Designation: D6066 – 11

# Standard Practice for Determining the Normalized Penetration Resistance of Sands for Evaluation of Liquefaction Potential[1]

This standard is issued under the fixed designation D6066; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice outlines a procedure to obtain a record of normalized resistance of sands to the penetration of a standard sampler driven by a standard energy for estimating soil liquefaction potential during earthquakes. The normalized penetration resistance determined in this practice may be useful for determination of other engineering properties of sands.

1.2 This practice uses Test Method D1586 with additions and modifications to minimize disturbance of saturated loose cohesionless sands during drilling. This practice combines results of Test Method D1586 and interprets the data for normalization purposes.

1.3 Due to inherent variability of the SPT, guidance is given on test configuration and energy adjustments. Penetration resistance is adjusted for energy delivered in the penetration test. Energy adjustments can be estimated or measured and reported.

1.4 Standard practice for normalizing penetration resistance values is given. Penetration resistance data are normalized to a standard overburden stress level.

1.5 The normalized penetration resistance data may be used to estimate liquefaction resistance of saturated sands from earthquake shaking. Evaluation of liquefaction resistance may be applied to natural ground conditions or foundations for either planned or existing structures.

1.6 Using this practice representative disturbed samples of the soil can be collected for identification purposes.

1.7 This practice is limited to use in cohesionless soils (see Test Method D2487 and classifications of SM, SW, SP, SP-SM, and SW-SM Practice D2488). In most cases, testing is performed in saturated deposits below the water table. In some cases, dry sands may be tested (see 5.4). This practice is not applicable to lithified materials or fine grained soils. Gravel can interfere with the test and result in elevated penetration resistance values. Normalization of penetration resistance values for gravelly soils is beyond the scope of this practice.

1.8 Penetration resistance measurements often will involve safety planning, administration, and documentation. This practice does not purport to address all aspects of exploration and site safety. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* 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] DCDMA safety manual,[3] drilling safety manuals, and other applicable state and local regulations must be observed.

1.9 The values stated in inch-pound units are to be regarded as standard. Within the text, the SI units, are shown in parentheses. The values stated in each system are not equivalents, therefore, each system must be used independently of the other.

1.9.1 In pressure correction calculations, common units are ton/ft$^2$, kg/cm$^2$, atm, and bars. Since these units are approximately equal (within a factor of 1.1), many engineers prefer the use of these units in stress correction calculations. For those using kPa or kN/m$^2$, 100 kPa is approximately equal to one ton/ft$^2$. The stress exponent, $n$, (see 3.3.2) is approximately equal for these units.

1.10 This practice may not be applicable in some countries, states, or localities, where rules or standards may differ for applying penetration resistance to liquefaction estimates. Other practices exist for estimating soil instability from penetration resistance data. Procedures may change with advances in geotechnical engineering. It is dependent on the user in consultation with experienced engineers to select appropriate methods and correction to data. In earthquake engineering studies, many phenomena can affect soil instability. The practice reflects only one current exploration technique and

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[1] This practice 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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[2] Available from OSHA, 1825 K. Street, NW, Washington, DC 20006.

[3] Available from the National Drilling Association, 6089 Frantz Road, Suite 101, Dublin, Ohio 43017.

method for normalizing penetration resistance data to a common level for comparisons to case history information.

1.11 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[4]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D1586 Test Method for Penetration Test (SPT) and Split-Barrel Sampling of Soils

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 Procedure)

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4633 Test Method for Energy Measurement for Dynamic Penetrometers

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

## 3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of terms included in Terminology D653 specific to this practice are:

3.1.2 *effective stress*—the average normal force per unit area transmitted from grain to grain of a soil mass (see 13.4.1).

3.1.3 *equilibrium pore water pressure, $u_o$*—at rest water pressure at depth of interest. Same as hydrostaic pressure (see 13.4.1.1).

3.1.4 *liquefaction*—the process of transforming any soil from a solid state to a liquid state, usually as a result of increased pore pressure and reduced shearing resistance.

3.1.5 *standard penetration resistance, N*—the number of blows of a 140 lbm (63.5 kg) hammer falling 30 in. (76 cm) required to produce 1 f of penetration of a specified (standard) 2-in. outside diameter, 1⅜-in. inside diameter sampler into soil, after an initial 0.5 f seating.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *anvil, n*—that portion of the drive assembly that the hammer strikes and through which the hammer energy is transmitted into the drill rods.

3.2.2 *automatic hammer, n*—a hammer drop system that uses mechanical means to lift and control drop height of the hammer.

3.2.3 *cathead, n*—a spinning sheave or rotating drum around which the operator wraps the rope used to lift and drop the hammer by successively tightening and loosening the rope turns around the drum.

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

3.2.5 *cleanout interval, n*—interval between successive penetration resistance tests from which material must be removed using conventional drilling methods. During the clean-out process, the previous penetration test interval (1.5 ft, 45 cm) is drilled through and additional distance is cleaned to assure minimal disturbance of the next test interval. The term clean out interval in this practice refers to the additional distance past the previous test.

3.2.6 *crown block*—a pulley, set of pulleys, or sheaves at the top of the drill derrick or mast on or over which the hoist or other lines, or both, run.

3.2.7 *cylinder hammer, n*—drive weight assembly consisting of a guide pipe, anvil, jar coupling, and an open cylindrical hammer. Also called a donut or casing hammer.

3.2.8 *downhole hammer, n*—a hammer lowered down the drill hole and attached a short distance above the sampler.

3.2.9 *donut hammer, n*—see cylinder hammer.

3.2.10 *drill rods, n*—rods used to transmit downward and rotary force to the sampler or drill bit.

3.2.11 *drill rod energy ratio, $ER_i$ (see Test Method D4633), n*—measured stress wave energy ratio. The ratio is that of energy measured in drill rods contained in the first compression wave to nominal energy of the drive weight system.

3.2.12 *drive interval, n*—interval from 0.0 to 1.5 ft (45 cm) below the cleanout depth that consists of the 0.5 ft (15 cm) seating and the 1.0 ft (30 cm) test interval.

3.2.13 *drive length, n*—total length of the drive interval penetrated during testing, that is, the measured distance the sampler is actually advanced.

3.2.14 *drive weight assembly, n*—an assembly that consists of the hammer, anvil, hammer fall guide system, drill rod attachment system, and any hammer drop system hoisting attachments.

3.2.15 *hammer, n*—that portion of the drive weight assembly consisting of the 140-lbm impact mass that is lifted successively and dropped to provide the energy that accomplishes the penetration and sampling.

3.2.16 *hammer drop system, n*—that portion of the drive weight assembly by which the operator accomplishes the lifting and dropping of the hammer to produce the blow.

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[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.

3.2.17 *number of rope turns, n*—the number of times a rope is wrapped completely around the cathead. Penetration resistance testing is performed using two nominal rope turns on the cathead. Depending on operator position, direction of cathead rotation, and the angle at which the rope leaves the cathead, the actual number of turns typically varies from 1¾ to 2¼ turns (Fig. 1).

3.2.18 *rope, cathead method, n*—a method of raising and dropping the hammer, which uses a rope strung through a center crown sheave or pulley on the drill mast and turns on a cathead to lift the hammer.

3.2.19 *safety hammer, n*—drive weight assembly consisting of a center guide rod, internal anvil, and hammer that encloses the hammer-anvil contact (Fig. 2).

3.2.20 *seating interval, n*—interval from 0.0 to 0.5-ft (0 to 15 cm) below the cleanout depth.

3.2.21 *test interval, n*—interval from 0.5 to 1.5 ft (15 to 45 cm) below the cleanout depth.

3.2.22 *trip hammers, n*—hammers hoisted by rope-cathead method and mechanically released for a drop without rope attached.

3.2.23 *vertical effective stress, n,* $\sigma'_v$—the average effective force per unit area transmitted from grain to grain of a soil mass normal to the horizontal plane (see 13.4.1 for calculation).

3.3 *Abbreviations:*

3.3.1 *Symbols and Abbreviations:*

3.3.2 *n*—stress exponent in the equation:

$$C_N = (\sigma'_{vref}/\sigma'_v)^n \tag{1}$$

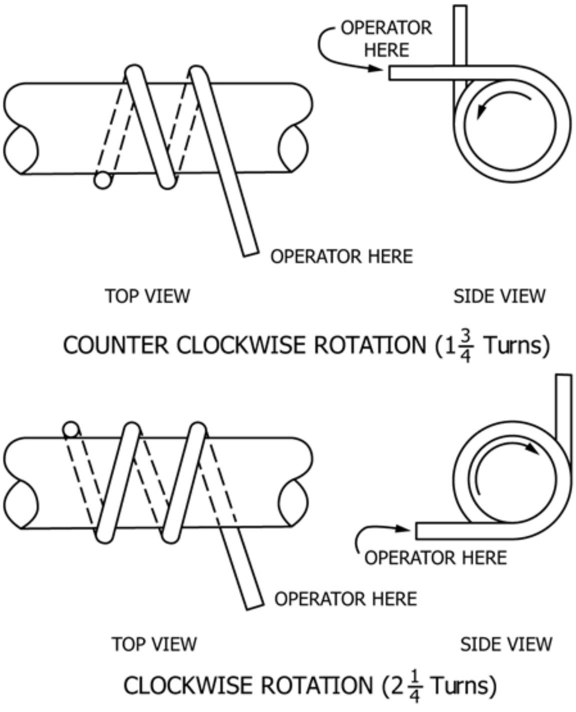

**FIG. 1 Number of Rope Turns on Cathead**

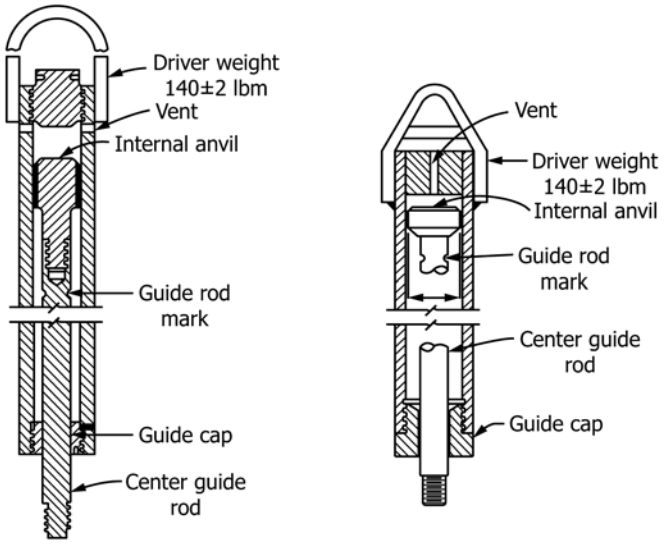

**FIG. 2 Internal Anvil Safety Hammers—Typical Designs**

where:

$\sigma'_{vref}$ = reference stress level,
$\sigma'_v$ = vertical effective stress at test depth,
$\sigma'_{vref}$ = 1 tsf (≈1 $kg_f/cm^2$, ≈ 1 bar, ≈ 1 atm), and
$C_n$ = $1/(\sigma'_v)^n$.

3.3.3 *N* value—the sum of the hammer blows required to drive the sampler over the test interval from 0.5 to 1.5 ft (15 to 45 cm) below the cleanout depth.

3.3.4 $N_{60}$—penetration resistance adjusted to a 60 % drill rod energy ratio (see 13.3.2).

3.3.5 $(N_1)_{60}$—penetration resistance adjusted for energy and stress level.

3.3.6 *SPT*—abbreviation for standard penetration test of penetration resistance testing.

## 4. Summary of Practice

4.1 Drilling is performed with minimal disturbance to advance a boring to the test interval. For loose sand, specific measures and quality checks may be required to assure minimal disturbance. If disturbance is evident, an alternate drilling method may be required.

4.2 After an initial seating drive of 0.5 ft (15 cm), a standard penetration resistance sampler is driven 1.0 ft (30 cm) into soil below the bottom of a drill hole using a 140-lbm hammer, dropped 30 in. (75 cm). Penetration resistance, *N*, is expressed as the number of hammer blows required to drive the sampler the 1.0-ft (30-cm) distance.

4.3 In Method A, the penetration resistance is adjusted to a drill rod energy ratio of 60 %, $N_{60}$, by using hammer systems with an estimated energy delivery. Safety hammers with rope-cathead operation are assumed to deliver approximately 60 % drill rod energy ($Er_i \approx 60$ %). Automatic hammer energy must be documented in previous measurements for a particular make and model, either by the manufacturer or from previous measurements by other entities.

4.4 In Method B, penetration resistance data is adjusted to 60 % drill rod energy ratio through directly measured drill rod stress wave energy using Test Method D4633 or other documented procedures. The adjustment can be made to the *N* value for a particular hammer system or the hammer system may be adjusted to deliver 60 % drill rod energy (see 6.4.2).

NOTE 1—Unless otherwise specified Method B should be used. Additionally, the use of automatic hammers rather than safety hammers with rope-cathead operation is preferable.

4.5 The $N_{60}$ value is normalized to an effective overburden pressure of 1-tsf (≈1 kg/cm$^2$, bar, atm) using overburden pressure correction factors from chamber tests. Typical adjustment factors are given to the user (see 13.4). The user may adjust the factors depending on the nature of the foundation soils, such as, previous stress history, particle size.

## 5. Significance and Use

5.1 Normalization of penetration resistance data is a frequently used method to evaluate the liquefaction susceptibility of sands. A large case history database from many countries has been accumulated to estimate instability of saturated sands during earthquakes (**1**,**2**,**3**,**4**).[5] This test is used extensively for a great variety of geotechnical exploration programs where earthquake induced instability of soil needs to be evaluated. Many widely published correlations and local correlations are available, which relate penetration resistance to the engineering properties of soils and the behavior of earthworks and foundations. The data from different countries with differing drilling techniques have been interpreted to develop a preferred normalization approach. This approach has been termed the $N_1$ method proposed by H. Bolton Seed and his colleagues (**2**,**3**). Evaluation of liquefaction potential is beyond the scope of this practice. Interpretation of normalized penetration resistance values should be performed by qualified personnel familiar with the multitude of factors influencing interpretation of the data. One purpose of this practice is to attempt to develop a more accurate data base of penetration resistance data from future liquefaction case histories. The normalized penetration resistance determined in this practice may be useful for determination of other engineering properties of sands.

5.1.1 This practice is based on field studies of limited depth and chamber testing of limited stress conditions (**1**,**2**,**5**,**6**). The existing data bases also are limited in soil types examined. Drilling equipment and methods vary widely from country to country. The majority of data is obtained using the fluid rotary method of drilling with small drill rods and donut or safety type hammers. Some studies have shown that other drilling methods, such as hollow stem augers can be used to successfully collect penetration resistance data (**7**,**8**). When using alternate drilling methods, however, it is easier to cause disturbance, and potential disturbance must be evaluated carefully. If there is any question regarding disturbance from alternative drilling methods, use of fluid rotary drilling is recommended.

5.1.2 A majority of case history liquefaction data has been collected at shallow depths of less than 50 ft. Stress correction information is limited to 3 to 6 ton/ft$^2$ (3000 to 6000 kPa) range. Knowledge is limited for energy transmission effects with drill rod lengths exceeding 100 to 150 ft (30 to 45 m).

5.1.3 This practice is limited to evaluation of level ground sites. For soils subjected to non-level ground conditions, other correction factors may be required (**3**).

NOTE 2—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.

5.2 This practice is dependent on existing data and the currently accepted practice for measurement of drill rod energy ratio, $ER_i$, Test Method D4633 and of the penetration resistance test, Test Method D1586. The current practice consists of adjusting raw *N* values to a drill rod energy ratio of 60 % (**2**). Recommended practice stresses measurement of the drill rod energy ratio because there often are losses in the impact anvil. This measurement is performed by instrumenting drill rods at the surface. Energy should be obtained by using both force and acceleration measurements for integration of the product of force and velocity.

5.2.1 For many automatic hammer systems, once the drill rod energy ratio is known for the particular design, periodic monitoring of hammer terminal impact velocity (kinetic energy), or drop height (potential energy), may be required to assure proper hammer operation. Most manufacturers can supply energy transmission data for automatic hammers. Kinetic energy or potential energy checks do not provide drill rod energy, $ER_i$, because of losses through the anvil, but they can provide a useful check that the hammer is operating correctly. Velocity checks or drop height checks can be performed using radar or tape extensometers, respectively.

5.2.2 *Method A*—Depends on assumed drill rod energies for hammer systems such as the safety and automatic hammer systems commonly used in North America and other countries (**2**,**9**,**10**). Assumed energy ratios for other hammer systems should be based on previously published measurements. The assumed values should be documented and source data referenced. The hammer system should be operated in the same method as when the documented energy data was collected.

5.2.3 *Method B*—Depends on performance of energy measurements for the system during testing. These measurements may be performed using Test Method D4633 or other methods, such as force-acceleration measurements. The measurement methods, configurations, calibrations, and computations should be documented or reported. It is possible to adjust hammer weight and drop height of the hammer system in place of performing the energy correction. If these adjustments are made, the developed methodology and supporting energy measurements should be reported.

5.3 The correction of $N_{60}$ to a reference stress level is based on a stress correction factor, $C_N$. A typical stress exponent, *n*, used in practice, ranges from 0.45 to 0.6 (**6**,**11**). The stress adjustment factor was developed using chamber testing of clean sands. The adjustments depend on particle size, density,

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

over consolidation and aging (**5**,**12**). Frequently, the soils of concern are young alluvial sand deposits of low density. These factors may not be applicable to sands with fines (SM, SC) or sands with more compressible minerals (mica or calcareous). With the lack of controlled data for these soils, however, current practice is to apply these factors to these soils for preliminary evaluations of soil stability. Other methods for normalizing soil values can be used and are acceptable if the method and reasoning are documented (**5**,**12**).

5.4 Soil liquefaction is most often associated with saturated sands. Most investigations will be performed below the water table. The normalization of penetration resistance also may be applicable to dry sands. In some cases, where future soil saturation is anticipated, testing can be performed in dry sands. If the testing is performed in dry sands, the user should be aware of possible changes in the soil upon saturation. This is especially true with dirty dry sands that may undergo collapse upon saturation. Dry sands are more stable during drilling such that a wider variety of drilling methods are acceptable and many of the drilling precautions in Section 11 may be waived.

5.5 Use of this practice provides a disturbed soil sample for identification and for laboratory testing. The classification information commonly is used to develop site stratigraphy and to identify zones where further, more detailed investigations may be required.

## 6. Apparatus

6.1 *Drilling Equipment*—Open hole fluid rotary drilling methods are recommended for minimizing sand disturbance during drilling. The drilling equipment must provide a power operated cathead and a crown block sheave, or pulley, centered over the borehole, if required by the hammer drop system. A maximum of two crown block sheaves is recommended for rope-cathead method hammer drop systems.

6.1.1 Drag, chopping, and fishtail bits may be used with open hole rotary drilling methods. To avoid soil disturbance, only upward discharge bits are permitted. Baffled fishtail bits are preferred in finer soils.

6.1.2 Roller cone bits may be used with open hole rotary drilling or casing advancement drilling methods if fluid discharge is deflected to avoid disturbing the bottom of the hole.

6.1.3 Hollow stem continuous flight augers, with or without a center plug assembly, may be used to advance the boring.

6.1.4 Rotary casing advancement drilling methods, with or without center plug bit, may be used.

6.1.5 Some drilling equipment and methods are not acceptable for advancing borings in loose sands. Wash boring, cable tool, and casing advancement with down hole hammer drilling methods are not acceptable due to possible disturbance of the test interval. These methods may be used to advance borings close to the test interval but final cleanout should be performed by the approved methods listed above.

6.2 *Drill Rod*—To maintain consistency, drill rod sizes should be limited to a smaller range than allowed in Test Method D1586. Most case history liquefaction data were collected with small drill rod. Flush joint steel AW or AWJ DCDMA drill rods having a mass of 3 to 5 lbm/ft (4.5 to 7.5 kg/m) are typical of drilling rods used in the data base. Use of differing rods is estimated to cause equivalent energy differences of 5 % (**7**,**13**). For depths exceeding 50 ft (15 m), larger rods, such as BW to NW sizes are preferred to avoid rod whipping or buckling. Flush joint BW or NW drill rods may be used in these cases. Other drill rods in these size ranges may be used if the type of rod is documented.

6.3 *Sampler*—The primary concern in sampler design is the inside diameter above the cutting shoe. It is typical practice in the United States to use barrels without liners with 1.5 in. (38 mm) inside diameter. Upset wall barrels aid recovery. A large portion of the empirical liquefaction database was collected in other countries, where the use of constant inside diameter 1.375 in. (35 mm) is practiced. A correction factor may be desired to convert penetration resistance with or without liners to compare to empirical databases (**2**,**10**,**14**). This factor ranges from 10 to 30 % and depends on the penetration resistance of the material. The correction factor is based on limited field data and has not been confirmed in chamber tests. For $N_m$ less than ten, this factor is insignificant and can be ignored. For higher $N_m$, for most cases, ignoring this correction builds in 10 to 30 % conservatism and is acceptable.

6.3.1 The sampler is to conform to the dimensions and materials shown on Fig. 2 of Test Method D1586. A 2-ft (60 cm) barrel length should be used for testing to accommodate slough and cuttings without plugging. Split barrel samplers or solid barrel-split liner samplers may be used. The solid barrel sampler is recommended for use in hard driving conditions if sampler buckling is a problem. The sampler must be made from steel of a type and hardness suitable to resist wear. The driving shoe must be made of hardened steel. Samplers meeting these requirements may not always be available from all manufacturers of drilling equipment.

6.3.2 *Retainers*—Basket traps or other devices for retaining the core may restrict the inside diameter of the sampler and may increase the penetration resistance. There is no information as to the effects of retainers on penetration resistance testing. Thin plastic retainers may have a negligible effect while metal retainers, such as flap valves that constrict the inside diameter may have a significant effect. If retainers are used, report the type of retainer used. If there are questions as to the effect of retainers, the following tests can be performed.

6.3.2.1 Perform a boring with retainers next to the SPT boring without retainers.

6.3.2.2 In each test interval where no recovery occurs after determining the penetration resistance without retainers, reinsert a sampler with retainers and redrive it through the same test interval.

6.3.2.3 If site conditions are uniform enough to allow performing a correlation to determine the effect of retainers, side by side comparisons of penetration resistance with and without retainers can be performed to allow use of retainers for the remainder of the program. Such studies must be performed under the direction of the engineer responsible for the testing program.

6.3.3 Larger diameter split barrel samplers, 3 and 3½-in. (75 and 88 mm) O.D., can be used with and without retainers to recover coarse grained soils. They are not acceptable for determining penetration resistance *N* values. These samplers, equipped with basket traps, may be used for sampler retrieval options listed in 6.3.2.2.

6.3.4 Two drive shoe styles frequently are shown in commercial drill manufacturers catalogs. Only the sharp ASTM drive shoe meeting tolerances shown on Fig. 2 of Test Method D1586 are acceptable for determining penetration resistance *N* value. The other style that is not acceptable typically is described as a blunt Terzaghi shoe.

6.4 *Drive Weight Assemblies*—Acceptable drive weight assemblies are listed below in order of decreasing reliability. The engineer in charge of the investigation should select the hammer system to be used in the field. Preference should be given to standardized hammers with reliable drop systems. The assembly should provide a hammer with mass of 140 lbm ± 2 lbm (63.5 kg ± 1 kg) and can apply blows at a rate of 20 to 40 blows/min. The total assembly mass must not exceed 240 lbm (109 kg). The guide system should incorporate safety features while providing low friction free fall of the hammer. Hammers and anvils must be made of steel of a type and hardness suitable to resist wear and deformation. Impact cushions between hammer and anvil should not be used. Contact surfaces between hammer and anvil must be sufficiently large to prevent yield stresses and resulting deformations. All hammer assemblies must provide for easy visual confirmation of drop height and hammer impact velocity using radar or other instrumentation techniques.

6.4.1 Field monitoring of hammer impact velocity and periodic drill rod energy measurement checks usually are only required on critical jobs, such as large ground improvements and liquefaction studies associated with expensive structures. For routine foundation investigations, visual confirmation of drop heights developed from known operational characteristics is sufficient. Hammer systems that deliver a drill rod energy ratio, $ER_i$, of less than 40 % should not be used.

6.4.2 *Automatic Hammers*—Assemblies with completely mechanical hammer-drop systems provide the best energy reproducibility. The performance of any model of a manufactured unit can be documented using calibration procedures referenced in 5.2. Using known energy transfer characteristics, field performance checks can be made by measuring hammer impact velocity or drop height using radar or tape extensometers. In special cases, the drop height may be varied from the nominal 30 in. (76 cm) to allow for delivery of known drill rod energies, $ER_i$ = 60 %. If drop heights different from nominal are used, data regarding energy transmission, equipment operation and equipment changes should be reported. Requirements for crown block sheaves in 6.1 may be waived for most of these systems. Automatic hammers have many adjustments and maintenance requirements for proper operation. Operations and maintenance guidelines should be provided for the system used. Operators should be trained in the use and adjustment of the system.

6.4.2.1 Most automatic hammer systems have efficient hammer/anvil aspect ratios and small diameter anvils, and thus, are very efficient. These systems have a hammer encased in a guide tube with a mechanism to drop the hammer freely. Most automatic hammers operate up to $ER_i$ = 95 %. Lower energies have been measured, however, with efficient systems due to operator errors (**15**,**16**). For Method A, normalization, it will be necessary to cite previous measurements made for the specific make and model of hammer used. Several systems currently available in the United States have been evaluated. Many manufacturers have calibration data to support these assumptions. If the hammer has unusual design features, such as a large anvil or unusual drop system, the system should be checked using calibration methods cited in 5.2.

6.4.2.2 Some automatic hammers operate at rates faster than rope-cathead hammers. It is desired to apply blows at a rate of 20 to 40 blows/min. The effect of blow count rate on sands is not known. Rate effects are thought to depend on drainage conditions and pore pressure buildup and dissipation during testing. If an automatic hammer is operated at a rate exceeding 40 blows/min, it should be clearly reported.

6.4.2.3 *Spooling Winch Systems*—Some automatic hammer systems use a wireline spooling winch to lift and drop the hammer. The winch is triggered either automatically or manually to reverse direction at a speed close to the hammer fall velocity. Measurements of these systems indicate a wide variability in delivered energy (**16**). These hammers only can be used in Method B, where energy of the system has been measured.

6.4.3 *Trip Hammers*—Assemblies that provide for rope lifting, or other hoisting mechanism, and a mechanical trip are economical and have energy reproducibility approaching that of automatic hammers. The performance of any model of a manufactured unit must be documented using calibration procedures referenced in 5.2. As stated in 6.4.2, field performance can be monitored with hammer impact velocity measurements and drop height checks and can be varied from the nominal 30 in. (76 cm) to adjust to a target energy, that is, $ER_i$ = 60 %. Trip hammers have many adjustments and maintenance requirements for proper operation. Trip hammer energy normally is rate dependent and the hammer should be operated at the same speed as those where calibrations have been performed. Operations and maintenance guidelines should be provided for the system used. Operators should be trained in the use and adjustment of the system. Adjustments and maintenance must be routinely performed to assure proper operation.

6.4.3.1 It is not possible to provide an assumed energy value under Method A for trip hammers. For use of Method A, normalization, energy measurements must be obtained and documented for the system used. There is published information on some hammer systems, such as the Pilcon or Dando hammers (**2**,**17**). Particular attention should be made to assure that the appropriate make and model hammer and anvil is documented as transmission characteristics can change as design changes are made.

6.4.4 *Internal Anvil Safety Hammers*—Typical internal anvil safety hammer designs are shown on Fig. 2. The assembly consists of a hammer that encloses an internal anvil. The hammer is operated using the rope-cathead drop system. The assembly must allow for an upward stroke of more than 30 in. (76 cm) to prevent back tapping the sampler during testing. A 30-in. (76-cm) drop height mark must be maintained on the guide rod to allow a reference for attaining an accurate drop. Drop height should be within 1 in. (25 mm) of the 30-in. (76 cm) nominal value. The impact anvil must be made of solid steel and be rigidly connected to a solid or hollow guide rod of at least AW size. The guide rod must be attached rigidly to the drilling rods. Jointed connections between the guide and drill rod without threads are not acceptable.

6.4.4.1 Internal anvil safety hammers have been measured extensively for energy transmission (**9**). Energy transmission can vary depending on design, but due to inherent geometry restrictions, the hammers usually only vary by 10 to 15 % $ER_i$. For this practice, using Method A, safety hammers are assumed to deliver an $ER_i = 60$ % when using the rope-cathead method with two wraps as shown on Fig. 1. Some researchers have suggested that the average energy for a safety hammer is higher, from 10–15 % of normalization value, that is, $Er_i = 70$ to 75 %. Some researchers suspect that safety hammers with solid steel guide rods may have lower energy transmission efficiency. If there are questions as to performance of the hammer system, then the hammer system can be measured for more accurate corrections.

NOTE 3—Use of the rope and cathead method with the safety hammer assembly will result in variation in *N* values, even in an apparently uniform material. Some of this variation is due to natural ground variability. If all precautions and procedures in this practice are followed, it is anticipated that *N* values can vary by approximately 10 % from operator variability alone.

6.4.5 *Cylinder Weight Hammers*—Cylinder weight (donut) type hammers operated by rope and cathead drop system are not recommended for use in penetration resistance testing unless their dimensions are standardized and energy transmission has been documented. Standardization should include both the hammer and anvil dimensions. Larger striking anvils reduce energy transmission to the rods. Some donut type hammers with larger anvils have energy transmissions of 40 to 50 % while ones with smaller anvils can reach 70 %. Donut hammers may have poor efficiency and are less desirable due to safety hazard aspects. They also suffer from the same variation possible with safety hammers because they are operated by the rope-cathead method.

6.4.5.1 It is not possible to provide an assumed energy value for donut type hammers in Method A, normalization, because their energy transmission varies so widely with design. For use of Method A, normalization, previous energy measurements must be obtained and documented for the system used. There is published information on some hammer systems such as the Japanese Industrial Standard (**10**). Many hammers vary in design, however, and it is recommended that the actual hammer used have energy measurements determined and documented.

6.4.6 *Down Hole Hammers*—Down-hole hammer systems are not approved for use in penetration resistance testing under this test designation. The kinetic energy of the hammer may not reach nominal values if the drop is slowed by water or air friction effects in the drill hole. Input energy content of the first wave pulse is prematurely terminated by reflected waves with short drill rod lengths (**18**).

6.5 *Rope*—The hoist rope should be a ¾ to 1 in. (20 to 25 mm) diameter manila rope, sized to fit the crown sheaves. It should be stiff, dry, and clean, and should be replaced when it becomes excessively frayed, oily, limp, or burned.

6.6 *Cathead*—The cathead should have a diameter ranging 6 to 10 in. (15 to 25 cm) and should be capable of rotating at more than 100 revolutions/min. The friction surface must be clean and free of paint, rust, oil, grease, or other contaminants.

## 7. Interferences and Technical Precautions

7.1 The rope-cathead procedure is both operator and mechanical system dependent. The measured penetration resistance of soil is dependent on the energy delivered to the sampler. Since both operator performance and equipment condition can affect the test, any deviation from standards should be noted.

7.2 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 should be performed to avoid friction buildup and to check the hammer and assembly mass.

7.3 Drop height adjustments for automatic and trip hammers should be checked daily and at first indication of variation in performance. Operation of automatic hammers shall be in strict accordance with operations manuals.

7.4 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 worn, dented, or distorted.

7.5 Soil deposits containing gravel, cobbles, or boulders typically result in penetration refusal and damage to the equipment.

7.6 Plugging of the vent ports and ball check system of the sampler results in unreliable penetration resistance values. Instances of vent port plugging must be noted on daily data sheets and reported in the boring log.

7.7 Drilling disturbance of the 1.5-ft (45-cm) drive interval results in unreliable penetration resistance values.

7.8 Drilling fluids may be required for testing (see 11.2.1).

7.9 Under adverse weather conditions, such as high winds, heavy rain, or snow, the results of penetration resistance testing using the rope and cathead method may be affected due to a change in rope-cathead friction. This effect should be evaluated in the field, and testing should cease if significant changes are evident.

7.10 Penetration testing should not be performed continuously in a borehole. The minimum recommended cleanout interval is 1.0 ft (30 cm) (see 3.2.5). If the cleanout interval is reduced to less than 1.0 ft (30 cm), pay special attention to maintain drill hole quality. Carefully note and compare cleanout depths to depths at beginning of sampling as described in Sections 11 and 12.

## 8. Sampling, Test Specimens, and Test Units

8.1 Frequently, samples are required for laboratory soil classifications. Care must be taken to reduce contamination. The mass of the sample obtained for testing should be sufficient to ensure representative specimens (see Method D2216 and Classification D2487). Typically, the complete recovered sample will be required for laboratory soil classification to ensure representative specimens. If sample mass is smaller than recommended in the procedures, it should be noted on the drilling logs. If several distinct soil layers are mixed for laboratory soil classification, a visual description (Practice D2488) of each layer must be included in the boring log.

8.2 Determination of water content as specified in Test Method D1586 is not necessary for sampling of sands. This is because sands experience volume change during testing and often water drains from the sample during retrieval. Water content of fine grained soils retrieved during sampling may be performed in accordance with Test Methods D1586 and D2216.

## 9. Preparation of Apparatus

9.1 *Drilling Equipment:*

9.1.1 Lubricate crown block sheaves as necessary for testing with trip hammers and rope-cathead operated hammers.

9.1.2 Replace cathead rope as required in 6.5 for testing performed by rope and cathead method.

9.1.3 Maintain hydraulic system if required for performance of automatic hammer testing.

9.1.4 If the cathead is rusty, prepolish it, using a wire brush.

9.2 *Penetration Resistance Apparatus:*

9.2.1 Check drive weight assembly for compliance with requirements in 6.4. Lubricate and clean the guide as required to minimize friction. Check drop height.

9.2.2 Clean sampler ball check, vent ports, and check condition of the driving shoe before each test.

## 10. Calibration and Standardization

10.1 Energy delivered to the drill rod can be measured according to procedures in Test Method D4633 or other methods listed in 5.2. Energy measurements are not required for safety hammers unless these measurements are required on critical programs. Often, on smaller investigations, use of assumed energy transmission is sufficient. In some cases, periodic hammer impact velocity or drop height checks can be performed to confirm the hammer is performing correctly.

10.2 For automatic, trip and donut hammers, it is necessary to have documented energy transmission data for the make and model used or to perform measurements during the investigation. Measurements are required for individual models of manufactured automatic and trip hammers. Before field use, operation adjustment requirements and allowable range of hammer impact velocities and drop heights can be specified. Under recommended operations, adjustments, and maintenance, the automatic and trip drive weight assemblies should provide a drill rod energy ratio which varies less than 10 % of the mean drill rod energy delivered.

## 11. Hole Preparation Procedures

11.1 *Hole Preparation Procedure, General:*

11.1.1 Penetration resistance testing is typically performed at 5-ft (1.5-m) intervals or when a significant change of materials is observed during drilling, unless otherwise specified.

11.1.2 The cleanout depth is measured to the nearest 0.1 ft (0.3 cm) and recorded on the "Penetration Resistance Daily Data Sheet" form (example shown on Fig. 3).

11.1.3 The minimum interval required for a complete penetration resistance test is 2.5 ft (75 cm) with a 1.5-ft (45-cm) drive interval and 1.0-ft (30-cm) cleanout interval. At such close intervals, special attention to drilling methods is required to avoid disturbance. Penetration tests should not be performed continuously with no cleanout interval because of possible disturbance from the previous test.

11.1.4 The hole diameter should be from 3 to 5 in. (75 to 125 mm) (use inner diameter for hollow stem augers). It is recommended that penetration resistance testing and large diameter sampling not be performed in the same drill hole.

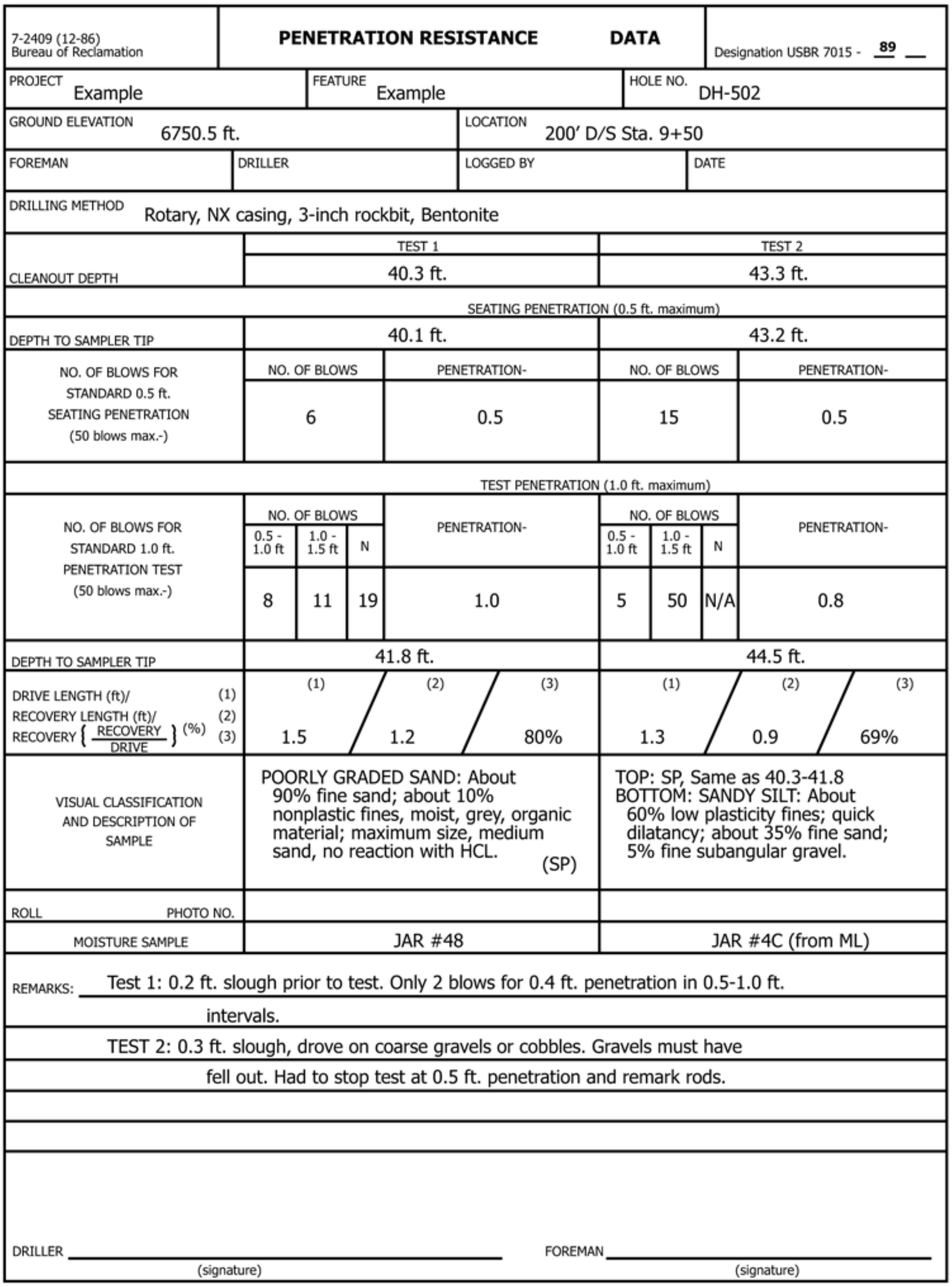
11.1.5 If an obstruction, such as coarse gravel, cobbles, boulders, debris, or a lithified layer is encountered, it should be noted and can be removed by drilling through the interval of the obstruction. Do not use the sampler as a chopping bit. If disturbance below the obstructions is anticipated, it should be noted. Sometimes, the boring may need to be abandoned.

11.1.6 Rotary drilling using drilling fluid has proven to provide the most reliable penetration resistance test data in loose sands as long as procedures in 11.2 are followed. Other drilling methods, such as hollow stem augers or rotary casing advancers, may be used provided that disturbance is not evident. Use of these alternate methods requires considerably more care. If there is any question regarding disturbance from other alternate methods, use of fluid rotary drilling is recommended. Disturbance from a given method can sometimes be evaluated by studying the penetration of successive increments of the sampler, especially the penetration rate of the seating interval **(14)**.

11.1.7 Use of a bypass system normally is required to maintain fluid levels for fluid rotary and fluid hollow stem drilling operations (see 11.2 and 11.3). The bypass line and shutoff valve are connected to a fluid circulation manifold inserted between the pump and water swivel. When withdrawing the cleanout drill string, fluid is added to maintain hydrostatic balance.

11.1.8 *Disturbance Checks/Quality Control*—Disturbance checks can be made after interval cleanout (11.2.7, 11.3.3) and upon reinsertion of the sampler (12.3) to evaluate test interval disturbance. Quality checks will assist in evaluating sand heaving and excessive jetting disturbances. The sample barrel normally will settle through most loose slough and cuttings and possibly into jetted or fractured materials. If the sampler or drill bit checks indicate heave, the zone below the drill string is likely to be disturbed and this occurrence must be reduced prior to testing. If the sampler or drill string settle to a depth in excess of that previously drilled, jetting, or fracturing disturbance is possible. If sharp cutting bits, such as the fishtail or wireline pilot bits, are used, the depth checks in 11.2.7 and

USBR



| | | |
|---|---|---|
| 7-2409 (12-86)<br>Bureau of Reclamation | **PENETRATION RESISTANCE DATA** | Designation USBR 7015 - 89 |

| | | |
|---|---|---|
| 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)

| | TEST 1 | | TEST 2 | |
|---|---|---|---|---|
| DEPTH TO SAMPLER TIP | 40.1 ft. | | 43.2 ft. | |
| | NO. OF BLOWS | PENETRATION- | NO. OF BLOWS | PENETRATION- |
| NO. OF BLOWS FOR STANDARD 0.5 ft. SEATING PENETRATION (50 blows max.-) | 6 | 0.5 | 15 | 0.5 |

TEST PENETRATION (1.0 ft. maximum)

| | 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 | |
| NO. OF BLOWS FOR STANDARD 1.0 ft. PENETRATION TEST (50 blows max.-) | 8 | 11 | 19 | 1.0 | 5 | 50 | N/A | 0.8 |

| | TEST 1 | | | TEST 2 | | |
|---|---|---|---|---|---|---|
| DEPTH TO SAMPLER TIP | 41.8 ft. | | | 44.5 ft. | | |
| | (1) | (2) | (3) | (1) | (2) | (3) |
| DRIVE LENGTH (ft)/ (1)<br>RECOVERY LENGTH (ft)/ (2)<br>RECOVERY $\left\{\frac{\text{RECOVERY}}{\text{DRIVE}}\right\}$ (%) (3) | 1.5 | 1.2 | 80% | 1.3 | 0.9 | 69% |

| | TEST 1 | TEST 2 |
|---|---|---|
| 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<br>BOTTOM: SANDY SILT: About 60% low plasticity fines; quick dilatancy; 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.

DRILLER ______________________ (signature)    FOREMAN ______________________ (signature)

**FIG. 3 Penetration Resistance Daily Data—Example**

11.3.3 may not be possible. Further evaluation of disturbance may be possible by evaluation of incremental penetration, especially that of the seating interval (**14**).

11.1.9 Some drilling equipment and methods are not acceptable for advancing borings in loose sands. Wash boring, cable tool, and casing advancement with down hole hammer drilling methods are not acceptable due to possible disturbance of the test interval. Solid stem continuous augers will not be successful in loose sand below the water table and can be used for unsaturated soils testing only. These methods may be used to advance borings close to the test interval, but final cleanout should be performed by approved methods listed above. The process of jetting through an open tube sampler and then sampling with the penetration sampler when the desired depth is reached is not permitted.

11.2 *Rotary Drilling With Drilling Fluids:*

11.2.1 *Drill Fluid*—The use of drilling mud is required. In some cases, the use of water can be successful if hydrostatic balance is maintained and heave or sanding in is not evident (**7**).

11.2.1.1 The use of air and air-foam is unacceptable for these studies.

11.2.1.2 Because of a large number of suppliers, varying grades of drill fluid products, and varying requirements of each project providing an exact procedure for design and mixing of drill fluids is impossible. For more information on specific drill fluids, consult with local manufacturers' or suppliers' representatives. Acceptable drilling fluids may be identified by the engineer responsible for the investigation. Drilling additives in contact with drinking water aquifers should meet the requirements of NSF Standard 60-1988.

NOTE 4—In some areas, certain types of drill fluid products are not allowed by state and local environmental authorities. Before using any drill fluid product, check with the authorities to determine its acceptability.

11.2.2 *Casing*—Use of a drilling fluid is preferred over casing the drill hole. If casing is required, care must be exercised when driving the casing to avoid disturbance to the test interval. Casing should be kept as far above the test interval as possible through proper use of drill fluids. Casing should not be driven to the bottom of the hole or test interval disturbance may occur. If casing is required to closely follow the drilling, attempt to maintain it at the previous test interval (2.5 ft above the cleanout depth). Keep detailed casing records.

NOTE 5—Use of casing near the testing interval increases the potential for heaving if fluid level is not maintained within the casing during removal of the clean out drill string and bit. This is because the hydraulic imbalance is focused at the base of the drill hole. If the fluid level drops below existing water table elevation, seepage gradients focused at the base of the hole will cause sand to heave. It is imperative in these situations to withdraw the drill string and bit slowly using a vented swivel hoisting plug while maintaining drill fluid level at the top of the drill hole.

11.2.3 *Fluid Levels*—The drilling fluid level within the borehole must be maintained at or above the in situ piezometric water level at all times during drilling, removal of drill rods, and sampling. Maintenance of the fluid level at ground surface is recommended as this provides the maximum beneficial effect and provides a constant and easily observable fluid level. When drilling in unstable soils at close testing intervals, it also is necessary to be careful to maintain fluid levels during extraction of the drill rods and sampler. The drill bit or sampler and rods should be withdrawn slowly using a vented swivel hoisting plug while maintaining the fluid level in the borehole by using a bypass line from the pumps.

11.2.4 *Drill Bits*—The fishtail bit is the best bit for drilling in sands. The fishtail bit should be equipped with baffles which direct fluid uphole. When harder or coarser layers must be penetrated, rock bits or other drag bits can be used, but there is a potential increase in jetting damage.

11.2.5 Record any loss of circulation of drilling fluid as an indication of possible voids in the soil or very high permeability layers. Also, record any increases in circulation as an indication of possible layers with artesian water pressure.

11.2.6 Record fluid circulation rates and any occurrence of excessive bit pressures.

11.2.7 *Cleanout Depth Check*—Cleanout depth is to be determined to the nearest 0.1 ft (3 cm). After removal of cuttings, slightly raise the drill bit and rods and cut off fluid circulation. After several minutes have elapsed, lower the drill bit and rods to check cleanout depth. If the thickness of cuttings, cave or heave exceeds 0.4 ft (10 cm), it is considered excessive and penetration resistance testing may be unreliable. The basis for 0.4 ft (12 cm) is arbitrary and not substantiated by data. One must consider the amount of settled material and possible plugging of the bit or vent ports. This depth check may not be possible for fishtail bits. It may be possible that more slough can be accepted depending on the barrel design and nature of the material. If there is excessive cuttings, cave, or heave present in the drill hole, continue circulation to remove this material and recheck the drill hole depth. While circulating, advance the drill bit to the previous cleanout depth. After removal of cuttings, slightly raise the drill bit and rods and cut off fluid circulation. After several minutes have elapsed, lower the drill bit and rods to check cleanout depth again. If excessive cuttings, cave, or heave are still present, clean out again. On the second try, advance the bit deeper than the previous cleanout interval and observe drill action. If there is little resistance then it is possible that heave has occurred and the test interval is disturbed. Take measures to avoid heave, such as thickening mud or use of casing and cleanout to a deeper past the disturbance. Continue this process until undisturbed material is present with an acceptable level of slough, cuttings, or cave. Record all drilling observations on the daily data sheet and the boring log. Record the cleanout depth on the daily data sheet as the depth that the drilling bit initially reached and not when resting on the thickness of cuttings.

11.2.8 Withdraw the cleanout drill string and bit slowly using a vented swivel hoisting plug to avoid rapid change in fluid levels within the borehole.

11.2.9 Proceed to Section 12 and perform the penetration test. If the depth at which the sampler rests does not meet criteria for excessive cuttings, cave, or heave given in 12.3, additional hole preparation will be required. Take measures to stabilize the boring and repeat cleanout and cleanout depth checks as outlined in 11.2.7. Some sand layers under extreme artesian pressures may be difficult to stabilize. In these cases it may be necessary to try a new drilling method or attempt a different, minimal intrusion test, such as the cone penetrometer (see Test Method D5778).

11.3 *Hollow Stem Auger Methods:*

11.3.1 Hollow stem augers may be advanced with or without the pilot bit assembly. Without the pilot bit, the hollow stem must be cleaned out using other drilling methods. Drilling below the water table without a pilot bit is sometimes used in extremely unstable soils to provide a protective casing. For the instance of no pilot bit below water table, rotary drilling shall be performed to clean soil inside the hollow stem according to 11.2 and Note 5.

11.3.2 Special precautions are required for use of auger systems in saturated sands. In all cases in soft or loose deposits, slowing the feed rate of the augers is necessary as the test interval is approached. When using hollow stem augers in saturated sands, the hollow stem must be filled with drilling fluid or water. Keep a complete record of water added and any circulation gains or losses. If a pilot bit is used, fluid level must be maintained with a bypass during bit withdraw. Some pilot bit assemblies create suction when pulled through the bottom bushing. Venting of the pilot bit bushing assembly, lead auger, or the bit itself, may aid in reducing heave. After the test interval is reached, it may be necessary to raise the hollow stem augers slightly and suspend the augers with a fork to prevent downward pressure on the test interval.

11.3.2.1 Hollow stem auger cutter heads transmit shearing stresses to the bottom of the drill hole and possibly could disturb the test interval, especially if cuttings are not efficiently removed and excessive down feed pressures are used. High blow counts in the seating interval may be evidence of sand compaction below the augers. Hollow stem auger blow counts should be evaluated carefully for possible disturbance effects. If there are any questions as to disturbance, fluid rotary drilling methods can be performed.

11.3.3 Slowly remove the pilot bit. If the pilot bit is connected to drill rods, withdraw the bit a few feet (1 m), wait a few minutes, then place the base of the pilot bit at the base of the hole. Record and compare the cleanout depth and depth at which the bit rests after this waiting period. If the thickness of slough is considered excessive and penetration resistance testing may be unreliable, the interval must be abandoned and additional measures or alternate drilling methods may be necessary. For wireline operated pilot bits, no cleanout check is possible.

11.3.4 If excessive cuttings, cave, or heave are present, redrill to a deeper test interval and observe drill action. If there is little resistance then it is possible that heave has occurred and the test interval is disturbed. Take measures to avoid heave, such as thickening mud and cleanout to drill past the disturbance. Continue this process until undisturbed material is present with less than 0.4 ft (10 cm) of cuttings, cave, or heave is present. Record all drilling observations on the Daily Data Sheet and the boring log.

11.3.5 If disturbance and heave are persistent, it may be necessary to raise and suspend the hollow stem augers from 4 to 6 in. (10 to 15 cm) above the cleanout depth and to use rotary drilling with drill fluids for clearing the final 4 to 6 in. (10 to 15 cm) of the hole. Rotary drilling shall be performed as described in 11.2 and Note 5.

11.3.6 Proceed to Section 12 and perform the penetration test. If the depth at which the sampler rests does not meet criteria for excessive cuttings, cave, or heave given in 12.3, additional hole preparation will be required. Take measures to stabilize the boring and repeat cleanout and cleanout depth checks as outlined in 11.3.3.

11.4 *Rotary Casing Advancer Method:*

11.4.1 The rotary casing advancer can be advanced with or without a plug bit. The advantage to the rotary casing advancer method is that the fluid remains in the casing during pilot bit removal, and thus, reduces heave. The disadvantage is that jetting disturbance is more likely. In soil deposits the casing bit is equipped with oversize carbide drag bit inserts to over cut the hole. These bits aid in developing annulus circulation. For BX-sized rotary casing advancers without pilot bit, often the interior of the drill rod does not require secondary cleaning. Use of a pilot is recommended if depth checks called for in 12.3 indicate excessive cuttings or heave are present.

11.4.2 The rotary casing advancer circulates drill fluid uphole between the borehole wall and casing. Both water or drill mud can be used as circulating media. Drill mud is preferred and may be required if there are circulation losses. Special care should be taken to maintain circulation and avoid hydraulic fracturing of the test interval. A pressure gage is required on the discharge line of the fluid pump to monitor fluid pressures. Hydraulic fracturing can occur if feed rate exceeds ability to remove cuttings and will be evident by a temporary rise in pump pressure. If fracturing is evident, penetration resistance samples should be inspected closely for disturbance. Disturbed zones also can be evaluated from drill action. Circulation must be maintained during advancement. Circulation rates and any losses or gains must be reported on daily drill report and drill log.

11.4.3 Remove the plug bit with the wireline. Proceed to Section 12 and perform the penetration test. If the depth at which the sampler rests does not meet criteria for excessive cuttings, cave, or heave given in 12.3, additional hole preparation will be required. If the sampler rests below the clean out depth, jetting disturbance is possible. Take measures to stabilize the boring and minimize disturbance and repeat cleanout depth checks as outlined in 12.3.

## 12. Procedure for Determining Penetration Resistance

12.1 All data are to be recorded on the Penetration Resistance Data Sheet form as in the example shown on Fig. 3 or on a similar form.

12.2 With the sampler attached to the drill rods, and with each rod joint securely tightened, slowly lower the sampler to the bottom of the hole. Do not drop the sampler and rods onto the soil to be sampled.

12.2.1 If energy measurements are to be made using Method B, attach measurement devices to the drill rods or hammer. These instruments should not interfere with proper conduct of the tests, that is, impede the height or rate of hammer drop.

12.3 Determine and record the depth to the nearest 0.1 ft (3 cm) at which the sampler tip rests. Compute and record the thickness of slough. If excessive slough, or cave greater than or equal to 0.4 ft (15 cm) is encountered at the bottom of the drill hole, remove the sampler and reclean the hole. The total amount of cuttings and slough should not exceed 0.4 ft (15 cm) (see 11.2.7 for cuttings). If the sampler rests at a depth below the cleanout interval, drilling disturbance from jetting or fracturing is possible. In this case, drilling should be continued through the disturbed zone and measures should be taken to reduce disturbance. Disturbance can be evaluated further by evaluation of incremental penetration (see 11.1.8).

12.4 Attach the hammer assembly securely to the drill rods. Using light hammer blows, advance the sampler through slough, cave, or cuttings to the cleanout depth that is the beginning of the 1.5-ft (45-cm) drive interval.

12.5 Mark the drill rods in three successive 0.5-ft (15-cm) increments so the advance of the sampler under the impact of the hammer can be observed easily for each 0.5-ft (15-cm) increment.

12.6 *Driving Sampler, General*—The drill rods and assembly must be maintained in the vertical position during testing.

Care must be exercised to maintain a proper drop height and uniform hammer blow rate during testing.

12.6.1 *Automatic and Trip Hammers*—Drive the sampler through the drive interval using operation guidelines specific to the hammer system. See operational guidelines as required in 6.4.2 and 6.4.3.

12.6.2 *Safety Hammers*—Drive the sampler through the drive interval with blows from the 140-lbm (63.5-kg) hammer falling 30 in. (76 cm), using the rope-cathead method with two nominal rope turns on the cathead. The operator should use approximately 1-¾ to 2-¼ rope turns on the cathead depending on whether the rope comes off the top or bottom of the cathead (Fig. 1). The rope is thrown into, but not completely off, the cathead to reduce rope friction. Apply hammer blows at a rate of 20 to 40 blows/min. Care must be exercised in obtaining accurate 30-in. (76-cm) drops during the test, as variations directly affect penetration resistance.

12.6.3 *Energy Measurements*—If energy measurements are made during testing, they should not delay conduct of the hammer blows. Measurement data should be reported and any delays in testing noted. The best practice is to sample a distribution of blows during the test, especially for hammer systems having wider blow to blow variation, such as rope and cathead methods.

12.7 Count the number of blows applied in each of the 0.5-ft (15-cm) increments, and stop the test when one of the following occurs (common metric practice is to record the test in centimeters, cm, in 15 cm increments):

12.7.1 A total of 50 blows has been applied during any of the three 0.5-ft (15-cm) drive increments.

12.7.2 A total of 100 blows has been applied.

12.7.3 There is no observed advance of the sampler during application of ten successive hammer blows.

12.7.4 The sampler is advanced the complete 1.5 ft (45 cm) without limiting blow counts as described in 12.7.1, 12.7.2, or 12.7.3.

12.8 If the sampler penetrates part of the 1.5-ft (45-cm) drive interval under the static mass of the rods or the rods and hammer assembly, record the penetration distance on the data form (Fig. 3). Drive the sampler through the remainder of the 1.5-ft (45-cm) drive interval using the procedure in 12.6.

12.9 If the sampler penetrates the complete 1.5-ft (45-cm) drive interval under the static mass of the rods or the rods and hammer assembly, stop penetration after 1.5 ft (45 cm) and attempt to retrieve the sample. If the sampler penetrates greater than the 1.5 ft (45 cm) drive interval before it is stopped, record complete penetration reached and maintain 1.0 ft (30 cm) cleanout between drive intervals.

12.10 Record the number of hammer blows for each 0.5 ft (15 cm) of penetration or penetration per blow as provided for in 12.10.1. The first 0.5 ft (15 cm) is the seating interval. The sum of the number of blows to penetrate the test interval is termed the penetration resistance or *N* value. If the sampler is driven less than 1.5 ft (45 cm) (as permitted in 12.7.2, and 12.7.3), the number of blows to penetrate each complete 0.5-ft (15-cm) increment or each partial increment is to be recorded. Determine partial penetration to the nearest 0.1 ft (3 cm) and record along with the appropriate number of blows. Note any irregularities in penetration. For example, if, within a 0.5-ft (15-cm) interval, only two blows result in 0.4-ft (12-cm) penetration but six additional blows are required to drive the remaining 0.1 ft (3 cm), the variation should be noted and recorded. Record the drive length as the sum of the distances penetrated in the seating and test intervals.

12.10.1 When performing penetration resistance testing for liquefaction potential evaluation in gravelly alluvium, the number of blows/0.1-ft (3-cm) of penetration or penetration per blow can be recorded. The purpose is to obtain extrapolated sand *N* values so the influence of gravel on the *N* value can be evaluated. This interpretation may provide insight as to sand layer resistance but is often unreliable due to plugging of the sampler with gravel. In addition, if penetration per blow is monitored, it should be performed with a rapid recording device, such that the rate of testing can still be performed at 20 to 40 blows/min.

12.11 To remove the sampler, apply two rotations to the drill rods to shear the soil at the bottom of the sampler. The hammer can be used to back tap the drill string to free the sampler, if necessary. Withdraw the drill strings slowly and detach the sampler from the drill rods. Rapid withdraw may result in a vacuum being developed at the tip of the sampler, with resulting complete or partial loss of the sample.

12.12 Determine and record recovery length of the sample to the nearest 0.1 ft (3 cm). Do not include slough and cuttings in the recovery length. Calculate and record percent recovery.

12.13 Calculate and record the *N* value. Calculate the *N* value only if penetration of the complete 1.0-ft (30-cm) test interval was achieved.

12.14 Perform a visual classification and description of the soil(s) obtained from the sampler according to Practice D2488 and record. If the sample mass is insufficient for a representative classification, the sample still is to be classified and this fact noted on the data form.

12.15 *Laboratory Classifications*—If required, classifications will be performed in accordance with Classification D2487. If the sample mass is insufficient for representative classification, this fact should be noted on the data form and drill log. Indicate location of samples under the remarks section on the data form.

12.16 Preserve the remaining sample to retard moisture loss and mark the sample container with the following information, or as specified by the project engineer:

12.16.1 Sample number,
12.16.2 Date,
12.16.3 Depth,
12.16.4 Drill hole number,
12.16.5 Location,
12.16.6 Project, and
12.16.7 Feature.
12.16.8 Protect the sample from breakage. Note the presence of slough or contamination in retained samples.

12.17 *Groundwater Information*—For holes drilled with bentonite mud, groundwater information is of questionable reliability; however, it should be monitored. Monitor groundwater levels before and after removal of protective casings or augers. Obtain groundwater levels at times suitable for the material encountered during drilling and after hole completion or as specified by the project engineer. Groundwater elevations should be measured daily and recorded on data forms. Where possible, a sufficient number of holes should be left open and vented caps provided to allow observations to be made over a period of days. In clean coarse-grained soils, shorter monitoring times may yield stabilized groundwater information, while in fine-grained soils longer times, 24 h or greater, may be required. If groundwater is not encountered or if the level is of doubtful reliability, such information also should be reported. Note if hole caving or closure occurs during observations.

12.17.1 Determination of hydrostatic water pressure (3.1.3 and 13.4) in the test interval may depend on many factors. Borehole information alone may not provide accurate information, especially if protective casings mask perched water table effects.

12.18 *Hole Completion*—Methods and details of hole completion should be recorded and reported on drilling logs.

## 13. Calculations

13.1 Calculate the *N* value (standard penetration resistance) using the following expression:

$$N_m = \text{No. of blows from 0.5 to 1.0 ft } (15 \text{ to } 30 \text{ cm}) \quad (2)$$

$$+ \text{No. of blows from 1.0 to 1.5 ft } (30 \text{ to } 45 \text{ cm})$$

13.1.1 The $N_m$ value is calculated only if penetration was achieved for the complete 1.0-ft (30 cm) test interval. Do not extrapolate $N_m$ values from tests with partial penetration. Instead, report the number of blows and distance penetrated.

13.2 Calculate percent recovery.

$$\text{Percent recovery} = 100 \times [\text{recovered sample} \quad (3)$$

$$\text{length , in. (cm) /drive length , in. (cm)}]$$

where 100 converts to percent.

13.3 *Energy Adjustments:*

13.3.1 Adjustment of raw *N* value for shallow depth. Experience with SPT energy measurements shows that at shallow depths, the energy input in the first stress wave is canceled prematurely by a reflected tensile wave **(18)**. This may result in higher *N* values near the surface, especially for depths of less than 10 ft. For *N* values obtained at depths of less than 10 ft, it is common practice to multiply the raw values by a factor of 0.75 to reduce the *N* value.

13.3.2 *Determination of $N_{60}$ Value*—Penetration Resistance normalized to 60 % drill rod energy ratio. Correct the raw *N* value to an equivalent rod energy ratio of 60 %, $N_{60}$, by the following equation:

$$N_{60} = N_m \times (ER_i/60) \quad (4)$$

where:

$N_m$ = measured *N* value, and
$ER_i$ = drill rod energy ratio, expressed as a percent, for the system used.

13.3.2.1 The selection of $ER_i$ depends on an assumed value if using Method A or a measured value if using Method B.

13.3.3 *Method A, Assumed System Performance*—If energy measurements are not obtained onsite as part of the investigation, an assumed value is used to calculate $N_{60}$. For safety hammers, a value of $ER_i = 60\ \%$ is often used. Cite testing references for hammers, which have been previously tested. Report the make and model of hammer used, the assumed value of $ER_I$, and documented energy measurement reports for the hammer system. Do not assume energy values for unusual undocumented systems. Trip hammers and donut hammers often do not have known energy transmission. If an assumed value is used, the user should assure the same mechanical system was used and that it was operated correctly.

13.3.4 *Method B, Measured System Performance*—If the specific hammer used in the investigation has been energy tested either onsite or before or after testing, report the drill rod energy ratio, $ER_I$, for the hammer system. Report previous calibration trials and any specific operations considerations. Report any field performance measurements and methods for applying the energy data to the $N_m$ values.

13.4 *Determination of $(N_1)_{60}$ Value*—In this practice, penetration resistance normalized to a 1 ton/ft$^2$ stress level. Calculate the $(N_1)_{60}$ value as follows:

$$(N_1)_{60} = C_N \times N_{60} \quad (5)$$

where:

$C_N$ = is the stress correction factor:

$$C_N = (\sigma'_{\text{vref}}/\sigma'_{\text{v}})^n \quad (6)$$

where:

$\sigma'_{\text{vref}}$ = reference stress level,
$\sigma'_{\text{v}}$ = vertical effective stress at test depth, and
$n$ = stress exponent (see 13.4.2).

For $\sigma'_{\text{vref}} = 1$ tsf ($\approx \text{kg}_f/\text{cm}^2{}_1 \approx$ bar, $\approx$ atm)

$$C_N = (1/\sigma'_{\text{v}})^n \quad (7)$$

For $n = 0.5$,

$$C_n = (1/\sigma'_{\text{v}})^{-0.5} = \sqrt{(1/\sigma'_{\text{v}})} = \quad (8)$$

For stress units in kPa and for $n = 0.5$ as simplified for tsf stress units **(11)**:

$$C_N = 9.8 \sqrt{(1/\sigma_{\text{v}})} \quad (9)$$

13.4.1 *Vertical Effective Stress, $\sigma'_v$, (tsf, kPa, kg/cm$^2$, bar, atm)*—The vertical effective stress is calculated by knowledge of hydrostatic pressures (3.1.2) and total stresses in the deposit. The vertical effective stress is the difference between total vertical stress and hydrostatic pressure.

$$\sigma'_{\text{v}} = \sigma_{\text{v}} - u_0$$

where:

$\sigma_{\text{v}}$ = $\sum h_{\text{us}} \times \Upsilon_{\text{wet or sat}}.$

And:

$\Upsilon_{\text{wet or sat}}.$ = The wet or saturated unit weight of the soil above the test zone.

13.4.1.1 The equilibrium water pressure can be estimated by calculation as follows:

$$u_0 = \text{estimated equilibrium water pressure} = h_i \times Y_{water} \quad (10)$$

where:

$h_i$ = height of water, ft (m), estimated from site conditions, and

$Y_{water}$ = unit weight of water = (62.4 lb/ft$^3$), (9.8 kN/m$^3$).

NOTE 6—For soil deposits under salt water the unit weight of water is 64.0 lb/ft$^3$, (10 kN/m$^3$).

13.4.1.2 In layered soils, with multiple perched aquifers, the assumption of a single height of water table may be in error. Often borehole water level data may be unreliable for estimation of water pressures in the test zone. Additionally, accurate piezometric data from independent measurements may be required for accurate determination of equilibrium pore water pressure.

13.4.1.3 For subsurface conditions with a single aquifer the effective stress is the summation of total stresses above the water table plus the summation of buoyant stresses below the water table:

$$\sigma'_v = \sum h_{us} \times Y_{wet} + \sum h_s \times (Y_{sat} - Y_{water}) \quad (11)$$

where:

$h_{us}$ = thickness of individual layers above the water table,

$Y_{wet}$ = wet unit weight of soil of the layers above the water table,

$h_s$ = thickness of saturated soil deposits below the water table,

$Y_{sat}$ = saturated unit weight of soil layers, and

$Y_{water}$ = unit weight of water (62.4 lb/ft$^3$, 1 gm/cm$^3$ (9.8 kn/m$^3$)).

13.4.1.4 Determination of vertical effective stress requires detailed knowledge of site conditions. Under perched or artesian aquifer conditions, it may be difficult to estimate water pressures. Borehole water level information may not provide accurate water pressure information (see 12.17, 12.17.1). In certain geologic conditions, such as cemented zones, overlying normally consolidated zones, the total stresses may be difficult to estimate. Estimation of vertical effective stress requires experienced engineering judgement.

13.4.2 *Stress Exponent, n*—The exponent is derived from chamber testing and depends on cavity expansion theory. The exponent varies with density, particle size, over consolidation ratio, and aging of the soil (**5**,**6**,**11**,**12**). Also, boundary effects are not accounted for among the chamber tests. Typical values for normally consolidated clean sands used in practice today range from 0.45 to 0.6. Examination of chamber penetration tests indicates that the exponent is lower in dense sands (as low as 0.4) (**12**). The typical value used in practice is $n = 0.5$ or the square root of effective vertical overburden pressure (**11**). Limited evidence from penetration in dirty (fines > 15 %) or compressible sands, suggests the exponent increases toward 1.0 as less drainage occurs during penetration such that selection of 0.6 or 0.7 may be appropriate for those soils. Fig. 4 (**19**) shows several trends in the $C_N$ factor suggested by several investigators. Note that the $C_N$ factor can reach very large values at shallow depth. Some investigators have recommended limiting the $C_N$ values to about 1.6 at very shallow depths.

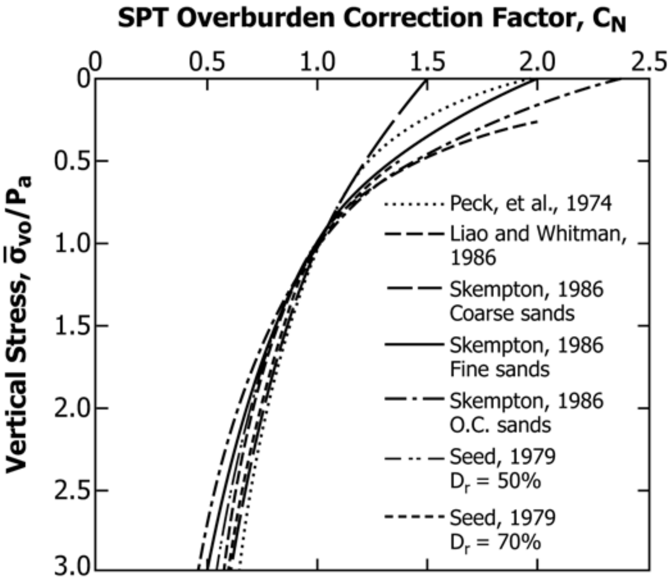


**FIG. 4 $C_N$ Factors by Various Investigations (20)**

13.4.3 Alternately, the $C_N$ factor can take other forms such as those proposed by Skempton (**5**,**11**). The user is reminded that the $C_N$ factor is a function of many variables such as particle size, density, stress history, and aging. Report the method of correction and the reasoning for varying applications.

## 14. Report

14.1 *Penetration Data Sheet*—A data sheet should be maintained as testing progresses. An example of a daily data sheet is shown on Fig. 3. The form allows for detailed notes for each individual test. The following information can be collected on the data sheet or as specified by the project engineer:

14.1.1 Project,
14.1.2 Feature,
14.1.3 Drill hole number,
14.1.4 Location-station, offset or coordinates and reference,
14.1.5 Ground elevation-note if surveyed or estimated,
14.1.6 Date,
14.1.7 Driller,
14.1.8 Foreman,
14.1.9 Logger,
14.1.10 Drilling methods,
14.1.11 Cleanout depth,
14.1.12 Depth to sampler tip,
14.1.13 Thickness of slough,
14.1.14 Number of blows in seating interval,
14.1.15 Number of blows for each of two 0.5-ft (15-cm) components of the test interval,
14.1.16 Partial penetration, blows/0.1-ft (3-cm) penetration, if required, replaces 14.1.14 and 14.1.15 above, that is, 50/0.3 ft,
14.1.17 Depth to sampler tip at end of drive,
14.1.18 Percent recovery,
14.1.19 Visual classification in abbreviated form,
14.1.20 Sample identification numbers, and

14.1.21 Remarks, notes regarding unusual occurrences, such as uneven penetration, delays in testing, variations in hammer performance, hole drilling difficulties, etc.

14.2 *Report/Drilling Log*—The report should include information recommended under Guide D5434 and identified as necessary and pertinent to the needs of the exploration program. Information normally is required for the project, exploration type, and execution, drilling equipment and methods, subsurface conditions encountered, groundwater conditions, sampling events, and installations. Other information besides that mentioned in Guide D5434 should be considered if deemed appropriate and necessary to the needs of the exploration program. Additional information should be considered as follows:

14.2.1 *Site Conditions:*

14.2.1.1 *Site Description,* description of the site and any unusual circumstances.

14.2.1.2 *Personnel,* documentation of all personnel at the site during the drilling process; driller, helpers, geologist or logger, engineer, and other monitors or visitors.

14.2.1.3 Weather conditions during drilling.

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

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

14.2.2 *Drilling Methods:*

14.2.2.1 Include description of the hammer system including make, model, type, anvil type, serial number, dimensions, and operation rate. Drill rig equipment including sampling barrels, liners, retainers, fluid pump, fluid circulation and discharge systems. Note intervals of equipment change or drilling method changes and reasons for change.

14.2.2.2 *Hammer Operation and Energy Measurements*—Report the energy values recorded during testing or the assumed values with their basis. Report locations of energy testing and the values obtained. If Method A is used, report the assumed value on the drilling log. Report the method of operating the hammer system. Report hammer adjustments and performance checks. If Method B is used, the report should conform to the requirements outlined in Test Method D4633.

14.2.2.3 Include descriptions of circulation rates, cuttings returns, including quantities, over intervals used. Note quantity and locations of loss of circulation and probable cause.

14.2.2.4 Include descriptions of drilling conditions related to drilling pressures, rotation rates, and general ease of drilling related to subsurface materials encountered.

14.2.2.5 Use drill rods.

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

14.2.4 *Graphic and Tabular Data*—Often it is useful to include graphic data on the boring logs or reports. Depth scale should be labeled clearly. Some of the data that may be advantageous to display include:

14.2.4.1 $N$ or $(N_1)_{60}$ value, graphic.

14.2.4.2 $N$ or $(N_1)_{60}$ value, tabular.

14.2.4.3 *Recovery,* tabular.

14.2.4.4 *Lithographic Log,* graphic, shows soil and rock types encountered.

14.2.4.5 *Sample Interval,* graphic, shows sampling intervals for spatial distribution of testing.

14.2.4.6 *Unified Soil Classification Symbol,* tabular.

14.2.4.7 *Classification and Description of Materials*—Both geologic and soil classification information should be reported on the drill log. Unified soil classification information should be presented in accordance with Classification D2487 or Practice D2488, or both. Material from the cleanout intervals between testing should be classified in general with the classification basis presented.

14.3 *Report/Written*—A written report should be generated that summarizes the results of the investigation. The report should include all assumptions and methodology for calculating and reporting the normalized penetration resistance data (Section 13). All assumptions or measurements regarding adjustment of penetration resistance values should be reported. Report all energy measurements and hammer impact velocity or drop height checks data taken during the investigation.

14.3.1 Examples of assumptions to report include:

14.3.1.1 Unit weights of soil deposits,

14.3.1.2 Effective stresses,

14.3.1.3 $n$ exponent for application of $Cn$, and

14.3.1.4 Energy measurements (Method B) or assumed energy values (Method A).

## 15. Keywords

15.1 earthquakes; liquefaction; penetration resistance; standard penetration test

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