Designation: D 6066 – 96$^{\epsilon 1}$

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

This standard is issued under the fixed designation D 6066; 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.

ϵ^1 NOTE—Paragraph 1.11 was added editorially October 1998.

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 D 1586 with additions and modifications to minimize disturbance of saturated loose cohesionless sands during drilling. This practice combines results of Test Method D 1586 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 D 2487 and classifications of SM, SW, SP, SP-SM, and SW-SM Practice D 2488). 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 3.3.1) 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 method for normalizing penetration resistance data to a common level for comparisons to case history information.

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

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

[3] Available from the Drilling Equipment Manufacturers Association, 3008 Millwood Avenue, Columbia, SC 29205.

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:*

D 653 Terminology Relating to Soil, Rock and Contained Fluids[4]

D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils[4]

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[4]

D 2487 Classification of Soils for Engineering Purposes Unified Soil Classification System[4]

D 2488 Practice for Description and Identification of Soils (Visual Manual Procedure)[4]

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing or Inspection of Soil and Rock, or both, as Used in Engineering Design and Construction[4]

D 4633 Test Method for Stress Wave Energy Measurement for Dynamic Penetrometer Testing Systems[4]

D 5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock[4]

D 5778 Performing Electronic Friction Cone and Piezocone Penetration Testing of Soil[5]

3. Terminology

3.1 *Definitions*—Definitions of terms included in Terminology D 653 specific to this practice are:

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

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

3.1.3 *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.

3.1.4 *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 D 4633), *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.

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).

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[4] *Annual Book of ASTM Standards*, Vol 04.08.

[5] *Annual Book of ASTM Standards*, Vol 04.09.

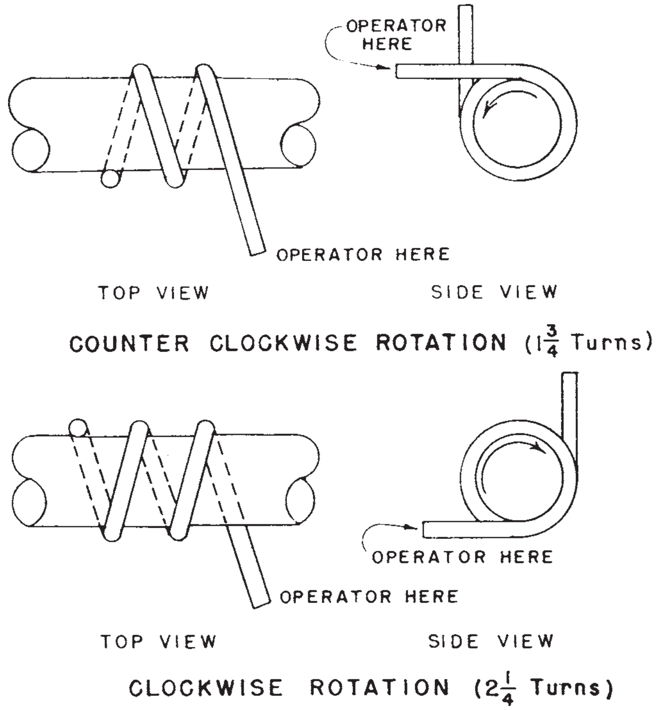

FIG. 1 Number of Rope Turns on Cathead

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.

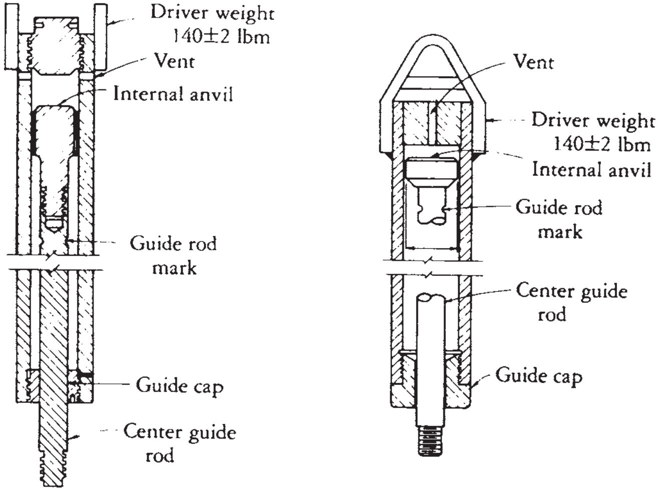

FIG. 2 Internal Anvil Safety Hammers—Typical Designs

3.2.23 *vertical effective stress, n,* σ'_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:Symbols and Abbreviations:*

3.3.1 *n*—stress exponent in the equation:

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

where:

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

3.3.2 *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.

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

3.3.4 $(N_1)_{60}$—penetration resistance adjusted for energy and stress level.

3.3.5 *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 D 4633 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).

4.5 The N_{60} value is normalized to an effective overburden pressure of 1-tsf ($\approx$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**).[6] 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 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 D 3740 generally are considered capable of competent testing. Users of this practice are cautioned that compliance with Practice D 3740 does not assure reliable testing. Reliable testing depends on several factors and Practice D 3740 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 D 4633 and of the penetration resistance test, Test Method D 1586. 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. There is some disagreement by practitioners on methods for determining energy (**9-15**). Drill rod energy can be determined by use of force transducers, or strain gages on the drill rods, below the hammer, for integration of the square of force (see Test Method D 4633). Energy also can be obtained by using both force and acceleration measurements for integration of the product of force and velocity. Reliable force and velocity data will exhibit correct proportionality throughout the time history of the impact event.

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 (**2,10,11**). 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 D 4633 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 (**6,16**). The stress adjustment factor was developed using chamber testing of clean sands. The adjustments depend on particle size, density, over consolidation and aging (**5,17**). 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 (**5,17**).

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

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 D 1586. 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 % (**7,18**). 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 (**2,11,19**). 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 D 1586. 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 D 1586 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 (**14**,**15**). 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 (**15**). 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**,**13**). 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 (**10**). Energy transmission