Designation: D1586/D1586M − 18

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.

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
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 in Geotechnical Data
D6066 Practice for Determining the Normalized Penetration Resistance of Sands for Evaluation of Liquefaction Potential
D6151/D6151M Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling
D6169/D6169M Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations
D6282/D6282M Guide for Direct Push Soil Sampling for Environmental Site Characterizations
D6286 Guide for Selection of Drilling Methods for Environmental 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.

3.2.2 *cathead, n—in drilling*, the rotating drum or windlass in the rope-cathead lift system around which the operator

[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.

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.

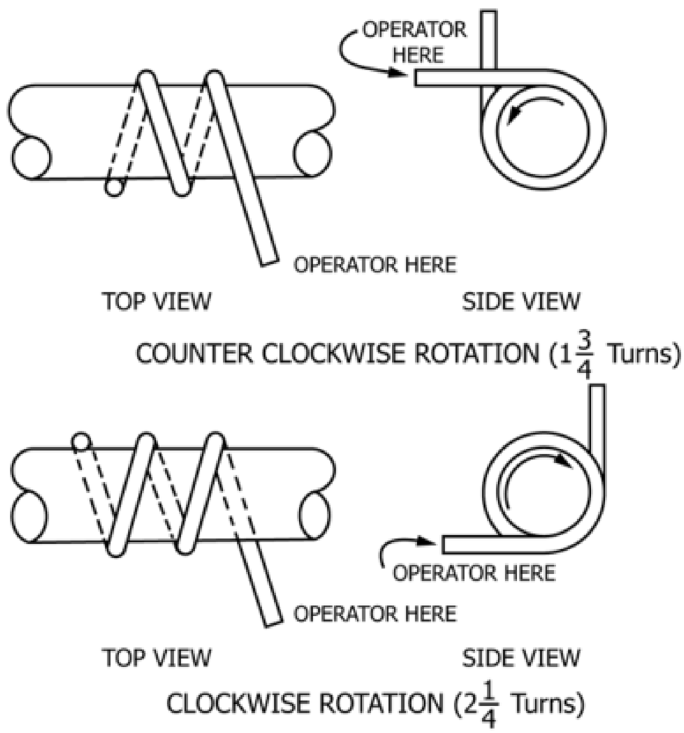


FIG. 1 Definitions of the Number of Rope Turns and the Angle for (*a*) Counterclockwise Rotation and (*b*) Clockwise Rotation of the Cathead

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).

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.[5] 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 Hollow-Stem Augers (Practice D6151/D6151M) or Sonic

[5] "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.

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.[6] 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.

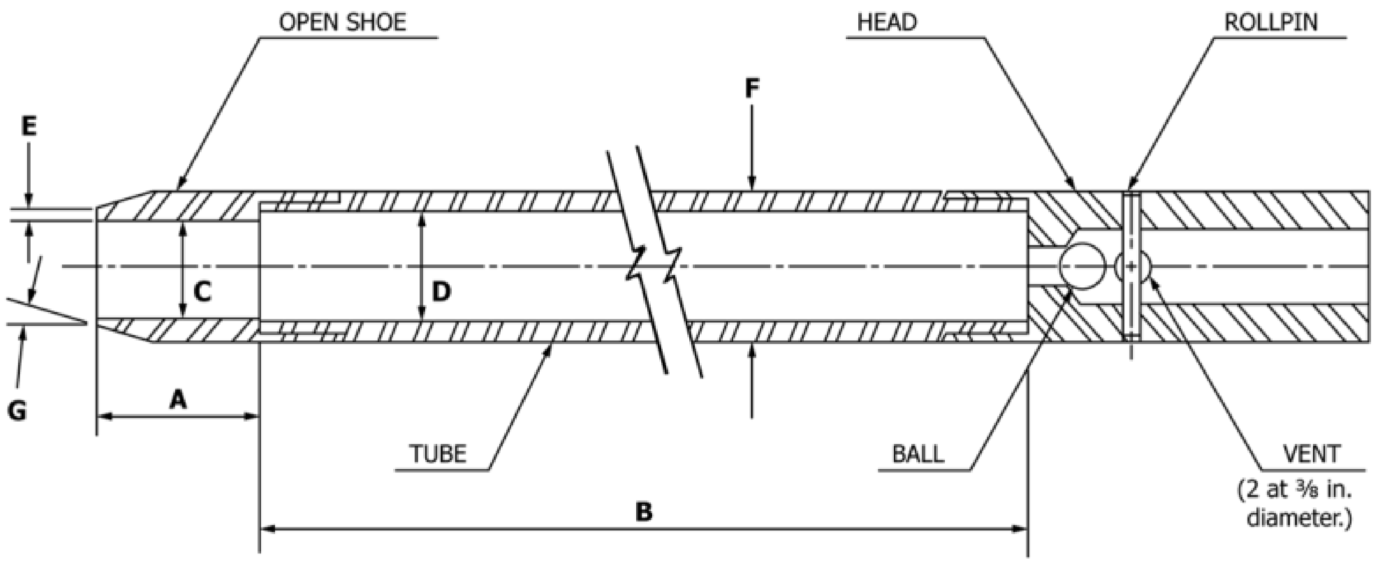
5.3.1 *Liners*—Typical practice in the North America has been to use the upset wall sampler. The use of an upset wall improves recovery of the sample but has been shown to reduce friction especially in denser soils. International practice favors the original use of a constant inside diameter sampler. 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

[6] 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[7] 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).

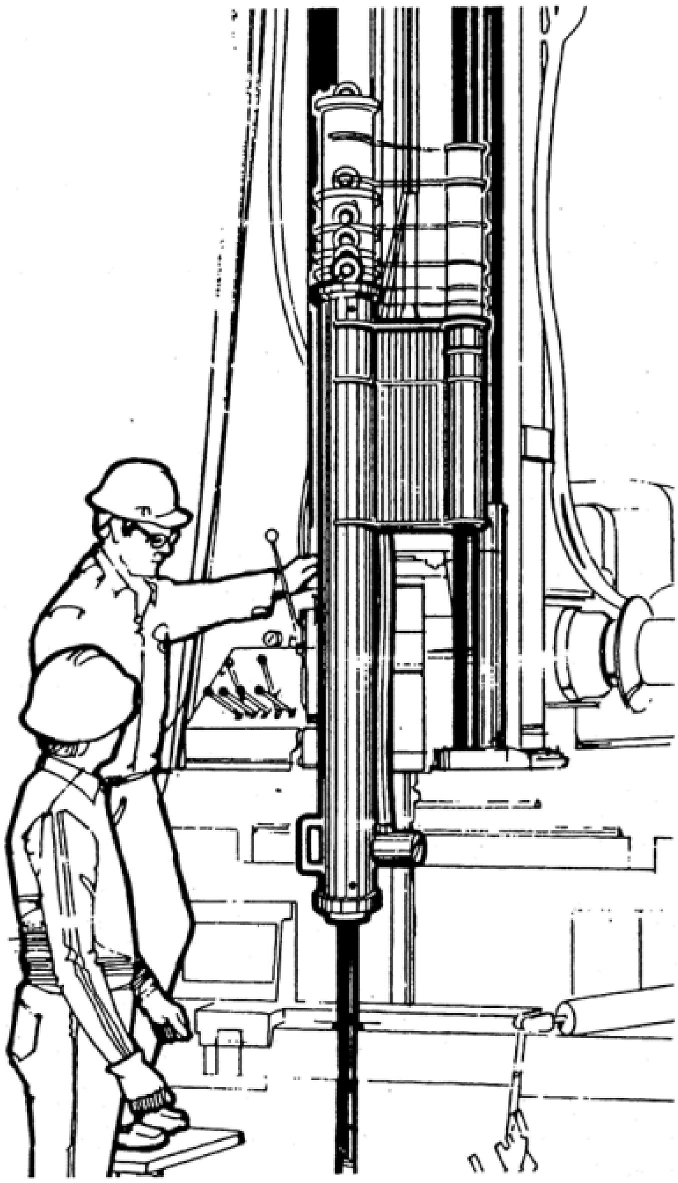


FIG. 3 Typical Hydraulic Automatic Hammer Drop System

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

[7] 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.

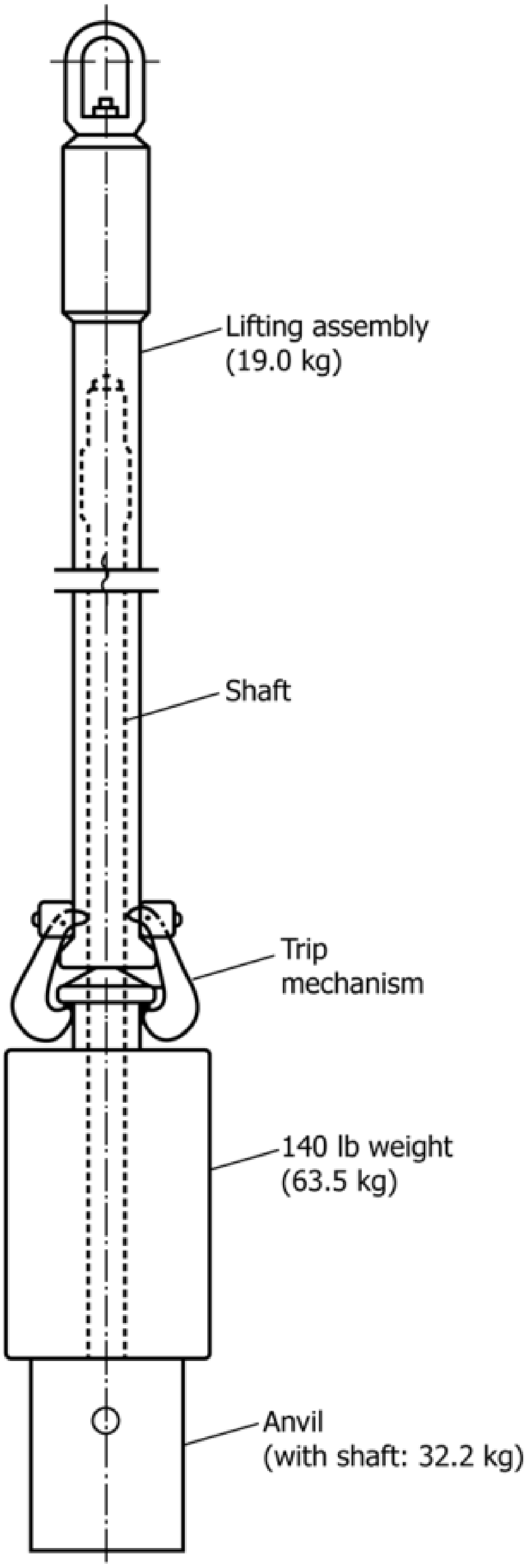


FIG. 4 Mechanical Automatic Trip Drop Donut Hammer System

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.

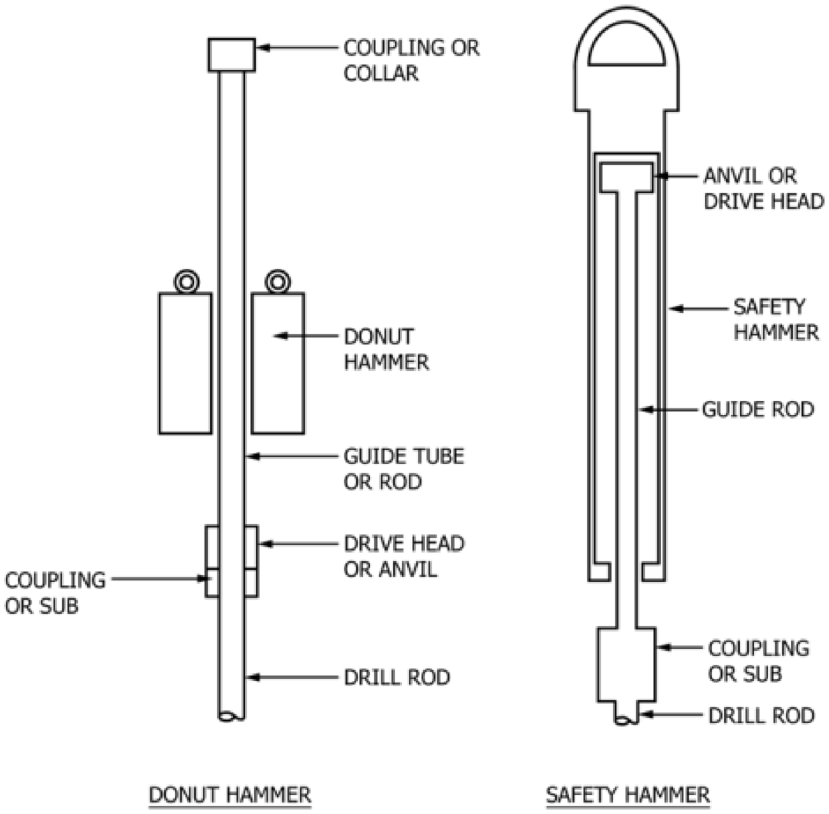


FIG. 5 Schematic Drawing of the Donut Hammer and Safety Hammer (see Note 3)

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.

8.1.3 Mark the drill rods in three successive 0.5 ft [0.15 m] increments so that the advance of the sampler under the impact of the hammer can be easily observed for each 0.5 ft [0.15 m] increments. If the penetration is known from the hammer system, i.e., Diedrich hammer or recorded using automated methods such as the eSPT system, or laser depth recorder (PileTrac)[7], the rods do not need to be marked, however, the marks can be used as a visual check. Record any hammer drops not meeting project requirements regarding fall heights, changes in hammer speed, or pauses during testing (Note 5).

8.2 Drive the sampler with blows from the 140 lbm [63.5 kg] hammer using procedures in Section 7 and count the number of blows for each 0.5 ft (0.15 m) increment until one of the following occurs:

8.2.1 A total of 50 blows during any one of the three 0.5 ft [0.15 m] increments described in 8.1.3.

8.2.2 A total of 100 blows have been applied.

8.2.3 There is no observed advance of the sampler during the application of 10 successive blows of the hammer. For automated systems an advance of less than 0.1 in. [2 mm] per blow can be considered refusal.

8.2.4 The sampler is advanced the entire 1.5 ft [0.45 m] without the limiting blow counts occurring as described in 8.2.1, 8.2.2, or 8.2.3.

8.2.5 If the sampler sinks under the weight of the hammer, weight of rods, or both, record the length of travel to the nearest 0.1 ft [0.025 m], and drive the sampler through the remainder of the test interval. If the sampler sinks the entire interval, stop the penetration, remove the sampler and sampling rods from the borehole, and advance the borehole through the very soft or very loose materials to the next sampling depth. Record the *N*-value as either weight of hammer, weight of rods, or both.

8.3 Record the number of blows (*N*) required to advance the sampler each 0.5 ft [0.15 m] of penetration or fraction thereof. The first 0.5 ft [0.15 m] is the seating drive. The sum of the number of blows required for the second and third 0.5 ft [0.15 m] of penetration is termed the "standard penetration resistance," or "*N*-value." If the sampler is driven less than 1.5 ft [0.45 m], as permitted in 8.2.1, 8.2.2, or 8.2.3, the number of blows per each complete 0.5 ft [0.15 m] increment and per each partial increment shall be recorded on the boring log. For partial increments, the depth of penetration shall be reported to the nearest 0.1 ft [0.25 m] or better in addition to the number of blows (Note 5).

NOTE 5—Often, liquefaction studies require recording of penetration per blow in gravelly soils as described in X1.7. For those cases, automated recording is desirable because the practice of hand marking the drill rods is hazardous and data recording is cumbersome. For latest automated hammer systems, the penetration per blow can be continuously recorded and the blow counts for each increment computed from the data. An example is the eSPT hammer system that uses terms of n_1, n_2, n_3, to specify the penetration increments and the *N*-value is the sum of n_2 and n_3. Another continuous depth recorder, PileTrac (www.piletrac.com), can also automate collection of penetration per blow data using exterior placed laser distance sensor.

8.4 Retrieve the sampler and open. Record the percent recovery to the nearest 5 % or the length of sample recovered to the nearest 0.1 ft [0.025 m] or better. Classify the soil samples recovered in accordance with Practice D2488, then place one or more representative portions of the sample into sealable moisture-proof containers (ziplock bags or jars) without ramming or distorting any apparent stratification. Seal each container to prevent evaporation of moisture. Affix labels to the containers bearing job designation, boring number, sample depth. . Protect the samples against extreme temperature fluctuation . If there is a soil change within the sampler, use a container for each stratum and note its location in the sampler barrel. Samples should be preserved and transported in accordance with Practice D4220/D4220M using Group B.

8.5 *Borehole Completion and Sealing*—Information on the sealing of boreholes and installations can be found in Guides D5782, D5783, and D5784/D5784M for drilling methods and in Practice D5092, and Guide D5299 for wells. Local regulating agencies or organizations may control both the method and the materials required for borehole sealing. The use of low solids content bentonite slurry should not be used in the unsaturated zones (Practice D5092).

8.6 *Equipment Decontamination*—Often is required to clean the drill rig and equipment prior to and after investigation at a specific site. Practice D5088 should be used if the investigation and sampling equipment require decontamination for environmental investigations.

9. Report: Test Data Sheet(s)/Form(s)

9.1 The methodology used to specify how data are recorded is covered in section 1.8.

9.2 Record as a minimum the following general information (data) Data obtained in each borehole shall be recorded in accordance with the Subsurface Logging Guide D5434 as required by the exploration program. An example of a sample data sheet is included in Appendix X3.

9.3 Drilling information shall be recorded in the field and shall include the following:

9.3.1 Name and location of job,

9.3.2 Names of driller, crew and logger,

9.3.3 Type and make of drilling machine,

9.3.4 Weather conditions,

9.3.5 Date and time of start and finish of borehole,

9.3.6 Boring number and location (station and coordinates, if available and applicable),

9.3.7 Surface elevation, if available,

9.3.8 Method of drilling and advancing and cleaning the borehole,

9.3.9 Method of keeping borehole open, fluid circulation rates and loses,

9.3.10 Depth of water surface to the nearest 0.1 ft [0.025 m] and drilling depth to the nearest 0.1 ft [0.025 m] or better at the time of a noted loss of drilling fluid, and time and date when reading or notation was made,

9.3.11 Location of strata changes, to the nearest 0.5 ft [0.15 m] or better,

9.3.12 Size of casing, depth of cased portion of borehole to the nearest 0.1 ft [0.025 m] or better,

9.3.13 Hammer system used including notes on configuration, blow count rates, and drop heights for driving the sampler. Report drop heights not meeting 30 in. [750 mm] requirements or other factors affecting required drop heights or drop speed during a particular test (ETR),

9.3.14 Sampler length and inside diameter of barrel, no liner, or liner and liner type if used, shoe type, and if a sample basket retainer is used, occurrence of plugged vent ports,

9.3.15 Size, type, and section length of the sampling rods, and

9.3.16 Remarks.

9.4 *Sample Data*—Data obtained for each sample shall be recorded in the field and shall include the following:

9.4.1 Top of cleanout depth to the nearest 0.1 ft [0.025 m] or better, and any occurrence of excessive heave,

9.4.2 Top of sample depth to the nearest 0.1 ft [0.025 m] or better, and, if utilized, the sample number, report any sinking of the sampler under weight of rods, or rods and hammer.

9.4.3 Strata changes within sample,

9.4.4 Sampler penetration and recovery lengths to the nearest 0.1 ft [0.025 m] or better, and

9.4.5 Number of blows per 0.5 ft [0.15 m] or partial increment (see 8.2.1 – 8.2.3).

9.4.6 Report the *N*-value rounded to the nearest whole number.

9.5 *Hammer Energy Data (optional)*—If the energy ratio (ETR) of the hammer system is known from previous measurements, report the data and how and when the data were obtained. Alternately, if an assumed value is used, report the basis for such based on the type of hammer and operation. For any hammer that has had previous past measurement and is currently being used, report the most recent date of measurement. Report hammer drop heights and blow rates to confirm hammer performance. If energy measurements are performed onsite during testing, report the energy data with locations and frequency on drill logs or in the report. Rope and Cathead hammers are operator dependent, so the operator should be identified.

9.5.1 N_{60} values calculated in Practice D6066 may also be reported. However never place N_{60} corrected data solely on the boring log. The log shall contain only the measured N values or both.

9.5.2 Report calculated N_{60} values to the nearest whole number.

9.6 Record as a minimum the following sampling data, regarding significant digits (see 1.8) as follows:

9.6.1 Report SPT N values to the nearest whole number.

9.6.2 Record all drilling and sampling measurements to the nearest 0.1 ft [0.025 m] or better.

9.6.3 *Sampling*—Report depth interval sampled, sample recovery lengths to the nearest 0.1 ft [0.025 m] or better.

9.6.4 *Recovery,* to the nearest five percent.

9.6.5 *In Situ testing*—Report the depths and types of in situ tests performed. For devices which were inserted below the base of the drill hole, report the depths below the base of the hole to the nearest 0.1 ft [0.025 m] or better, and any unusual conditions during testing.

10. Precision and Bias

10.1 *Precision*—Test data on precision is not presented due to the nature of this test method. It is either not feasible or too costly at this time to have ten or more agencies participate in an in situ testing program at a given site.

10.1.1 Subcommittee 18.02 is seeking additional data from the users of this test method to provide a limited statement on precision. Present knowledge indicates the following:

10.1.1.1 Variations in *N*-values of 100 % or more have been observed when using different standard penetration test apparatus and drillers for adjacent boreholes in the same soil formation. Current opinion, based on field experience, indicates that when using the same apparatus and driller, *N*-values in the same soil can be reproduced with a coefficient of variation of about 10 %.

10.1.1.2 The use of faulty equipment, such as an extremely massive or damaged anvil, a rusty cathead, a low speed cathead, an old, oily rope, or massive or poorly lubricated rope sheaves can significantly contribute to differences in *N*-values obtained between operator-drill rig systems.

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

11. Keywords

11.1 blow count; in-situ test; *N*-value; penetration resistance; soil; split-barrel sampling; SPT; standard penetration test

APPENDIXES

(Nonmandatory Information)

X1. SPT GUIDANCE ON METHODS AND EQUIPMENT

X1.1 History

X1.1.1 The International Society for Soil Mechanics and Foundation Engineering published a review of SPT on an international scale in 1988 (**1**).[8] SPT started in the 1920's when pile driving companies started using wash boring methods, standard metal pipe, and different samplers driven by a hammer. ASTM first published a recommended procedure in 1958 and in 1967 a standard was adopted. Additional references (**2, 3**) provide more history. Rodgers reports history of both SPT and Cone Penetration Testing (CPT) (Test Method D5778) in reference (**4**). CPT can be more reliable than SPT because it does not suffer from drilling disturbance problems and mechanical variables in the SPT; however, there is no soil sample.

X1.2 Energy Measurements and Hammer Systems

X1.2.1 In the 1970's Schmertmann and Palacios began testing the SPT energy transmission effects and found some significant problems with the hammer designs, the test equipment, and drilling procedures. Table X1.1 is from a 1978 paper postulating the effects from energy measurements and hammer systems and other test variables on the SPT *N*-value (**5**). This table shows some of the factors which since that time many have been further researched, so these numbers are estimates which have now been refined. Energy measurements were collected using force transducers up until the 1990's (**5, 6, 7**). In 1985 it was decided that SPT data should be corrected for energy to a 60 % level of PE (**8, 9**). Energy measurement methods switched from force transducers to also adding the use of accelerometers for velocity in the Force-Velocity method in Test Method D4633 in 2005 (**10**). Since that time there have been numerous publications on hammer types and energy measurements. It has now become common practice for high level quality assurance projects, to measure the ETR of the particular hammer system and use corrected N_{60} values for design purposes (Practice D6066).

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

X1.2.2 Refer to Test Method D4633 on how to measure drill rod energy transmission and note that Practice D6066 requires energy measurements for liquefaction evaluations. The requirements for measuring energy depend on the project requirements. Some operators calibrate hammers annually or based on frequency of use. Automatic hammers when operated at a constant speed deliver very consistent energy so calibration frequency can be reduced as long as the operation rate is checked. New automatic hammers are being designed to constantly monitor the drop height (e.g., eSPT system[7]). Projects requiring a high level of quality assurance should use automatic hammers and have them calibrated and documented for a particular test site.

X1.2.3 Rope and cathead operated hammers are also operator dependent and energy can vary widely. Certain drill rigs have features on cathead systems that impede free fall. The drill rig should have preferably only two crown sheaves. Drills with three crown sheaves have been shown to deliver lower energy, and subsequently higher *N* values. Field data have shown large variations in energy from extreme cold to warm weather effects on rope. The condition of the rope will also change the energy.

X1.3 Hammer Systems

NOTE X1.1—Below is a partial summary of some experience regarding the hammer systems listed in the standard.

X1.3.1 *Automatic Hammer Systems:*

X1.3.1.1 The typical hydraulically operated chain cam hammer system is highly reliable for delivering consistent ETR with a standard deviation of only 2 to 3 % during an individual test. A typical range of ETR is from 70 to 95 % of maximum PE. The hammers are blow rate dependent and for more information see (**11**). The original designers set a rate of about 50 blows per minute to throw the hammer slug 30 in. [750 mm] in the air. The 30 in. [750 mm] drop assumes the anvil top is fully inside the guide tube. To maintain the drop height the

TABLE X1.1 Factors Affecting the Variability of the Standard Penetration Test *N* (Schmertmann, 1978 (5)).

NOTE 1—Metric conversions: 1 ft = 0.3048 m; 1 in. = 2.54 cm.

Cause: Basic	Cause: Detailed	Estimated % by Which Cause Can Change *N*
Effective stresses at bottom of borehole (sands)	1. Use drilling mud versus casing and water	+ 100%
	2. Use hollow-stem auger versus casing and water and allow head imbalance	+ 100%
	3. Small-diameter hole (3 in.) versus large diameter (18 in.)	50%
Dynamic energy reaching sampler (All Soils)	4. 2 to 3 turn rope-cathead versus free drop	+ 100%
	5. Large versus small anvil	+ 50%
	6. Length of rods	
	Less than 10 ft	+ 50%
	30 to 80 ft	0%
	more than 100 ft	+ 10%
	7. Variations in height drop	± 10%
	8. A-rods versus NW-rods	± 10%
Sampler design	9. Larger ID for liners,	− 10% (sands)
	but no liners	− 30% (insensitive clays)
Penetration inteval	10. $N_{0 \text{ to } 12 \text{ in.}}$ instead $N_{6 \text{ to } 18 \text{ in.}}$	− 15% (sands)
		− 30% (insensitive clays)
	11. $N_{12 \text{ to } 24 \text{ in.}}$ versus $N_{6 \text{ to } 18 \text{ in.}}$	+ 15% (sands)
		+ 30% (insensitive clays)

drop system must follow the anvil as penetration occurs. Different approaches have been made to accomplish this. Most hammers float in a carrier and permanently rest on the anvil exerting full mass. The Lift cylinder (Fig. X1.1) can be equipped with a double acting cylinder to maintain contact but in this case additional pressure is added to the rods. For the double acting cylinder, the operator can use a follower control on the cylinder but must be careful not to load the rods in soft material. The hydraulic motor speed can be adjusted with a Flow Control constrictor (see Fig. X1.1). Operators not familiar with the drill may allow the Flow Control (Fig. X1.1) to go off speed so it's important to check the blow rate of automatic hammers. They should always be operated at a constant Throttle Speed (Fig. X1.1) so the hydraulic supply pressure is constant. Once the hammer speed has been set, the hammer performance can be checked periodically by using the View Slot (Fig. X1.1) and the hammer can deliver consistent ETR if blow rate and speed are checked and constant during testing. There are now several different manufacturers of these hammer systems and it is not known how much they vary in performance. New automatic hammer systems are being developed to continuously measure drop heights and penetration data such as the eSPT hammer.[7]

X1.3.1.2 The typical chain cam is operated at high speed of 50 to 55 BPM to achieve the 30 in. [750 mm] drop height using an anvil with a specific length inside the guide tube. These hammers achieve high energy but for those involved with liquefaction investigations (Practice D6066) the speed is faster than recommended 20 to 40 BPM (Seed, et., al. (**8**)). On most liquefaction sites the ETR is measured and the hammer than can be adjusted to give the desired speed or energy. For example, is you wish to slow the hammer to 40 BPM the hammer will not drop 30 inches. To maintain the drop height some have equipped the anvil with a spacer ring, so the anvil is lower inside the guide tube. In other cases, the rate is reduced to the desired speed and the lower ETR is used to correct the data to N_{60}. Another reason for slowing the hammer is to record penetration per blow in gravelly soils (see X1.7).

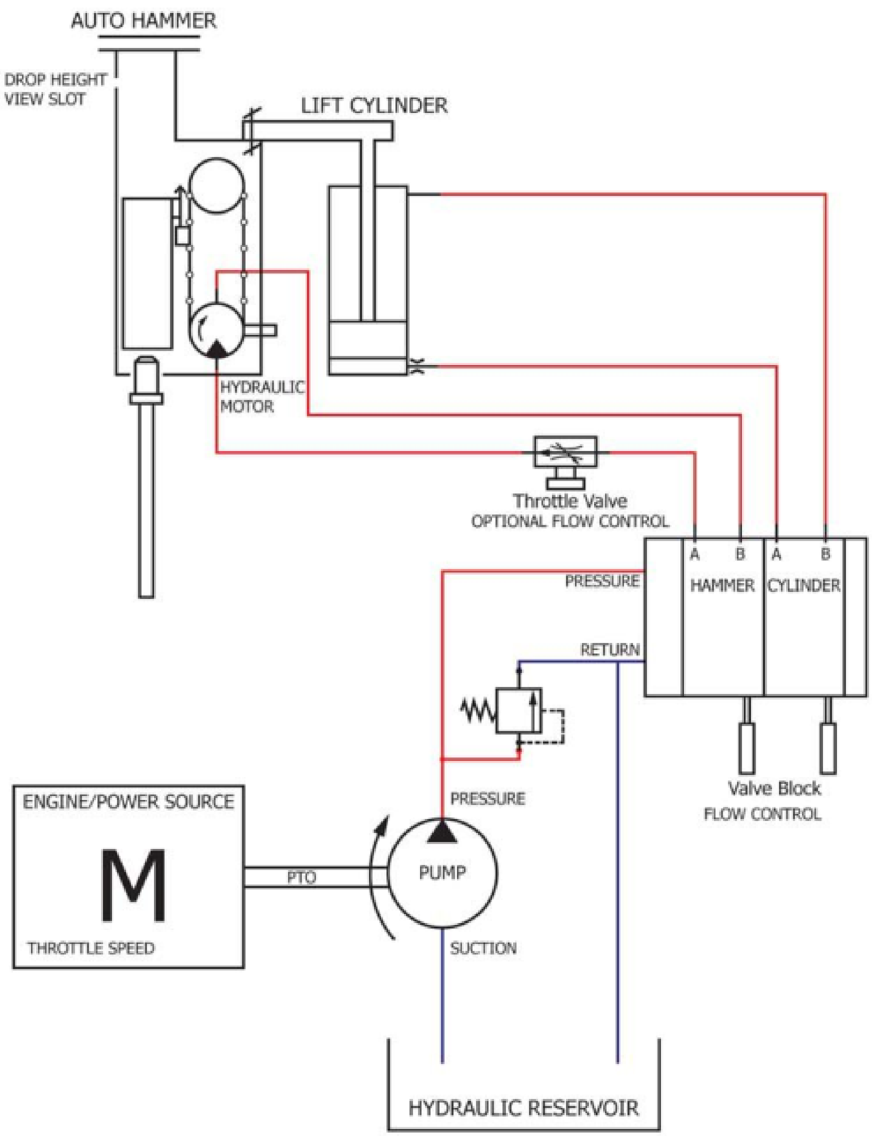


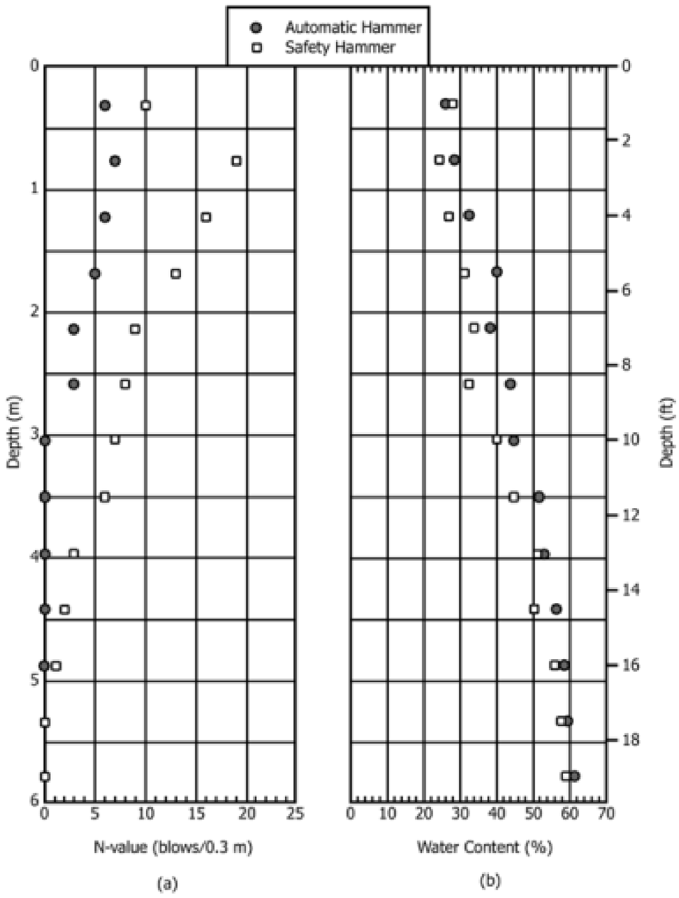
FIG. X1.1 Schematic of Hydraulic Motor Operation of Chain Cam Automatic Hammer System (courtesy MARL Technologies)

X1.3.1.3 A study of 32 automatic hammer systems was summarized by Biringen and Davie in 2008 (**12**) as part of major investigations for nuclear power plants. Their study also looked at previous automatic hammer studies from Utah DOT and Florida DOT. Although the hammer brands and blow rates were not reported, they found average ETR of automatic hammers averaged around 80 % with standard deviations of 6 to 8 %. Based on this and without any energy measurements they recommended a blanket correction factor of 1.24 to correct Nauto to N_{60} with that value being the lower bound standard deviation energy and thus a conservative correction factor. A more recent study of six CME automatic hammers of Alabama DOT resulted in an average ETR of 91 % and ranging from 82 to 96 % when operated near the design speed of 50 bpm (**13**).

X1.3.1.4 The automatic hammer systems impart considerable static mass to the rods and sampler prior to the test causing sinking under the weight of rods and hammer in soft clays. Fig. X1.2 by Luttenegger and Kelley (1997) (**14**) shows dramatically the effect in clays. This affect does not occur in sands or denser materials. They observed that typical safety and donut hammers had masses of 150 to 220 lbm [70 to 100 kg] including the 140 lbm [63.5 kg] hammer mass while auto hammers had masses of 500 to 530 lbm [230 to 240 kg]. As discussed section 4.3.2, the SPT is not reliable in soft clays and this example shows one of the primary reasons. Even a lighter safety hammer will sink through soft clays at depth due to the high rod weight from the longer drill string. For soft clays, alternate tests are recommended. If one must perform a check test of automatic hammers, use the mechanical trip or rope and cathead safety hammer or donut hammers. Their paper also shows a comparison of donut, safety, and automatic hammers at a sand site and show that energy correction worked well at that site and that all hammer systems are acceptable if the energy is known (Fig. X1.3). But for conditions where complete sinking occurs, *N* values are lost. Ideally, the hammer system should exert minimal additional weight on the rods and sampler. Some automatic hammer systems are made to float above the impact anvil using a guide tube and hydraulic lift such as the Diedrich and eSPT hammer systems. Luttengger and Kelly (**14**) did not test the floating Diedrich hammer although they list an assembly mass.

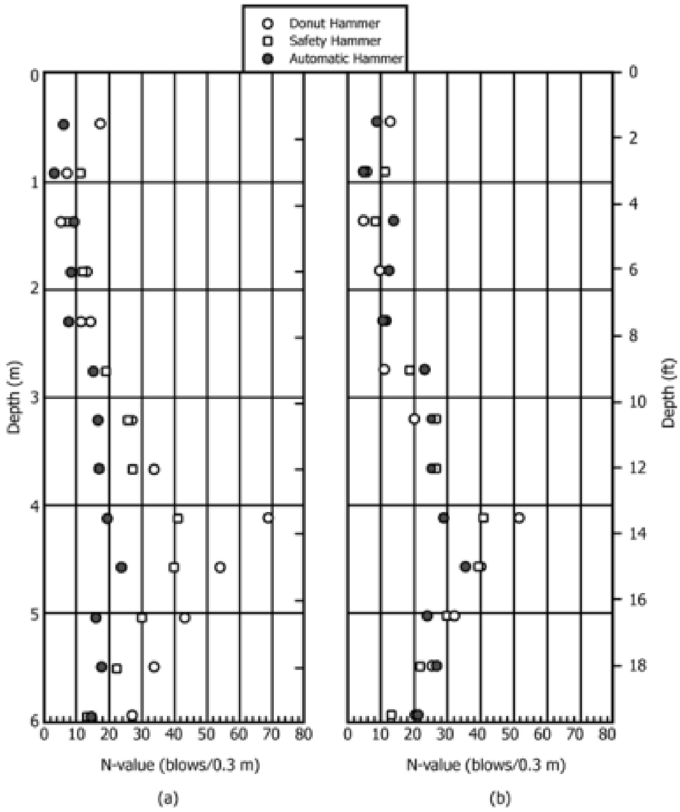
X1.3.2 *Mechanical Trip Hammers:*

X1.3.2.1 Mechanical Trip hammers are available in many countries. These trip hammers were reviewed by H. B. Seed (**8**) and summarized in Table X1.2 during the SPT review for liquefaction studies. Table X1.2 shows an effort to understand



National Geotechnical Experimentation Site, Amherst, Mass.: (a) Uncorrected Blow Count Data; (b) Water Content Data

FIG. X1.2 Illustration of Automatic and Safety Hammer Data in Clays at the NGES Test Site (Luttenegger and Kelly, 1997 (14))



Plattsburgh, N.Y., Sand Site: (a) Uncorrected Blow Count Data; (b) Corrected (N_{60}) Blow Count Data

FIG. X1.3 Comparison of Automatic, Safety and Donut Hammers at a Sand Site (a) Raw Data, (b) Corrected N_{60} Values (Lutenneger and Kelly, (14))

TABLE X1.2 Summary of Pilcon Mechanical Trip Hammer ETR (Seed, (8))

Study (1)	Hammer (2)	Energy Ratio (%) (3)
Decker, Holtz, and Kovacs (in press)	Pilcon	55
Douglas and Strutznsky (8)	Pilcon	62
Liang (29)	Pilcon-type	58
Overall average		60

the Chinese trip hammers which were similar to British Pilcon hammers. The ETR of these hammers depends on the hammer-anvil impedance ratio which means that larger anvils have lower energy transmission. There are quite few variations in design and some systems even have two impact anvils or built in anvil cushioning. The estimated ETR of the Chinese and British hammers was estimated at 60 % and that is due to the large anvil. Japanese Tombi trip hammers had 78 % energy transmission because the impact anvil is very small.

X1.3.3 *Safety Hammers:*

X1.3.3.1 Safety hammers found common use in North America in the 1970's as an improvement to donut hammers. The long assembly length could be accommodated on truck mounted drills. Kovacs and Salamone (**7**) measured numerous safety hammer systems and the average energy was 61 % and when efficiently operated run as high as 75 % ETR (**15**). These hammers have higher standard deviation of ETR during an individual test, i.e., 5 to 10 %. Two rope turns, or wraps should be used on the cathead to operate the hammer. The energy transmission depends on the number of rope turns used on the cathead. Extra rope turns (wraps) can cause large energy transmission losses. Use of a new stiff rope can result in temporary increase of ETR until the rope has been broken in.

X1.3.4 *Donut Hammers:*

X1.3.4.1 The older Donut hammers have shown a wide variation of low energies ranging from 35 to 65 %. Once again, the ETR depends on the hammer anvil impedance ratio. Based on data from Kovacs, Seed estimated an average energy of these hammers at 45 % (**8**). Due to the large variation in ETR for these hammers it would be unwise to use an assumed value of ETR, so some kind of previous or on-site energy measurements (Test Method D4633) should be required for the hammer prior to its use. Some countries such as Japan use hammers with fixed hammer and anvil dimensions and there are considerable energy data available so that an assumed value could be used on small projects (Kovacs, Seed (**7, 8**)). As with the safety hammer, two rope turns, or wraps should be used on the cathead to operate the hammer. The energy transmission depends on the number of rope turns used on the cathead. Extra rope turns (wraps) can cause large energy transmission losses. Use of a new stiff rope can result in temporary increase of ETR until the rope has been broken in.

X1.3.5 *Spooling Winch Hammers:*

X1.3.5.1 Published data indicate the spooling mechanism can sometimes impede the free fall of the hammer resulting in very low energy measurements (**15**). Before using this test at any given site, the ETR must be measured to confirm proper operation. This hammer system should not be used if the ETR has not been checked.

X1.4 Mechanical Variables

X1.4.1 *Sampler Split Barrel – Inside Diameter – Liners and No Liners:*

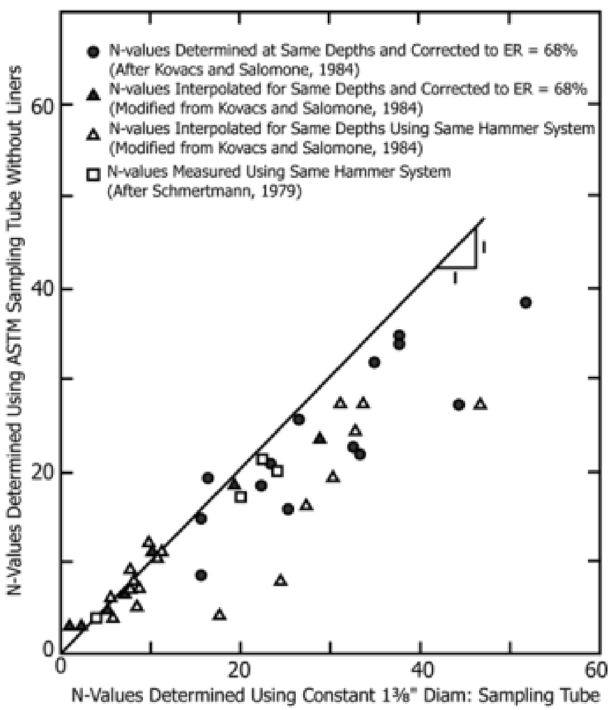
X1.4.1.1 There is limited research on the effects of the upset wall sampler barrel with and without liners. The available data were summarized by H.B Seed (**8**) and shown on Fig. X1.4 for liquefaction evaluation. The studies were predominantly done at sand sites. As would be expected, the differences are more pronounced in denser soils where internal friction buildup occurs in a constant wall diameter. Since the bulk of international data are collected with constant wall diameters, it is recommended that, for liquefaction studies, to correct for liners by EERI (**16**) a shown on Fig. X1.5. For most standard investigations the effect is minor for $N < 20$ and data are lacking for clay soils. Sample recovery is higher with upset wall split barrels due to reduced friction on the soil core.

X1.4.2 *Sampler Design:*

X1.4.2.1 The bulk of the samplers manufactured in North America are made to the Diamond Drill Core Manufacturers Association (DDCMA) specifications shown on Fig. X1.6 (**17**). These barrels have upset wall design.

X1.4.3 *Drill Rod Type and Rod Length:*

X1.4.3.1 There is no definitive research on the effect of A versus N size drill rods on *N* values. These sizes of rods should



Effect of Type of Sampling Tube on N-Value

FIG. X1.4 Comparison of Use of SPT Barrel With and Without Liners in Sands (Seed (8))

Standard split spoon without room for liners (the inside diameter is a constant 1⅜ in.). $C_S = 1.0$.

Split-spoon sampler with room for liners but with the liners absent (this increases the inside diameter to 1½ in. behind the driving shoe):

$$C_S = 1.1 \quad \text{for} \quad (N_1)_{60} \leq 10$$

$$C_S = 1 + \frac{(N_1)_{60}}{100} \quad \text{for} \quad 10 \leq (N_1)_{60} \leq 30$$

$$C_S = 1.3 \quad \text{for} \quad (N_1)_{60} \geq 30$$

(from Seed et al. 1984, equation by Seed et al. 2001)

FIG. X1.5 Recommended Liner Correction for SPT in Sands for Liquefaction Evaluation (EERI (15))

transmit energy effectively to the sampler. If anything, the energy reaching the sampler would be less in N rods than smaller diameter A rods because of reflections and dispersion of the stress wave (strain energy) component in the rods with larger joint pins. There is no indication that a loose joint or rod whip and friction on the borehole wall cause significant reductions in energy flowing through the rods, however this can be noted if suspected. For general practice, the differences in drill rods and the losses from length in typical depth ranges up to 100 ft [30 m] are less than 5 % and can be ignored for most production testing. However, for liquefaction evaluations corrections are sometimes used for short length and longer rods as follows irrespective of rod type.

X1.4.3.2 *Short Rod Lengths < 30 ft [10 m]*—Early energy transmission research using the F2 method assumed sampler penetration occurred primarily from the first big incident wave. Schmertmann proposed, in Table X1.1 for depths less than 30 ft [10 m] there could be some reduction in energy to the sampler because of termination of hammer contact by the reflected compression wave and reduction factors were applied for shallow blow counts. These corrections are still found today in some liquefaction guidelines (**16**). However, recently, researchers have argued that no reductions should be applied, and it was found that hammer anvil contact was maintained (**18, 19**). Part of these conclusions are due to the fact new ETR measurements use the FV method and include energy content of the first incident wave and subsequent smaller reflected pulses that occur past the first major stress pulse (see Test Method D4633, Appendix X1 and Odenbrecht et al., (**20**).

X1.4.3.3 *Long Rod Lengths > 100 ft [30 m]*—Besides the short rod corrections for liquefaction studies, there is also concern with energy losses of very long drill rods. Based on some early studies it was recommended that for borings of excess of 100 ft [30 m] one should reduce energy about 1 % for every 10 ft [3 m] (**21**). More recent energy measurements seem to confirm N rods lose energy at a greater rate compared to A rods and in some instances, the loss rate is greater (or efficiency is less) than previously expected (**22, 23**).

X1.4.4 *Drive Shoes:*

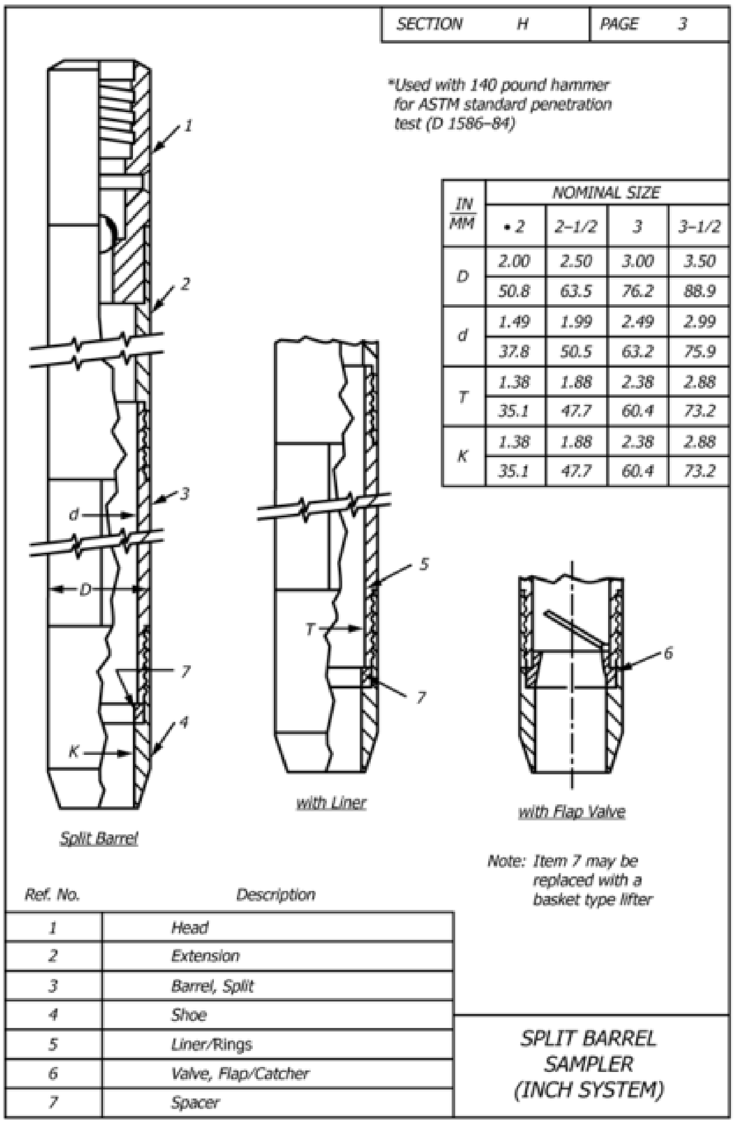
X1.4.4.1 As noted in the standard, manufacturers produce several types of drive shoes used for sampling. Fig. X1.7 shows shoes commonly used and only the sharper shoe to the left is made for sampling fine soils while the thicker, blunter, shoes are used in coarser and denser soils. Thicker shoes are not in conformance with section 5.3. There has been no known controlled study on the effects on *N* values between these different styles of drive shoes.

X1.5 Operational Variables

X1.5.1 *Drilling Methods – Research on SPT and Drilling Methods:*

X1.5.1.1 One of the early reports on drilling methods was Parsons (**24**) where he discovered poor SPT data in sands that were drilled with water below the water table. The results are summarized on Fig. X1.8. Although the drilling methods were not clearly described it was assumed that the low blow counts in sand were caused by the removal of the drill bit and a drop in borehole fluid causing sand to flow into the base of the boring. It is not clear how the casing was used or if they were rotary or wash borings. Check test holes were carefully drilled using auger and drilling mud to clear the test zone which resulted in very high blow counts in the dense sand.

X1.5.1.2 A study of mud rotary, hollow-stem augers, water fluid rotary drilling with driven casing was reported by Whited and Edil in 1986 (**25**). Thirty-six borings in differing geologic conditions in Wisconsin were conducted by transportation drill crews experienced with SPT. Hollow-stem auger borings were advanced with the pilot bit in-place and when below the water table drill fluid (Mud) was injected using a spindle adaptor. The water borings were advanced by driving the casing in 1.5 m increments while cleaning the casing with roller bit and clear water. The conclusions of the study were that the drilling methods had no effect on SPT in clay soils. The driven casing



IN / MM	NOMINAL SIZE			
	• 2	2–1/2	3	3–1/2
D	2.00	2.50	3.00	3.50
	50.8	63.5	76.2	88.9
d	1.49	1.99	2.49	2.99
	37.8	50.5	63.2	75.9
T	1.38	1.88	2.38	2.88
	35.1	47.7	60.4	73.2
K	1.38	1.88	2.38	2.88
	35.1	47.7	60.4	73.2

Ref. No.	Description
1	Head
2	Extension
3	Barrel, Split
4	Shoe
5	Liner/Rings
6	Valve, Flap/Catcher
7	Spacer

FIG. X1.6 DDCMA Split Barrel Design (17)

borings yielded high blow counts above the water table and lower blow counts below the water table in sands. This is due to suspected densification above the water table in sands and the focusing effect of groundwater seepage force at the base of the casing and sand disturbance by water imbalance by removing cleanout tools. The report does not mention if a bypass line is used to add fluid when drilling below the water table. There was some tendency for hollow-stem auger holes to record lower blow counts in sands below the water table. The important finding in this study is that driven casing should be kept away from the test zone.

X1.5.1.3 A study of mud rotary drilling and hollow-stem auger drilling was performed by Seed et al., (**26**) for purposes of investigating USGS blow count case history liquefaction database. The study focused on sands below the water table and all drilling methods use a fluid bypass to maintain the fluid levels at the top of the boring during removal of the cleanout string. Four different sites were investigated comparing 66 SPT drilled with water (in augers or casing) and 147 SPT drilled with drill mud. The results indicated minimal differences in the two drilling methods. On Fig. X1.9 there was a trend of lower *N*-value with Hollow-stem versus mud rotary borings.

X1.5.1.4 These conclusions by Seed et al., (**26**) were worth quoting; "In either case it is clear that borehole fluid type (drilling mud or water) had no significant effect on penetration resistance so long as good drilling and sampling techniques are used, including prevention of hydraulic inflow at the base of the borehole." The purpose of the study was to prove careful hollow stem augering can be used, but the Fluid Rotary Drilling method using drill mud is considered to be the most reliable method and should be used as the reference test.

X1.5.2 *Hollow-Stem Auger Type and Problems in Sands:*

X1.5.2.1 There are two types of Hollow-stem Augers (Practice D6151/D6151M) the "Inner Rod" type and "Wireline" type. Both systems can be operated with a pilot bit or long inside sampling barrel and removal of these tools causes a suction effect in sands below the water table. In order to

Drive samplers usually employ three types of cutting heads, or shoes, shown here. The sharp tapered heads are intended for soil sampling, while the more blunt tips are designed for greater longevity when sampling granular soils.

FIG. X1.7 SPT Drive Shoes for Fine and Coarse-Grained Soils (Rodgers, 2006 (4))

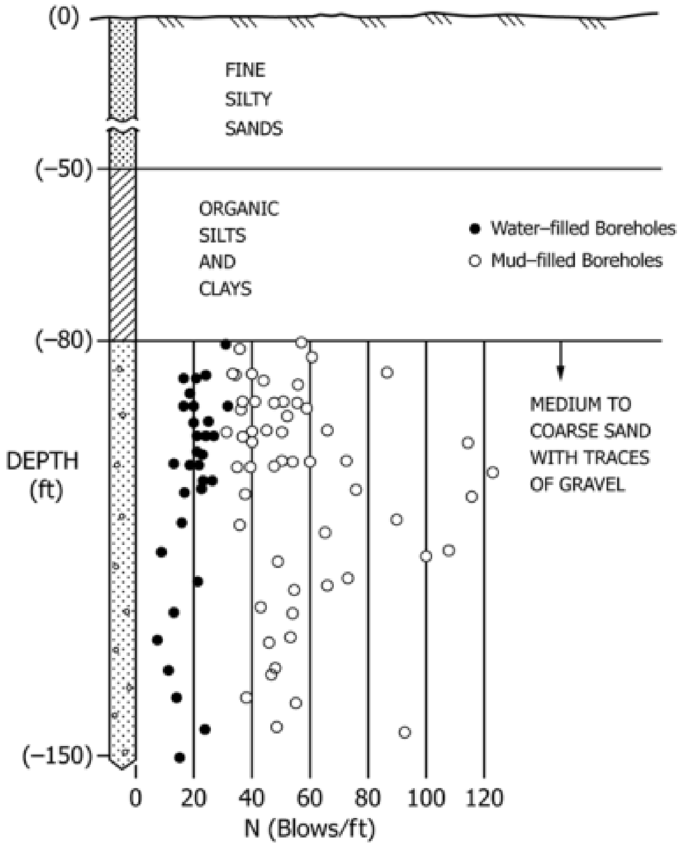


FIG. X1.8 Comparison of SPT Drilled With Water versus Drilling Fluid (Mud) (Parsons (24))

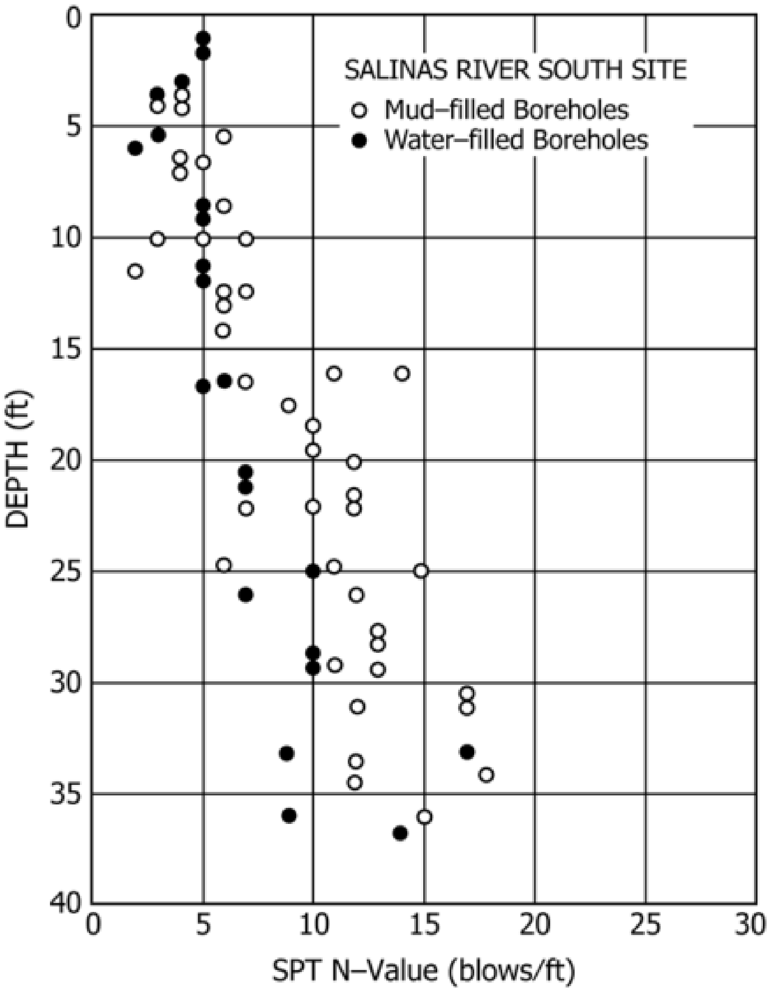
minimize disturbance to the test zone below the water table, the inner tube should be kept full of fluid and the barrel or bit removed slowly to reduce suction effect. The lesser used wireline systems have had many problems with sands below the water table because the bit or barrel is removed rapidly. When this happens and if sand flows into the barrel, it will not be able to re-latch. This may require that the whole auger string be pulled upward to clear the sand inside causing even more suction and disturbance in the bottom of the boring. Hollow-stem augers have also been advanced without an interior pilot bit, however, material may require cleaning if there are soils inside the augers. This can be checked by comparing the bit or barrel depth the SPT sampler depth.

X1.5.3 *Sonic and Direct Push Drilling Methods:*

X1.5.3.1 There is very limited information on comparison of SPT *N*-values from Sonic or Direct Push drilling methods but some studies are underway. One study on Sonic drilling by Wentz et al., (27) shows that there were negligible pore pressure increases in sands as close as 300 mm to casings but comparisons to conventional rotary drilling were inconclusive. A study by Wotherspoon et al., (28) compared numerous Sonic and Direct Push SPT *N*-values to *N* values predicted by CPT methods at a site in Canterbury, N.Z. showed that the drilling methods may be affecting soils with lower *N*-values and that site-specific correlations may be required. This points to a need to check site specific SPT *N*-values from these drilling methods to conventional methods such as the fluid rotary drilling or hollow stem auger drilling.

X1.5.4 *Drill Hole Diameter:*

X1.5.4.1 A Borehole diameter correction was proposed by Skempton (9) for use in liquefaction evaluation. He noted the majority of case history borings were 2.6 to 4 in. [65 to 100 mm] diameter but some borings as large as 8 in. [200 mm] are allowed for SPT. He proposed correction factors of 1.05 and 1.15 for 6 in. [150 mm] and 8 in. [200 mm] diameter borings, respectively. This standard specifies 3 to 6 in. [75 to 150 mm] borehole diameter. He stated that the size effect in clays was



-Data for Salinas River South Site.

FIG. X1.9 Comparison of Mud Rotary versus Hollow-Stem Augers at Salinas Site (Seed et al., (26))

probably negligible but that these correction factors are recommended of liquefaction potential in sands. He noted that there is no research on this topic and it is needed.

X1.6 Notes on Soil Types – Coarse Grained Soils

X1.6.1 *Maximum Particle Size – Research on SPT in Sands:*

X1.6.1.1 The maximum particle size is listed in section 4.3 as ½ the sampler diameter or smaller. Actually, the test is generally applicable to soils containing no gravels, soils with gravels, depending on the percentage will begin to artificially raise the blow count over non-gravel soils, and hence affect geotechnical engineering estimates based on SPT data.

X1.6.1.2 SPT chamber test research has been conducted for clean quartz sands by several agencies and the result were summarized by Jamiolkowski et al., (**29**) in 1988. Numerous field and chamber studies have been performed in an effort to correlate *N* and Relative Density as a function of effective overburden pressure. Actually, the ratio at which particle size begins to elevate blow count at a constant Dr and pressure is approximately 1⁄10 the diameter of the penetrometer or smaller. There were differences in coarse versus fine to medium sands tested by USACE in chambers (**29**). There are also data from field studies with coarser sands. Based on a review of the field and laboratory data, Skempton (**9**) proposed the following modification of Terzaghi's chart in Appendix X2 as follows on Fig. X1.10.

X1.7 Recording Penetration per Blow (PPB) in Gravelly Sands

X1.7.1 As outlined in the EERI publication on soil liquefaction (**16**) the presence of coarse particles in sands can interfere with obtaining usable SPT data for the sand matrix. Some agencies dealing with these soils, record PBB or penetration per 0.1 ft [0.025 m]. The goal is to extrapolate a reliable sand *N*-value as shown on Fig. X1.11(b). This method is only reliable for gravel contents of up to 15 to 20 %. For more information consult the EERI report.

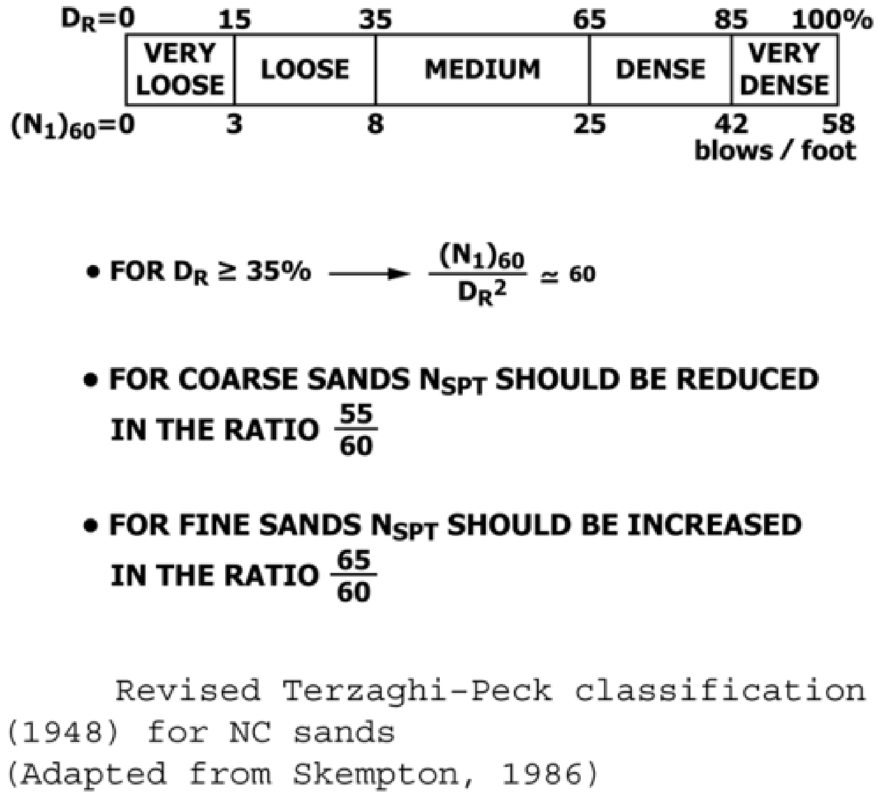
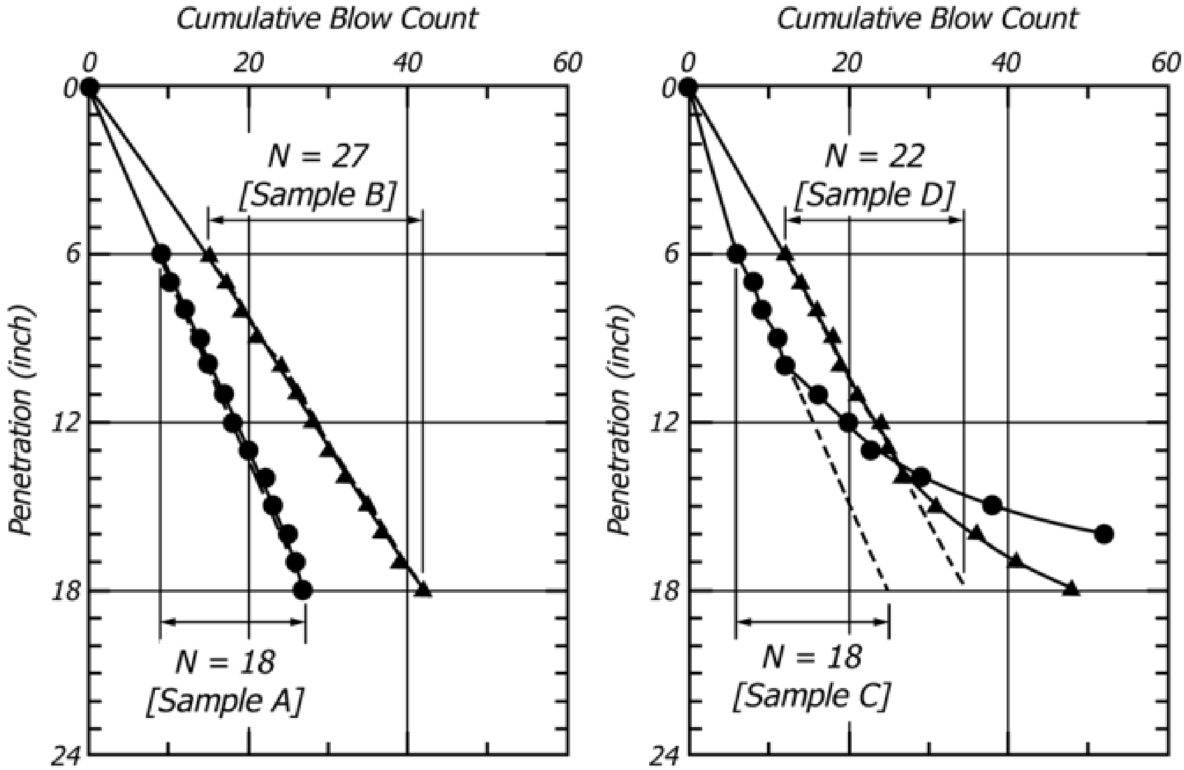


FIG. X1.10 Revised Classification and Estimated Relative Density of Sands Considering Differences Between Coarse and Medium to Fine Sands (Skempton (9))

X1.7.2 Use of automated systems that have laser distance recorders (PileTrac) or system like the new automated eSPT hammers greatly facilitate recording and post processing of data and reduce errors (see 8.3 and Note 5). Recording by hand can be done but requires a third person recorder or hand marking on drill rods which is hazardous. Manual recording must be input into spreadsheets.



Examples of interpreting SPT blow counts on a per-inch basis:
(a) smooth driving patterns that do not require corrections to *N* values and
(b) strong increases in driving resistance that, along with sample recoveries, suggest that the sampler encountered large particles; this graph also shows the adjusted *N* value, based on extrapolating the pre-obstruction driving rate.

FIG. X1.11 EERI Example of Recording Penetration per Blow in Sands (16).

X2. SOIL CONSISTENCY DECRIPTORS

X2.1 The standard uses consistency descriptors in discussion of drilling and sampling of soils. Fig. X2.1 are two tables extracted from Terzaghi and Peck, *Soil Mechanic in Engineering Practice*, second edition, 1967, Wiley & Sons. These two tables provide SPT *N* values from this standard and the corresponding basic soils consistency descriptors for clays and sands.

Relation of Consistency of Clay, Number of Blows N on Sampling Spoon, and Unconfined Compressive Strength

	q_u in tons/ ft^2					
Consistency	Very Soft	Soft	Medium	Stiff	Very Stiff	Hard
N	< 2	2–4	4–8	8–15	15–30	> 30
q_u	< 0.25	0.25–0.50	0.50–1.00	1.00–2.00	2.00–4.00	> 4.00

Relative Density of Sands according to Results of Standard Penetration Test

No. of Blows *N*	Relative Density
0–4	Very loose
4–10	Loose
10–30	Medium
30–50	Dense
Over 50	Very dense

FIG. X2.1 Terzaghi and Peck Descriptors of Soil from SPT *N* Values

X3. EXAMPLE DATA SHEET

X3.1 See Fig. X3.1.

	PENETRATION RESISTANCE DAILY DATA	
PROJECT Example	FEATURE Example	HOLE NO. DH-502
GROUND ELEVATION 6750.5 ft.	LOCATION 200' D/S Sta. 9•50	
FOREMAN	DRILLER	LOGGED BY / DATE
DRILLING METHOD Rotary, NX casing, 3–inch rockbit, Bentonite		

	TEST 1				TEST 2			
CLEANOUT DEPTH	40.3 ft.				43.3 ft.			
SEATING PENETRATION (0.5 ft. maximum)								
DEPTH TO SAMPLER TIP	40.1 ft.				43.2 ft.			
NO. OF BLOWS FOR STANDARD 0.5 ft. SEATING PENETRATION (50 blows max.-)	NO. OF BLOWS			PENETRATION-	NO. OF BLOWS			PENETRATION-
	6			0.5	15			0.5
TEST PENETRATION (1.0 ft. maximum)								
NO. OF BLOWS FOR STANDARD 0.5 ft. SEATING PENETRATION (50 blows max.-)	NO. OF BLOWS			PENETRATION-	NO. OF BLOWS			PENETRATION-
	0.5 - 1.0 ft	1.0 - 1.5 ft	N		0.5 - 1.0 ft	1.0 - 1.5 ft	N	
	8	11	19	1.0	5	50	N/A	0.8
DEPTH TO SAMPLER TIP	41.8 ft.				44.5 ft.			
DRIVE LENGTH (1) / RECOVERY LENGTH (2) / RECOVERY {RECOVERY / DRIVE} (%) (3)	(1) 1.5	(2) 1.2	(3) 80%		(1) 1.3	(2) 0.9	(3) 69%	
VISUAL CLASSIFICATION AND DESCRIPTION OF SAMPLE	POORLY GRADED SAND' About 90% fine sand; about 10% nonplastic fines, moist, grey, organic material; maximum size, medium sand, no reaction with HCL. [SP]				TOP' SP, Same as 40.3–41.8 BOTTOM' SANDY SILT' About 60% low plasticity fines; quick; dilalancy; about 35% fine sand; 5% fine subangular gravel.			
ROLL PHOTO NO.								
MOISTURE SAMPLE	JAR #48				JAR #4C (from ML)			

REMARKS: Test 1' : 0.2 ft. slough prior to test. Only 2 blows for 0.4 ft. penetration in 0.5–1.0 ft. intervals.

TEST 2' : 0.3 ft. slough, drove on coarse gravels or cobbles. Gravels must have fell out. Had to stop test at 0.5 ft. penetration and remark rods.

-IF 50 BLOWS DO NOT YIELD MAXIMUM PENETRATION, RECORD PENETRATION FOR 50 BLOWS AND DISCONTINUE TEST.

DRIVER ________________ (Signature) FOREMAN ________________ (Signature)

FIG. X3.1 Example Data Sheet

REFERENCES

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SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this test method since the last issue, D1586–11, that may impact the use of this test method. (Approved December 1, 2018.)

(1) A major revision was undertaken in 2018. The standard had significant changes to the significance and use and apparatus sections. The major changes were:
(2) Section 4: The section was revised to include important information regarding SPT energy measurements on the test result. Its use in sand and clays was clarified and in soft clay was use has been shown to be problematic.
(3) Section 4: Sampler with or without liners are allowed and the differences are discussed the Appendix.
(4) Section 4: Recommends the use of automatic or trip hammer system but allows other systems.
(5) Sections 4 and 5: Preferred drilling methods are provided but most all methods are allowed based on approval of the user.
(6) Sections 4 and 5: Preferred hammer systems are also given but any hammer system meeting basic requirements can be used. It is strongly recommended that the user determine or know the energy of the hammer system they use and at a minimum the hammer type must be reported.
(7) General: Appendix X1 has been added to give the user more information on the effects of equipment usage and the various drilling methods.