Designation: D3441 – 16

Standard Test Method for Mechanical Cone Penetration Testing of Soils[1]

This standard is issued under the fixed designation D3441; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

1. Scope*

1.1 This test method covers the procedure for determining the point resistance during penetration of a conical-shaped penetrometer as it is advanced into subsurface soils at a steady rate.

1.2 This test method may also used to determine the frictional resistance of a cylindrical sleeve located behind the conical point as it is advanced through subsurface soils at a steady rate.

1.3 This test method applies to mechanical-type penetrometers. Field tests using penetrometers of electronic type are covered elsewhere by Test Method D5778.

1.4 Cone penetration test data can be used to interpret subsurface stratigraphy, and through use of site specific correlations, they can provide data on engineering properties of soils intended for use in design and construction of earthworks and foundations for structures.

1.5 Mechanical penetrometers of the type described in this test method operate either continually (in which cone penetration resistance is measured while cone and push rods are moving continuously until stopped for the addition of a push rod) or discontinuously (in which cone penetration resistance and, optionally, sleeve friction are measured during a penetration stop of the push rods) using an inner rod system and a penetrometer tip (that must be telescoping in case of discontinuous operation).

1.6 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes shall not be considered as requirements of the standard. The illustrations included in this standard are intended only for explanatory or advisory use.

1.7 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this test method.

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

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

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

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

D5778 Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils

D6026 Practice for Using Significant Digits in Geotechnical Data

3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of 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] 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.

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

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cone tip, n*—the conical point of a cone penetrometer on which the end bearing component of penetration resistance is developed. The cone has a 60° apex angle, a diameter of 35.7 mm, and a corresponding projected (horizontal plane) surface area or cone base area of 1000 mm^2.

3.2.2 *cone penetrometer, n*—a penetrometer in which the leading end of the penetrometer tip is a conical point designed for penetrating soil and for measuring the end-bearing component of penetration resistance.

3.2.3 *cone resistance, q_c, n*—the measured end-bearing component of penetration resistance.

3.2.3.1 *Discussion*—The resistance to penetration developed on the cone is equal to the vertical force applied to the cone divided by the cone base area. Cone resistance may vary from cone resistance measured by the electronic cone test (Test Method D5778) (see 4.4.1).

3.2.4 *cone penetration test (CPT), n*—a series of penetration readings performed at one location over the entire vertical depth when using a cone penetrometer. Also referred to as a cone sounding.

3.2.5 *friction cone penetrometer, n*—cone penetrometer with the capability of measuring the friction component of penetration resistance.

3.2.6 *friction ratio, R_f, n*—the ratio of friction sleeve resistance to cone resistance, f_s / q_c, expressed as a percentage.

3.2.6.1 *Discussion*—The friction ratio for mechanical penetrometers is not comparable to the friction ratio measured by electronic or electrical penetrometer (Test Method D5778) (see 4.4.1).

3.2.7 *friction sleeve resistance, f_s, n*—the friction component of penetration resistance developed on a friction sleeve, equal to the shear force applied to the friction sleeve divided by its surface area.

3.2.8 *friction sleeve, n*—an isolated section on a penetrometer tip upon which the friction component of penetration resistance develops.

3.2.9 *friction reducer, n*—a narrow local protuberance on the outside of the push rod surface, placed above the penetrometer tip, that is provided to reduce the total side friction on the push rods and allow for greater penetration depths for a given push capacity.

3.2.10 *inner rods, n*—rods that slide inside the push rods to extend the telescoping penetrometer tip and friction sleeve (when so equipped) of a mechanical penetrometer.

3.2.11 *mechanical penetrometer, n*—a penetrometer that uses a set of inner rods to operate a telescoping penetrometer tip and to transmit the component(s) of penetration resistance to the surface for measurement.

3.2.12 *penetrometer, n*—an apparatus consisting of a series of cylindrical push rods with a terminal body (end section), called the penetrometer tip, and measuring devices for determination of the components of penetration resistance.

3.2.13 *penetrometer tip, n*—the end section of the penetrometer, which comprises the cone tip, and in the case of the friction-cone penetrometer, the friction sleeve.

3.2.14 *push rods, n*—the thick-walled tubes used to advance the penetrometer tip.

4. Significance and Use

4.1 Tests performed using this test method provide a detailed record of cone resistance that is useful for evaluation of site stratigraphy, homogeneity and depth to firm layers, voids or cavities, and other discontinuities. The use of a friction sleeve can provide an estimate of soil classification, and correlations with engineering properties of soils. When properly performed at suitable sites, the test provides a rapid means for determining subsurface conditions.

4.2 This test method provides data used for estimating engineering properties of soil intended to help with the design and construction of earthworks, the foundations for structures, and the behavior of soils under static and dynamic loads.

4.3 This method tests the soil in-situ and soil samples are not obtained. The interpretation of the results from this test method provides estimates of the types of soil penetrated. Engineers may obtain soil samples from parallel borings for correlation purposes, but prior information or experience may preclude the need for borings.

4.4 Electronic cone data (D5778) is generally more reliable and reproducible. Mechanical cone equipment may prove useful when penetrating strong or rocky soils that might damage electronic cone equipment. Mechanical cone equipment typically requires less operator expertise to operate and to properly maintain than electronic cone equipment. However, mechanical cone equipment is not recommended for liquefaction investigations or investigations where a high level of quality assurance must be obtained.

4.4.1 Cone test data from the mechanical cone (D3441) are generally comparable with the electronic cone (D5778) but there are differences because of the geometry of the cone and friction sleeve sections. Users of these test data are cautioned that engineering correlations from electronic cones should not be used for these mechanical cones. Users should verify that the application of empirical correlations such as those predicting soil types from R_f are for the correct penetrometer.[3]

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides means of evaluating some of these factors.

5. Interferences

5.1 The use of penetrometer components that do not meet required tolerances or show visible signs of non-symmetric wear can result in erroneous penetration resistance data.

[3] De Ruiter, J., "Electric Penetrometer for Site Investigations," *Journal of the Soil Mechanics and Foundation Division*, Vol. 97, No. 2, February 1971, pp 457-472.

5.2 Push rods not meeting requirements of 6.3 may result in excessive directional penetrometer drift and possibly unreliable penetration resistance values.

5.3 Soil particles and corrosion can increase the friction between inner rods and push rods, possibly resulting in significant errors in the measurement of the resistance component(s). Clean and lubricate the inner rods.

5.4 If a mantle of reduced diameter is attached above the cone (as described in 6.1.2) for the purpose of reducing friction in the mantle above the cone tip, a small but unknown amount of side friction may develop along this mantle and will be included in the cone resistance.

5.5 If the proper rate of advance of the penetrometer is not maintained for the entire stroke and through the measurement intervals, penetration resistance data will be erroneous.

5.6 To avoid drilling disturbance effects, a cone sounding shall not be performed any closer than 25 borehole diameters to an unfilled or uncased borehole.

5.7 When performing cone penetration testing in a prebored hole, estimate the depth of drilling disturbance below the open hole and note the penetration resistance data obtained in this zone. The depth of disturbance is typically assumed to be equal to at least three borehole diameters, but depends on drilling technique and stratigraphy.

5.8 Significant bending of the push rods can influence penetration resistance data. The use of a rod guide is recommended at the base of the thrust machine and also in prebored holes to help prevent push rod bending.

5.9 Passing through or alongside obstructions may deflect the penetrometer and induce directional drift. Note any indications of obstructions, such as buried logs or boulders, and be alert for subsequent improper penetrometer tip operation.

5.10 Refusal, deflection, or damage to the penetrometer may occur in coarse grained soil deposits with maximum particle sizes that approach or exceed the diameter of the cone. Partially lithified and lithified deposits may also cause refusal, deflection, or damage to the penetrometer.

5.11 Especially in soft soils the thrust resistance should be corrected to include the accumulated weight of the inner rods from the penetrometer tip to the topmost rod.

6. Apparatus

6.1 *Mechanical Penetrometers:*

6.1.1 The sliding mechanism necessary in a mechanical penetrometer tip must allow a downward movement of the cone in relation to the push rods of at least 35 mm.

NOTE 2—For certain combinations of depth and tip resistance(s), the elastic compression of the inner rods may exceed the downward stroke that the thrust machine can apply to the inner rods relative to the push rods. In this case, the tip will not extend and the thrust readings will rise elastically to the end of the machine stroke and then jump abruptly when the thrust machine makes contact with the push rods. In such cases the inner rods should be extended.

6.1.2 The mechanical penetrometer tip design shall include protection against soil entering the sliding mechanism and affecting the resistance component(s). Fig. 1 shows the design and action of one mechanical cone penetrometer tip where a mantle of reduced diameter is attached above the cone to minimize possible soil contamination of the sliding mechanism.

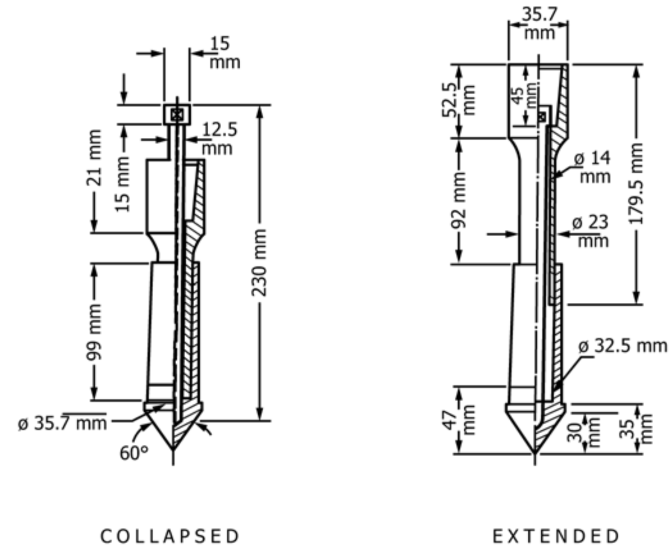


FIG. 1 Example of a Mechanical Cone Penetrometer Tip (Dutch Mantle Cone)

6.1.3 *Friction Cone Penetrometer*—Fig. 2 shows the design and action of one telescoping mechanical friction cone penetrometer tip. The lower part of the tip, including a mantle to which the cone attaches, advances first until the flange engages the friction sleeve and then both advance.

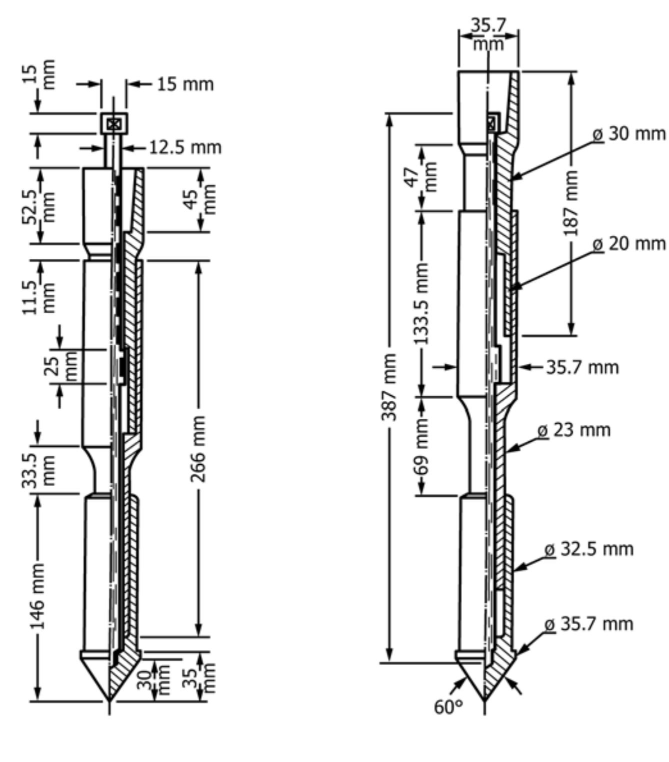


FIG. 2 Example of a Mechanical Friction-Cone Penetrometer Tip (Begemann Friction-Cone)

NOTE 3—The shoulder at the lower end of the friction sleeve encounters end-bearing resistance. In sand, as much as two thirds of the sleeve resistance may consist of bearing on this shoulder. Ignore this effect in soft to medium clays.

6.2 *Cone tip and Friction Sleeve:*

6.2.1 *Cone Tip*—The cone tip shall have 60°(±5°) point angle and a base diameter d_c between 35.3 and 36 mm, resulting in a projected area of approximately 1,000 mm^2. The point of the cone tip shall have a radius less than or equal to 3 mm.

6.2.2 *Friction Sleeve*—The friction sleeve shall have a diameter d_f between d_c and d_c + 0.35 mm, with d_c the base diameter of the cone tip. No other part of the penetrometer tip shall project outside the sleeve diameter. The surface area of the sleeve shall be 15,000 mm^2 ± 2 %.

6.2.3 The cone tip and the friction sleeve shall be made from steel of a type and hardness suitable to resist wear due to abrasion by soil. The friction sleeve shall have and maintain with use a roughness of 0.4 µm ± 0.25 µm measured in the longitudinal direction.

6.2.4 *Wear of Tip*—Penetration into abrasive soils eventually wears down or scours the penetrometer tip. Cone tips that have worn to the point that they no longer meet the dimensional requirements given in 6.2.1 or the roughness requirements given in 6.2.3 shall be replaced.

6.3 *Push Rods*—Made of suitable steel, these rods must have a section adequate to sustain without buckling, the thrust required to advance the penetrometer tip. They must have an outside diameter not greater than the diameter of the base of the cone for a length of at least 0.4 m above the base, or, in the case of the friction-cone penetrometer, at least 0.3 m above the top of the friction sleeve. The push rods shall present no protruding parts at their inner side in order to allow free movement of the inner rods. They must screw or attach together to bear against each other and form a rigid-jointed string of rods with a continuous, straight axis.

6.4 *Reduction of Friction Along Push Rods*—To accomplish the friction reduction, introduce a special rod with an enlarged diameter or special projections, called a "friction reducer," into the string of push rods or between the push rods and the tip. Another allowable method to reduce friction is to use push rods with diameter less than that of the tip. Any such projections or changes in diameter must meet the restrictions of 6.3. Non-mechanical techniques to reduce friction, such as the use of drilling mud above the tip, are also permissible. The purpose of this friction reduction is to increase the penetrometer depth capability, and not to reduce any differences between resistance components determined by mechanical and electronic penetrometers as noted in 1.3.

6.5 *Inner Rods*—Mechanical penetrometers require a separate set of steel or other metal alloy inner rods within the steel push rods. The inner rods must have a constant outside diameter with a roughness less than 3.2 µm AA. They must have the same length as the push rods (±0.1 mm) and a cross section adequate to transmit the cone resistance without buckling or other damage. Clearance between inner rods and push rods shall be between 0.75 ± 0.25 mm.

6.6 *Thrust Measuring Equipment*—The penetration resistance shall be measured at the surface by a suitable device such as a hydraulic or electric load cell or a proving ring. The thrust measurement equipment shall be calibrated to provide thrust measurements in kN with an accuracy of ±2.5 % or better and a precision of 1 kN or less. Calibrate the thrust measurement equipment at regularly scheduled intervals as recommended by the manufacturer, such as annually or after a specified amount of accumulated testing. However, the equipment shall be calibrated at least every two years and following any repair of the equipment.

NOTE 4—Special, and preferably redundant, instrumentation may be required in the offshore environment to ensure this accuracy and the proper operation of all the remote systems involved.

6.7 *Thrust Machine and Reaction*—The thrust machine shall provide a continuous stroke, preferably over a distance greater than 1 m. The thrust machine should be capable of adjusting push direction through the use of a leveling system such that push initiates in a vertical orientation. The machine must advance the penetrometer tip and push rods at a smooth, constant rate while the magnitude of thrust can fluctuate. The thrust machine must be anchored or ballasted, or both, so that it provides the necessary reaction for the penetrometer and does not move relative to the soil surface during thrust.

NOTE 5—Cone penetration soundings usually require thrust capabilities ranging from 100 to 200 kN. The type of reaction provided may affect penetrometer resistance(s) measured in near surface layers. If these conditions are evident, they should be noted in reports.

6.8 *Prevention of Rod Bending Above Surface*—Use a tubular rod guide, at the base of the thrust machine, of sufficient length to prevent significant bending of the push rods between the machine and the ground surface. Special situations, such as when working through water, will require a special system of casing support to adequately restrict the buckling of the push rods.

7. Hazards

7.1 The following safety recommendations are in addition to general safety requirements applicable to construction operations: (Also see 1.9.)

7.1.1 Permit only authorized personnel within the immediate test area, and only as necessary to operate test equipment.

7.1.2 Provide a stable and level work area around the thrust machine. Keep all test and adjacent work areas, walkways, platforms, etc., clear of scrap, debris, small tools, and accumulations of snow, ice, mud, grease, oil, or other slippery substances.

7.1.3 Prior to beginning a sounding, perform site surveys to ensure hazards such as overhead and underground utilities will not be encountered.

7.1.4 Carry out all operations in connection with cone penetration in a manner that minimizes, avoids, or eliminates the exposure of people to hazard. Test personnel should wear safety glasses, gloves, safety shoes, and appropriate hearing protection.

7.1.5 Be aware of and avoid pinch and crush hazards while using thrust equipment.

7.1.6 The application of thrust to the penetration rods can result in damage to equipment and hazard to personnel. The applied thrust at which rods may break is a function of the rod design, the thrust equipment configuration, and the ground conditions. Standard push rods can be damaged or broken at loads less than their rated capacity. The amount of force that push rods are able to sustain decreases as the unrestrained rod length increases. Push rod joints and push rod-penetrometer tip connections provide weak links in the rod string. Excessive lateral rod deflection is the most common cause for rod breakage.

8. Procedure

8.1 *General:*

8.1.1 Position the thrust machine over the location of the sounding, and anchor and/or ballast the machine. Set the hydraulic rams of the penetrometer thrust system to as near vertical as possible. The axis of the push rods must coincide with the thrust direction.

8.1.2 Set the hydraulic ram feed rate to advance the penetrometer at a rate of 20 ± 5 mm/s. This rate must be maintained during the entire stroke and during the downward advance of the rods while taking readings.

NOTE 6—To provide the operator the time needed to properly read the resistance values when using the mechanical friction-cone penetrometer, the rate may be reduced to 10 ± 2.5 mm/s. However, this should be noted in the reports in accordance with 10.2.12.

8.1.3 Check push rods for straightness and permanent bending. Push rods are assembled and tightened by hand, but care must be taken and threads may need cleaning to ensure that the shoulders are tightly butted to prevent damage to the push rods. Add the friction reducer(s) to the string of push rods as required, usually on the first push rod behind the penetrometer tip and other rods as required.

8.1.4 Inspect penetrometer tips before and after soundings for damage, soil ingress, and wear. In very soft and sensitive soils where accurate sleeve data is essential, dismantle cone penetrometer tips and friction sleeves after each sounding to clean and lubricate as required. If damage is found after a sounding, record this information with the sounding.

8.2 *Mechanical Penetrometers:*

8.2.1 *Continuous Penetration Testing*—Advance the penetrometer tip by applying sufficient thrust on the push rods until stopped to add a push rod. In case of a telescoping penetrometer tip, the cone shall remain in push-out position. Record the total penetration force and the cone resistance readings obtained with at least two significant digits, but not exceed the precision of their measurement.

8.2.2 *Discontinuous Penetration Testing:*

8.2.2.1 *Cone Penetrometers:*

(1) Advance the penetrometer tip to the required test depth by applying sufficient thrust on the push rods, and

(2) Apply sufficient thrust on the inner rods to extend the penetrometer tip (see Fig. 1).Obtain the cone resistance at a specific point, Q_c, (see 8.2.2.3) during the downward movement of the inner rods relative to the stationary push rods. Repeat Step (*1*). Apply sufficient thrust on the push rods to collapse the extended tip and advance it to a new test depth. By continually repeating this two-step cycle, obtain cone resistance data at constant increments of depth that shall not ordinarily exceed 200 mm.

8.2.2.2 *Friction-Cone Penetrometer*—Use the procedure as described in 8.2.2.1, but obtain two resistances during the Step (*2*) extension of the tip (see Fig. 2). First obtain the cone resistance, Q_c, during the initial phase of the extension. When the lower part of the tip engages and pulls down the friction sleeve, immediately obtain a second measurement of the total resistance of the cone plus the sleeve, Q_f. Do not stop the extension of the tip between the two resistance readings. Subtraction of the first reading from the second reading gives the sleeve resistance.

NOTE 7—Because of soil layering, the cone resistance may change during the additional downward movement of the tip required to obtain the friction measurement.

NOTE 8—The soil friction along the sleeve puts an additional overburden load on the soil above the cone and may increase cone resistance above that measured during the initial phase of the tip extension by an unknown but probably small amount. Ignore this effect.

8.2.2.3 *Recording Data*—Record the cone resistance readings obtained at each test depth with at least two significant digits, but not exceed the precision of their measurement. To obtain reproducible cone-resistance test data, or cone and friction-resistance test data when using a friction-cone tip, record only those thrust readings that occur at a well-defined point during the downward movement of the top of the inner rods in relation to the top of the push rods. Because of the elastic compression of inner rods, this point ordinarily should be at not less than 25 mm apparent relative movement of the inner rods. When using the friction-cone penetrometer, this point shall be just before the cone engages the friction sleeve.

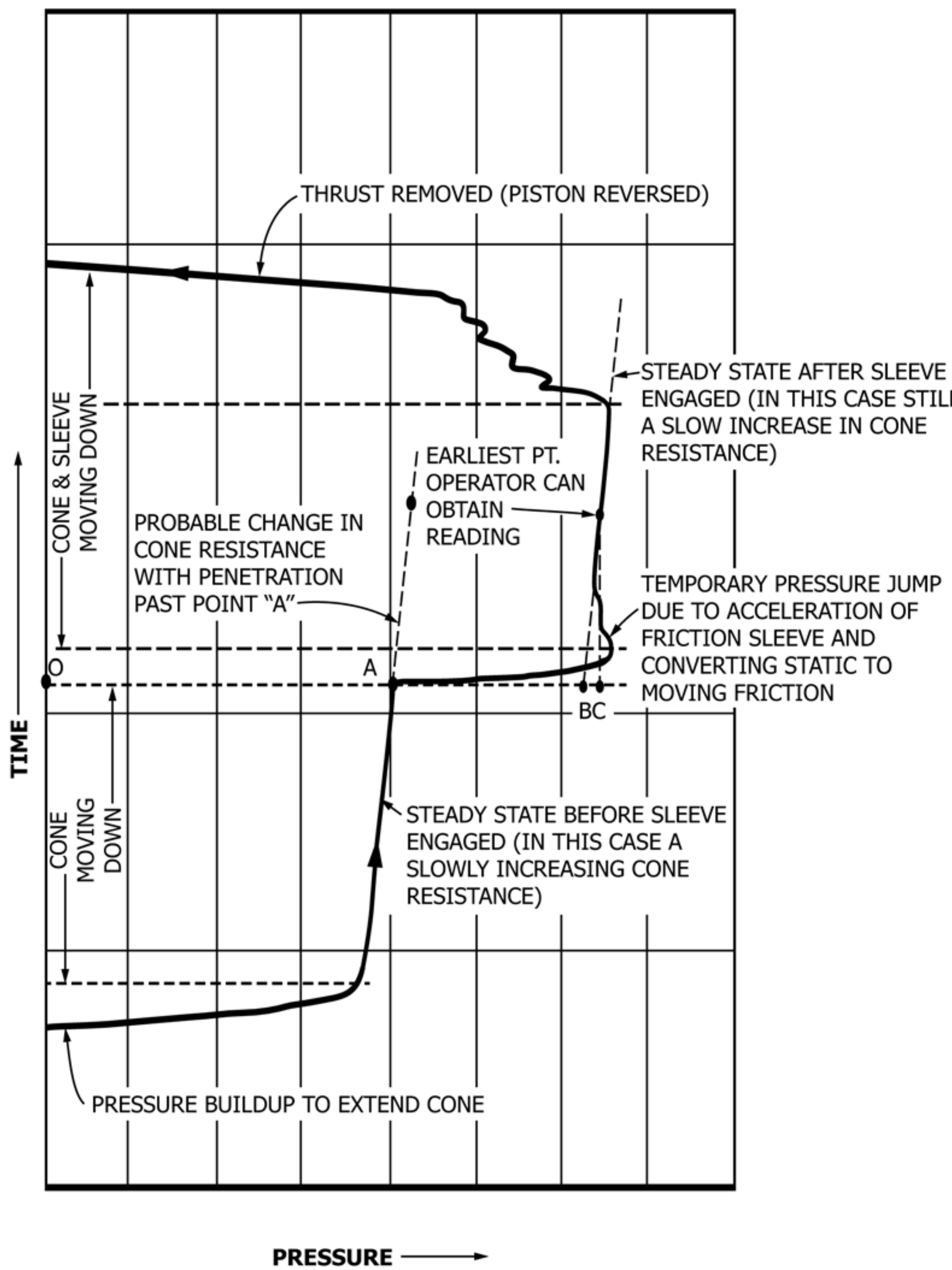
Obtain the cone plus friction-resistance reading as soon as possible after the jump so as to minimize the error described in Fig. 3. Unless using continuous recording as in Fig. 3, the operator should not record a cone plus friction resistance if he suspects the cone resistance is changing abruptly or erratically.

NOTE 9—Fig. 3 shows one example of how the thrust in the hydraulic load cell can vary during the extension of the friction-cone tip. Note the jump in gauge pressure when the cone engages the sleeve.

NOTE 10—The friction sleeve resistance measured during the extension of the penetrometer tip applies to the soil at some distance above the soil in which the cone resistance was obtained. When comparing these resistances for the soil at a specified depth, for example when computing friction ratios or when plotting these data on graphs, take proper account of the vertical distance between the base of the cone and the mid-height of the friction sleeve.

8.3 *Drift of Tip*—For penetration depth exceeding about 12 m, the tip will probably drift away from a vertical alignment. Occasionally, serious drifting occurs, even at less depth. Reduce drifting by using push rods that are initially straight and by making sure that the initial cone penetration into soil does not involve unwanted initial lateral thrust. Passing through or alongside an obstruction such as boulders, soil concentrations, thin rock layers, or inclined dense layers, may deflect the tip and induce drifting. Note any indications of encountering such obstructions and be alert for possible subsequent improper tip operation as a sign of serious drifting.

8.4 *Obstructions and Interruptions*—The normal advance of a static penetration test may be interrupted for purposes such as



NOTE 1—"O-A" represents the correct cone resistance reading just before the pressure jump associated with engaging the friction sleeve during the continuing downward extension of the tip. "A-B" is the correct friction resistance if the friction sleeve could be engaged instantaneously and the cone plus friction resistance read instantaneously. However, the operator cannot read a pressure gauge dial until it steadies, such as at Point "C." By this forced wait, the operator has introduced a friction resistance error of "B-C." The operator must read the gauge as soon as possible after the jump to minimize this error. Erratic or abrupt changes in cone resistance may make this error unacceptable.

FIG. 3 Annotated Chart Record of the Pressure Changes in the Hydraulic Load Cell Measuring Thrust on Top of the Inner Rods During an Example Extension of the Mechanical Friction-Cone Penetrometer Tip

removing the penetrometer and drilling through layers or obstructions too strong to penetrate statically. If the penetrometer is designed to be driven dynamically without damage to its subsequent static performance (those illustrated in Figs. 1 and 2 are not so designed), the engineer may drive past such layers or obstructions. Delays of over 10 min due to personnel or equipment problems shall be considered an interruption and may have a disturbance effect on the initial test readings obtained after the delay. Make a record of the delay so that any data obtained within the disturbed zone can be evaluated later and disregarded as appropriate.

8.5 *Jamming of the Tip*—Soil particles between sliding surfaces or bending of the tip may jam the mechanism during the many extensions and collapses of the telescoping mechanical tip. Stop the sounding as soon as uncorrectable jamming occurs.

9. Calculations

9.1 The applied thrust force is converted to stress for reporting purposes using the basic equations given in 9.3 and 9.4.

9.2 *Weight of Inner Rods*—For improved accuracy at low values of thrust resistance, correct the thrust data to include the accumulated weight of the inner rods from the penetrometer tip to the topmost rod.

9.3 *Cone Resistance, q_c- Required:*

$$q_c = 1000 \;\; Q_c/A_c \tag{1}$$

where:

q_c = cone resistance (MPa),
Q_c = thrust force measured on cone tip (kN), and
A_c = cone base area = 1000 mm^2.

9.4 *Friction Sleeve Resistance, f_s- Required only for friction cone penetrometers:*

$$f_s = 1000 \;\; F_s/A_s \tag{2}$$

$$F_s = Q_f - Q_c \tag{3}$$

where:

f_s = friction sleeve resistance (MPa),
F_s = thrust force measured on friction sleeve (kN),
Q_f = thrust force measured on cone tip plus friction sleeve, and
A_s = friction sleeve side area = 15,000 mm^2.

(The factor of 1000 in Eq 2 applies specifically for the units indicated.)

The thrust readings, Q_f and Q_c, are consecutive measurements taken during a single test, as described in 8.2.2.

9.5 *Friction Ratio, R_f- Required only for friction cone penetrometers:*

$$R_f = 100 \;\; f_s/q_c \tag{4}$$

where:

R_f = friction ratio (%)

(The factor of 100 in Eq 4 converts the decimal ratio to percent.)

9.5.1 Calculation of the friction ratio requires the user to obtain a cone resistance and friction sleeve resistance at approximately the same depth in the soil mass. The depth of the cone resistance is taken as the reference depth. The offset distance between the cone tip and the midpoint of the friction sleeve is intended to be approximately the same as the increment in test depths. Therefore, the friction sleeve resistance from the next deeper cone test is used for the friction ratio calculation. Report any deviation in offset depth or test depth increment.

9.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026 unless superseded by this practice.

NOTE 11—If the soil mass includes alternating layers of soft and hard materials, then the depth profile of friction ratio values may appear erratic. This is because the cone resistance is sensed, to varying degrees, ahead of the cone. The erratic data may not be representative of soils actually present.

NOTE 12—The friction sleeve resistance and friction ratio obtained from the mechanical friction cone penetrometers can differ considerably from similar values obtained from electronic friction cone penetrometers. When using soil classification charts that use R_f and q_c, it is important to use charts based on correlations for the type of penetrometer.

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

10.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.8 and Practice D6026.

10.2 Record as a minimum the following general information for each cone penetration test sounding:

10.2.1 Operator name,
10.2.2 Project information,
10.2.3 Feature notes,
10.2.4 Ground surface elevation and water surface elevation (if available),
10.2.5 Sounding location, including coordinates,
10.2.6 Sounding number,
10.2.7 Sounding date,
10.2.8 Type of penetrometer equipment used,
10.2.9 Type of thrust machine,
10.2.10 Thrust calibration,
10.2.11 Zero-drift in thrust measurements,
10.2.12 Test procedures followed, and
10.2.13 Any deviations from this apparatus or procedures herein.

10.3 Record as a minimum the following test data for both cone penetrometers and friction cone penetrometers:

10.3.1 Depth of test (nearest 0.01 m or less),
10.3.2 Thrust force on the cone tip, Q_c (nearest 1 kN or less),
10.3.3 Cone resistance, q_c (nearest 0.5 MPa or less),
10.3.4 Plot of cone resistance versus depth,
10.3.5 Soil type based on adjacent borings (optional), and
10.3.6 Any test observations or anomalies.

10.4 Record as a minimum the following additional test data for friction cone penetrometers:

10.4.1 Depth of test (nearest 0.01 m or less),
10.4.2 Thrust force on the cone tip plus friction sleeve, Q_f (nearest 1 kN or less),
10.4.3 Friction sleeve resistance, fs (nearest 0.05 MPa or less),
10.4.4 Friction ratio, R_f (nearest 0.1 % or less),
10.4.5 Soil type based on friction ratio and cone resistance (optional),
10.4.6 Plot of friction sleeve resistance versus depth,
10.4.7 Plot of friction ratio versus depth, and
10.4.8 Any test observations or anomalies.

11. Precision and Bias

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

11.1.1 The Subcommittee D18.02 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

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

12. Keywords

12.1 cone penetration test; CPT; Dutch Cone; end bearing; field test; *In-situ* test; penetrometer; point resistance; site exploration; sleeve friction; soil investigation

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (2005) that may impact the use of this standard. (July 1, 2016)

(1) A small change has been made in the title to match D5778.
(2) Changed to SI units alone (ASTM preference).
(3) Added D18 caveats for significant digits and guidance for reporting significant digits in the report section.
(4) An addition to the Significance and Use to provide a rationale for using this standard.
(5) Added Interferences, Hazards, and Calculations.
(6) Revised Report section.
(7) General editorial changes to improve organization and readability.