conducting the test that may impact ETR. If using a previously calibrated hammer, check and report that the hammer drops heights and rates still comply with the calibrated condition. The total mass of the hammer assembly bearing on the drill rods can be changed to avoid sinking in soft clays (see X1.3.1.4).

5.4.2.1 *Automatic Hammer*—The typical automatic hammer finding widespread use in drilling today is an enclosed hydraulic motor operated chain cam hammer lifting system (Fig. 3). These hammers are safer and produce very reproducible drop heights or energy. These assemblies are often heavy and may add considerable static pressure to the test zone. Some hammer systems like the Diedrich or eSPT or others[8] are designed to float over the impact anvil. Many of the automatic drop hammer systems are built on the drill and may be safely swung into position for testing but rest on the impact anvil. The drop height of 30 in. [750 mm] assumes the top of the anvil is fully inside the guide tube. If the hammer has an adjustable follower, the operator should avoid exerting extra pressure on the anvil (see X1.3.1.1). A chain cam automatic hammer should be equipped with a view slot on the guide tube to allow drop height checks although some automated systems may not require it. Heavy automatic hammers resting on the sampler may result in unreliable penetration test data in soft and very soft clays (see X1.3.1.4). The speed of a chain cam automatic hammer affects the drop height and consequently the energy transmission, ETR; therefore, the hammers must be routinely checked to be sure they are operating at the correct blow rate and drop height. The automatic hammer system should be adjusted to provide the desired blow rate and energy transmission for the project requirements prior to testing. If ETR data are not known, then adjust and operate the hammer to assure 30 in. [750 mm] drop height. If ETR is known, an automatic hammer may be adjusted to provide drop heights of less than 30 in. [750 mm] if the blow rate needs to be reduced from manufacturers design speed (see X1.3.1.2).

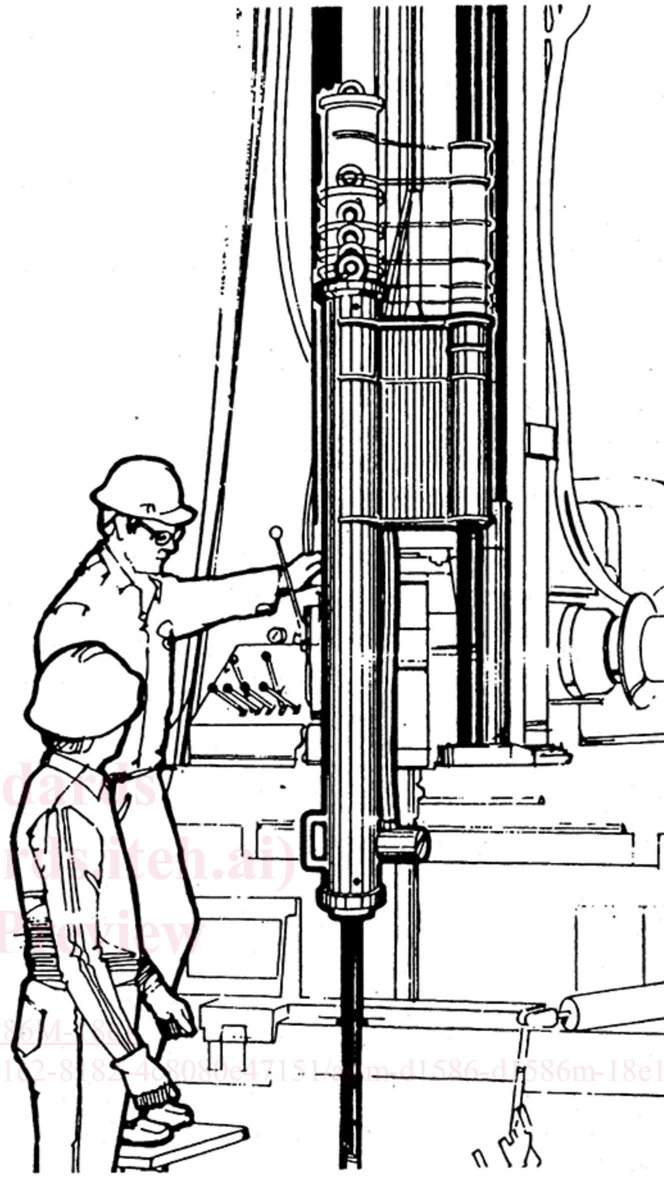


FIG. 3 Typical Hydraulic Automatic Hammer Drop System

5.4.2.2 *Mechanical Trip Donut Hammer Drop System*—These hammer systems use fingers or pawls that grip a donut

[8] The Diedrich (www.Diedrichdrill.com), and eSPT (www.marltechnologies.com) hammer systems and laser depth recorder PileTrac (www.piletrac.com) are known to the subcommittee D18.02 at this time with special characteristics cited in the text. If you are aware of alternative suppliers meeting these criteria or other special equipment, please provide this information to the subcommittee D18.02. Other hammer apparatus meeting these features can be added to the standard and will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

hammer and release the hammer at the 30 in. [750 mm] drop height (Fig. 4). The fall guide is a central tube. This hammer is lifted with a rope and cathead but rope turns and cathead speed do not significantly affect drop height. These hammers are often available internationally even where truck mounted drills are not used. They are not as safe as built in automatic hammers and must be hoisted and lowered using a cathead and the hammer anvil impact surface is exposed providing a dangerous pinch point. Some of these hammers have fairly large anvils which provide lower ETR. Safety problems include hoisting, lowering, cathead operation pinch points at the impact surface, and metal fragments which can come off the anvil.

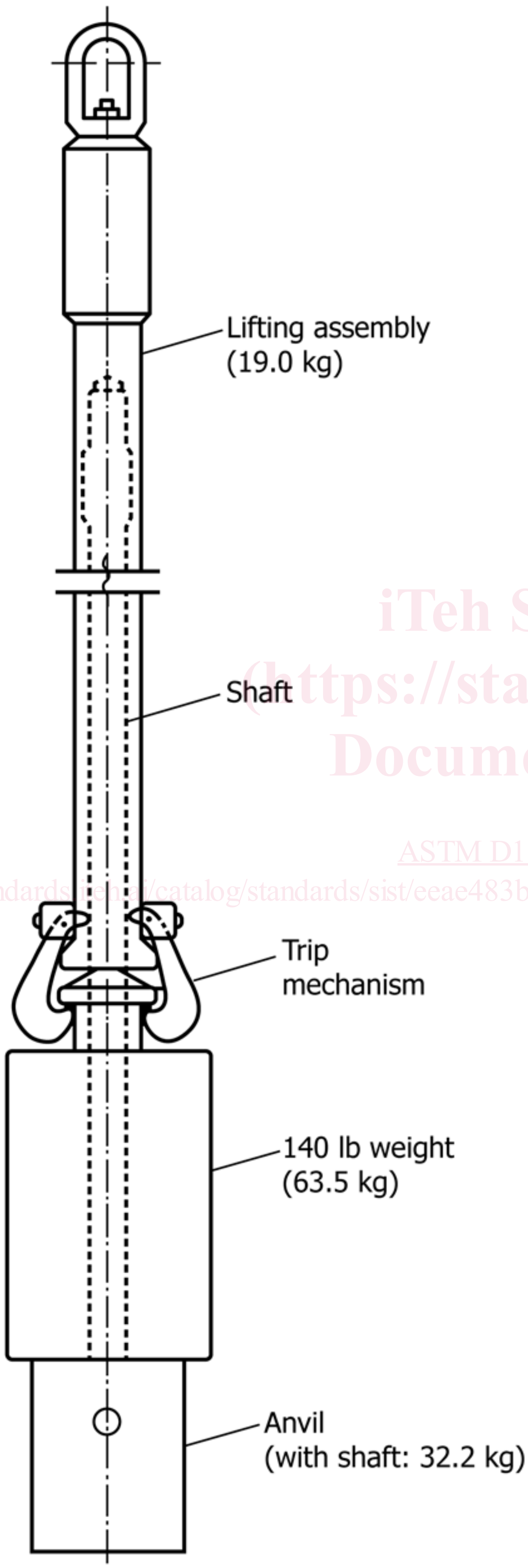


FIG. 4 Mechanical Automatic Trip Drop Donut Hammer System

5.4.2.3 *Rope and Cathead Operated Safety Hammer*—The safety hammer drop system shown on Fig. 5 is a long hammer assembly used on truck mounted drills in North America and was developed to enclose the impact surface for safer operation. This hammer system uses an operator cathead rope drop with two rope turns on the cathead. Since it is dependent on the operator, the energy transmission may vary between operators and single operator precision has a much larger variation than automatic hammers. The geometry is slender, with a small impact anvil, and ETR can be much higher than a donut hammer (see X1.3.3). In order to allow 30 in. [750 mm] drop height without back tapping, the hammer lift height should provide for an additional 3 to 4 in. [75 to 100 mm] of vertical lift. The hammer should have a mark on the fall guide tube, which is generally another section of A rod, so the operator can see the 30 in. [750 mm] drop height. Safety concerns include hoisting, lowering, and cathead operation.

5.4.2.4 *Rope and Cathead Operated Donut Hammer*—The donut hammer is the original design and the dimensions can vary widely (Fig. 5). Some countries have standardized dimensions of the hammer and anvil to maintain consistent energy transmission. This hammer system also uses an operator cathead rope drop with two rope turns on the cathead. Since it is dependent on the operator, the energy transmission may vary between operators and single operator precision has a much larger variation than automatic hammers. Donut hammer with large impact anvils generally have lower energy transmission ratios, ETR (see X1.3.4). Safety concerns include hoisting, lowering, cathead operation, pinch points at the impact surface, and metal fragments off the anvil.

NOTE 3—It is suggested that the hammer fall guide be permanently marked to enable the operator or inspector to judge the hammer drop height.

5.4.2.5 *Spooling Winch Hammer Systems*—This hammer system uses an automated wireline spool behind the mast to lift a safety or donut hammer the prescribed 30 in. [750 mm] drop and then unwind at a computed free fall speed for the hammer system. Several published studies have shown these hammers do not perform well and often restrict the drop speed resulting in very low drill rod energy, ETR and resulting very high blow counts (see X1.3.5). These hammer systems should not be used unless their performance is checked onsite using energy measurements prescribed by Test Method D4633.

5.5 *Accessory Equipment*—Accessories such as labels, sample containers, data sheets, groundwater level, and SPT energy measuring devices shall be provided in accordance with the requirements of the project and other applicable ASTM standards.

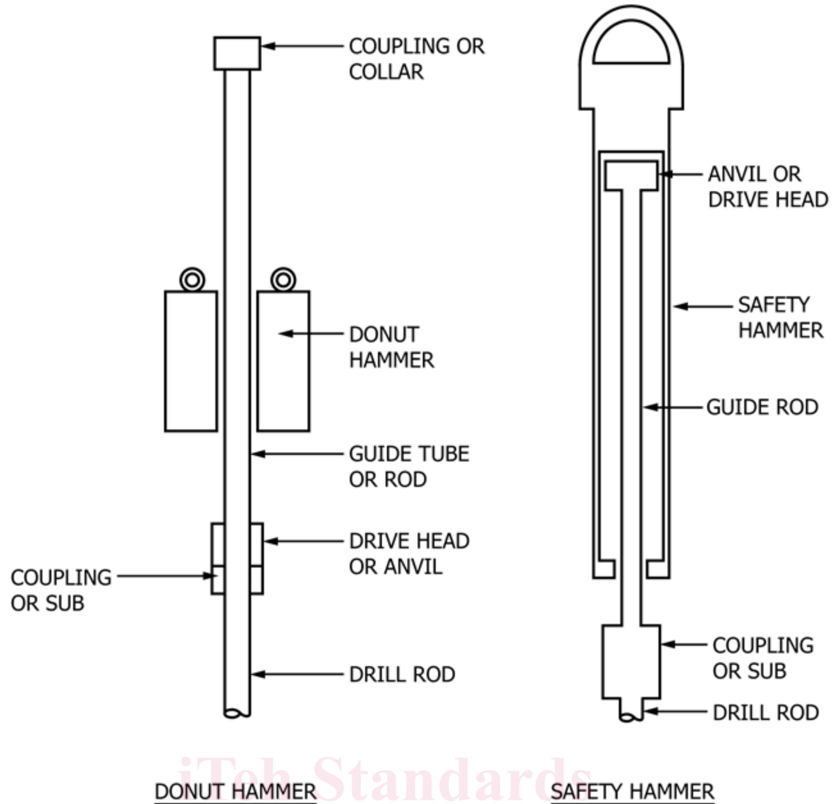


FIG. 5 Schematic Drawing of the Donut Hammer and Safety Hammer (see Note 3)

6. Drilling Procedure

6.1 The borehole shall be advanced incrementally to permit intermittent or continuous sampling. Record the depth of drilling to the nearest 0.1 ft [0.025 m] or better.

6.2 Any drilling procedure that provides a suitably clean and stable borehole before insertion of the sampler and assures that the penetration test is performed on essentially intact soil shall be acceptable. Stable borehole conditions are confirmed for each test by comparing the cleanout depths to sampler depths prior to tests and examining recovered soil cores. Each of the following procedures has proven to be acceptable for some subsurface conditions. The subsurface conditions anticipated should be considered when selecting the drilling method to be used (see 4.5 and 5.1).

6.2.1 *Open-Hole Fluid Rotary Drilling Method (D5783).*

6.2.2 *Hollow-Stem Auger Method (D6151/D6151M).*

6.2.3 *Solid Stem Auger Method (D1452/D1452M)*—Open hole solid stem augers can be used to advance borings as long as the hole remains open, stable, and clean. These open uncased borings are subject to sloughing or caving of cohesionless soils below the water table and may not be suitable for those conditions. In stiff cohesive soils borings can often be extended below the water table. Typical diameter is 4 in. [100 mm].

6.2.4 *Fluid Rotary Casing Advancer (D5872/D5872M)*—Since this drilling method circulates fluids up the exterior annulus of the rotary casing, care must be taken to maintain fluid circulation (Practice D6066).

6.2.5 *Other Drilling Methods,* with concerns listed. It is the responsibility of the user (driller, site geologist/engineer) to examine the test conditions and evaluate if disturbance requires change of drilling method or procedures. Use of fluid rotary or hollow-stem auger drilling is recommended if there are serious concerns and a check boring is required. The other drilling methods have distinct issues with their usage:

6.2.5.1 *Wash Boring Method*—Wash borings are an older drilling method using pumped water to a chopping bit which is raised and lowered impacting the base of the boring and circulating the fluid and cuttings upward. Casing is also used to help keep the boring stabilized. This method has been listed previously in this procedure but is recognized as a jetting method, Section 12 of Guide D6286. Concerns with this method include jetting and impact disturbance in the base of the boring and disturbance caused by casing near the test zone. See X1.5.1.1 for research information on this method.

6.2.5.2 *Sonic Drilling (D6914/D6914M)*—Concerns with this drilling method include the strong vibrations produced which could influence and disturb sandy soils in the test zone. This method does not use drilling fluid and disturbance in sands below the water table can occur if fluid balance is not maintained during removal of the inner barrel. The advantage is the outer casing protect the borehole from caving. There is some preliminary research on effects of sonic drilling on SPT *N*-values which are currently inconclusive (see X1.5.3) pointing to a need to perform site specific checks with conventional drilling methods on effect on *N*-values if required.

6.2.5.3 *Dual-Wall Reverse Circulation*—If used with a casing hammer, this method could disturb sandy soils at the base of the boring. When drilling with air, circulation must be maintained as there is high risk of soil fracturing in the test zone. This method also provides continuous protective casing to stabilize the hole.

6.2.5.4 *Direct Push Casings*—SPT has been routinely used with larger diameter dual tube equipment without problems in many types of soils. The primary concern with this method is the hammer impacts disturbing sandy soils in the test zone below the water table. This affect can be mitigated by using a large diameter dual tube sampler in sampling mode (Guide D6282/D6282M) instead of driving with a center plug point. Fluid should be added in saturated sands during extraction of the inner tube. The outer dual tube stabilizes the boring for testing. There is some preliminary research on effects of Direct Push drilling on SPT *N*-values which are currently inconclusive (see X1.5.3) pointing to a need to perform site specific checks with conventional drilling methods on effect on *N*-values if required.

6.3 All drilling methods, to be successful, require the driller to advance the drill rate slow enough to ensure that the cuttings are removed, and circulation is maintained during the drilling process. If drilled too fast using fluids, the bit or hole may plug, the fluid circulation may be lost, and soil at the base of the boring may be hydraulically fractured. Report any major fluid losses.

6.4 *Drilling Below Groundwater*—The drilling fluid level within the borehole or hollow-stem augers shall be maintained at or above the in situ groundwater level at all times during drilling, removal of drill rods, and sampling. Numerous investigations and published data show adverse effects of allowing fluid levels to drop (see X1.5.1). If the site requires that casing be installed close to the test interval it is advised to keep it as far from the test zone as possible. When drilling in unstable saturated sands, the use of a bypass line is required to add fluid when removing the cleanout string to maintain the fluid balance. If soil heaves into a casing a considerable distance, there could be a large disturbed zone at the base of the boring. If this occurs, it must be reported. If sand is flowing into the casings, more viscous drill fluids may be required.

6.5 Several drilling methods produce unacceptable boreholes. The process of jetting through an open tube sampler and then sampling when the desired depth is reached shall not be permitted. Casing shall not be advanced below the sampling elevation prior to sampling. Advancing a borehole with bottom discharge bits is not permissible. It is not permissible to advance the borehole for subsequent insertion of the sampler solely by means of previous sampling with the SPT sampler.

7. Hammer Operating Procedures

7.1 The lifting and dropping of the 140 lbm [63.5 kg] hammer shall be accomplished using either of the following using automatic or rope and cathead methods. Drill rod energy transfer ETR can be measured according to procedures in Test Method D4633 (see 4.2 and Note 4). For proper performance, the hammer drop height (PE) and blow rate should be continuously monitored during testing and any deviations noted.

7.1.1 *Automatic and Trip Hammers*—By using a trip, automatic, or semi-automatic hammer drop system that lifts the 140 lbm [63.5 kg] hammer and allows it to drop 30 ± 1.0 in. [750 ± 30 mm] with limited frictional resistance. Check the drop height and blow count rate as required based on previous testing (see 5.4.2.1 and X1.3.1).

7.1.2 *Rope and Cathead Method*—By using a cathead to pull a rope attached to the hammer. When the cathead and rope method is used the system and operation shall conform to the following:

7.1.2.1 The cathead shall be essentially free of rust, oil, or grease with a diameter in the range of 6 to 10 in. [150 to 250 mm]. The mast should only have two well lubricated crown sheaves for the rope. A third crown sheave could reduce ETR.

7.1.2.2 The cathead should be operated at a speed of rotation of about 100 RPM.

7.1.2.3 The operator should generally use either 1-¾ or 2-¼ rope turns on the cathead, depending if the rope comes off the top (1-¾ turns for counterclockwise rotation) or the bottom (2-¼ turns for clockwise rotation) of the cathead during the penetration test, as shown in Fig. 1. It is generally accepted that 2-¾ or more rope turns impede the fall of the hammer and should not be permitted. The cathead rope should be relatively dry, clean, and should be replaced when it becomes excessively frayed, oily, or burned.

7.1.2.4 For each hammer blow, a 30 in. [750 mm] lift and drop shall be employed by the operator. The operation of pulling and throwing the rope shall be performed rhythmically without holding the rope at the top of the stroke. If the hammer drop height is not 30 ± 1.0 in. [750 ± 30 mm], then record the actual drop heights used.

NOTE 4—Test Method D4633 provides information on making energy measurement for variable drop heights and Practice D6066 provides information on adjustment of the *N*-value to a constant energy level (60 % of theoretical, N_{60}). Practice D6066 allows the hammer drop height to be adjusted to provide 60 % energy.

8. Sampling and Testing Procedure

8.1 After the borehole has been advanced to the desired sampling elevation and excessive cuttings have been removed, record the cleanout depth to the nearest 0.1 ft [0.025 m], and prepare for the test with the following sequence of operations:

8.1.1 Attach the split-barrel sampler to the sampling rods and lower into the bottom of the borehole. Do not allow the sampler and rods to drop onto the soil to be sampled. Record the sampling start depth to the nearest 0.1 ft [0.025 m] or better. If the sampler penetrates past the cleanout depth record the partial penetration prior to driving.

8.1.2 Attach the anvil and hammer assembly to the top of the drill rods.and rest the dead weight of the sampler, rods, anvil, and hammer on the bottom of the borehole. Compare the sampling start depth to the cleanout depth in 8.1. If excessive cuttings are encountered at the bottom of the borehole, remove the sampler and sampling rods from the borehole and remove the cuttings. See section 8.2.5 if the sampler begins to settle under the weight of rods, or rod and hammer.