Designation: D5778 – 20

Standard Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils[1]

This standard is issued under the fixed designation D5778; 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 test method covers the procedure for determining the resistance of a friction cone or a piezocone as it is advanced into subsurface soils at a steady rate.

1.2 This test method applies to electronic friction cones and does not include hydraulic, pneumatic, or free-fall cones, although many of the procedural requirements herein could apply to those cones. Also, offshore/marine Cone Penetration Testing (CPT) systems may have procedural differences because of the difficulties of testing in those environments (for example, tidal variations, salt water and waves). Field tests using mechanical-type cones are covered elsewhere by Test Method D3441.

1.3 This test method can be used to determine pore water pressures developed during the penetration when using a properly saturated piezocone. Pore water pressure dissipation, after a push, can also be monitored for correlation to time rate of consolidation and permeability.

1.4 Additional sensors, such as inclinometer, seismic (Test Methods D7400), resistivity, electrical conductivity, dielectric, and temperature sensors, may be included in the cone to provide additional information. The use of an inclinometer is recommended since it will provide information on potentially damaging situations during the sounding process.

1.5 CPT 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.

1.6 *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

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values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

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

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

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D3441 Test Method for Mechanical Cone Penetration Testing of Soils
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D6026 Practice for Using Significant Digits in Geotechnical Data

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

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[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**

D7400 Test Methods for Downhole Seismic Testing

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, see Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparent load transfer, n*—resistance measured on either the tip or friction sleeve of a friction cone while that element is in a no-load condition but the other element is loaded.

3.2.2 *baseline, n*—a set of zero load readings that are used as reference values during performance of testing and calibration.

3.2.3 *cone tip, n*—the conical point of a cone on which the end bearing resistance is developed.

3.2.4 *cone penetration test, n*—pushing of a cone at the end of a series of cylindrical push rods into the ground at a constant rate of penetration. Also referred to as a cone sounding.

3.2.5 *cone, n*—assembly containing the cone tip, friction sleeve, any other sensors and measuring systems as well as the connection to the push rods.

3.2.6 *cone tip resistance, q_c, n*—the measured end-bearing component of cone resistance, equal to the vertical force applied to the cone tip divided by the cone base area.

3.2.7 *corrected total cone tip resistance, q_t, n*—cone tip resistance corrected for water pressure acting behind the cone tip (see 13.1.1).

3.2.7.1 *Discussion*—Correction for water pressure requires measuring water pressures with a piezocone element positioned behind the cone tip at location u_2 (See section 3.2.20).

3.2.8 *electronic cone, n*—a cone that uses transducers to obtain the measurements.

3.2.9 *electronic piezocone, n*—an electronic cone that can measure the pore water pressure simultaneously with the cone tip resistance and the friction sleeve resistance.

3.2.10 *equilibrium pore water pressure, u_0, n*—at rest water pressure at depth of interest. Also referred to as piezometric pressure.

3.2.11 *excess pore water pressure, Δu, n*—pore water pressure in excess of the equilibrium pore water pressure caused by the penetration of the cone into the ground.

3.2.11.1 *Discussion*—Excess pore water pressure can either be positive or negative for filters with a piezocone element positioned behind the cone tip at location u_2 (see 3.2.20).

3.2.12 *friction ratio, R_f, n*—the ratio of the friction sleeve resistance, f_s, to the cone tip resistance, q_c, with the latter measured at the depth for the middle of the friction sleeve, expressed as a percentage.

NOTE 1—Some methods to interpret CPT data use friction ratio defined as the ratio of sleeve friction, f_s, to cone tip resistance corrected for pore pressure effects q_t, (**1**). It is not within the scope of this standard to recommend which methods of interpretation are to be used.

3.2.13 *friction reducer, n*—local and symmetrical enlargement of the diameter of a push rod to obtain a reduction of the friction along the push rods.

3.2.14 *friction sleeve, n*—an isolated cylindrical section of a cone upon which the friction component of penetration resistance develops.

3.2.15 *friction sleeve resistance, f_s, n*—the friction component of cone resistance developed on a friction sleeve, equal to the shear force applied to the friction sleeve divided by the friction sleeve surface area. Also referred to as local side friction or sleeve friction.

3.2.16 *full-scale output, n*—the output of an electronic transducer when loaded to 100 % rated capacity.

3.2.17 *measuring system, n*—all sensors and auxiliary parts used to transfer and/or store the electrical signals generated during the cone penetration test.

3.2.17.1 *Discussion*—The measuring system normally includes components for measuring force (cone resistance, sleeve friction), pressure (pore pressure), inclination, clock time and penetration length.

3.2.18 *penetration depth, n*—vertical depth of the base of the cone, relative to a fixed point.

3.2.19 *penetration length, n*—sum of the lengths of the push rods and the cone.

3.2.20 *piezocone porewater pressure measurement location: u_1, u_2, u_3, n*—fluid pressure measured by the piezocone at specific locations (**2, 3, 4**)[3]: u_1—porous filter location on the midface or tip of the cone, u_2—porous filter location at the shoulder position in the cylindrical extension of the cone tip (standard location) and, u_3—porous filter location behind the friction sleeve.

3.2.21 *pore water pressure, n*—pore water pressure measured during penetration.

3.2.22 *pore water pressure ratio, B_q, n*—the ratio of excess pore water pressure, Δu_2, measured with a piezocone element positioned behind the cone tip at location u_2 (see 3.2.20) to corrected total cone tip resistance q_t, minus the total vertical overburden stress, σ_{vo}.

3.2.23 *push rods, n*—the tubes or rods used to advance the cone.

3.3 *Abbreviations:*

3.3.1 *CPT*—cone penetration test.

3.3.2 *FSO*—full scale output.

3.3.3 *MO*—measured output.

4. Summary of Test Method

4.1 A cone is advanced through the soil at a constant rate of 20 mm/s. The force on the cone tip required to penetrate the soil is measured using an electric transducer. The cone tip resistance q_c is calculated by dividing the vertical force applied to the cone tip by the cone base area.

[3] The boldface numbers given in parentheses refer to a list of references at the end of the text.

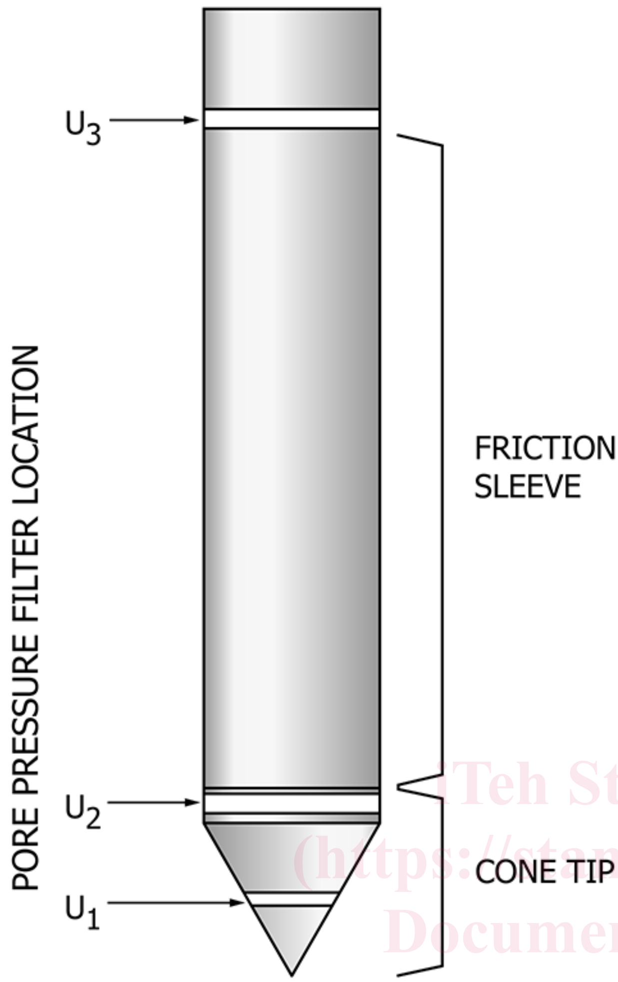

FIG. 1 Piezocone Pore Water Pressure Measurement Locations (courtesy ConeTec Data Services)

4.2 A friction sleeve is present on the cone immediately behind the cone tip, and the force exerted on the friction sleeve is measured using an electric transducer. The friction sleeve resistance, f_s is calculated by dividing the shear force applied to the friction sleeve by the surface area of the friction sleeve.

4.3 Most modern cones are capable of registering pore water pressure induced during advancement of the cone using an electric pressure transducer. These cones are formally called "electronic piezocones," but given their prevalence they are often simply referred to as "cones." The dissipation of either positive or negative excess pore water pressure can be monitored by stopping penetration, unloading the push rods, and recording pore water pressure as a function of time. When pore water pressure becomes constant it is measuring the equilibrium value (designated u_0) at that depth.

4.4 The forces and, if applicable, pressure readings are taken at penetration length intervals of no more than 50 mm. Improved resolution may often be obtained at 20- or 10-mm interval readings.

5. Significance and Use

5.1 Tests performed using this test method provide a detailed record of cone tip resistance, which is useful for evaluation of site stratigraphy, engineering properties, homogeneity and depth to firm layers, voids or cavities, and other discontinuities. The use of a friction sleeve and pore water pressure element 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.

5.2 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.

5.3 This method tests the soil in situ and soil samples are not obtained during the test. 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.

NOTE 2—The quality of the results produced by this standard is dependent on the competence of the personal performing the test, 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 and Practice D3740 provides a means of evaluating some of those factors.

6. Interferences

6.1 Refusal, deflection, or damage to the cone may occur in coarse grained soil deposits with maximum particle sizes that approach or exceed the diameter of the cone.

6.2 Partially lithified and lithified deposits may cause refusal, deflection, or damage to the cone.

6.3 Push rods can be damaged or broken under extreme loadings. The amount of force that push rods are able to sustain is a function of the unrestrained length of the rods and the weak links in the string, such as push rod joints and push rod-cone connections. The force at which rods may break is a function of the equipment configuration and ground conditions during penetration. Excessive rod deflection is the most common cause for rod breakage.

7. Apparatus

7.1 *Cone*—The cone shall meet requirements as given below and in 10.1. In a conventional cone, the forces at the cone tip and friction sleeve are measured by two load cells within the cone. (Fig. 2)

7.1.1 In the subtraction-type cone (Fig. 2a) the cell nearest the cone tip measures the compressive force on the cone tip, while the second cell measures the sum of the compressive forces on both the cone tip and friction sleeve. The compressive force from the friction sleeve portion is then computed by subtraction. This cone design is common in the industry because of its rugged design, even though the calculated friction sleeve force may not be as accurate since it is very small compared to the cone tip force.

7.1.2 In the compression-type cone (Fig. 2b) there are separate load cells for the cone tip and the friction sleeve. This design results in a higher degree of accuracy in friction sleeve

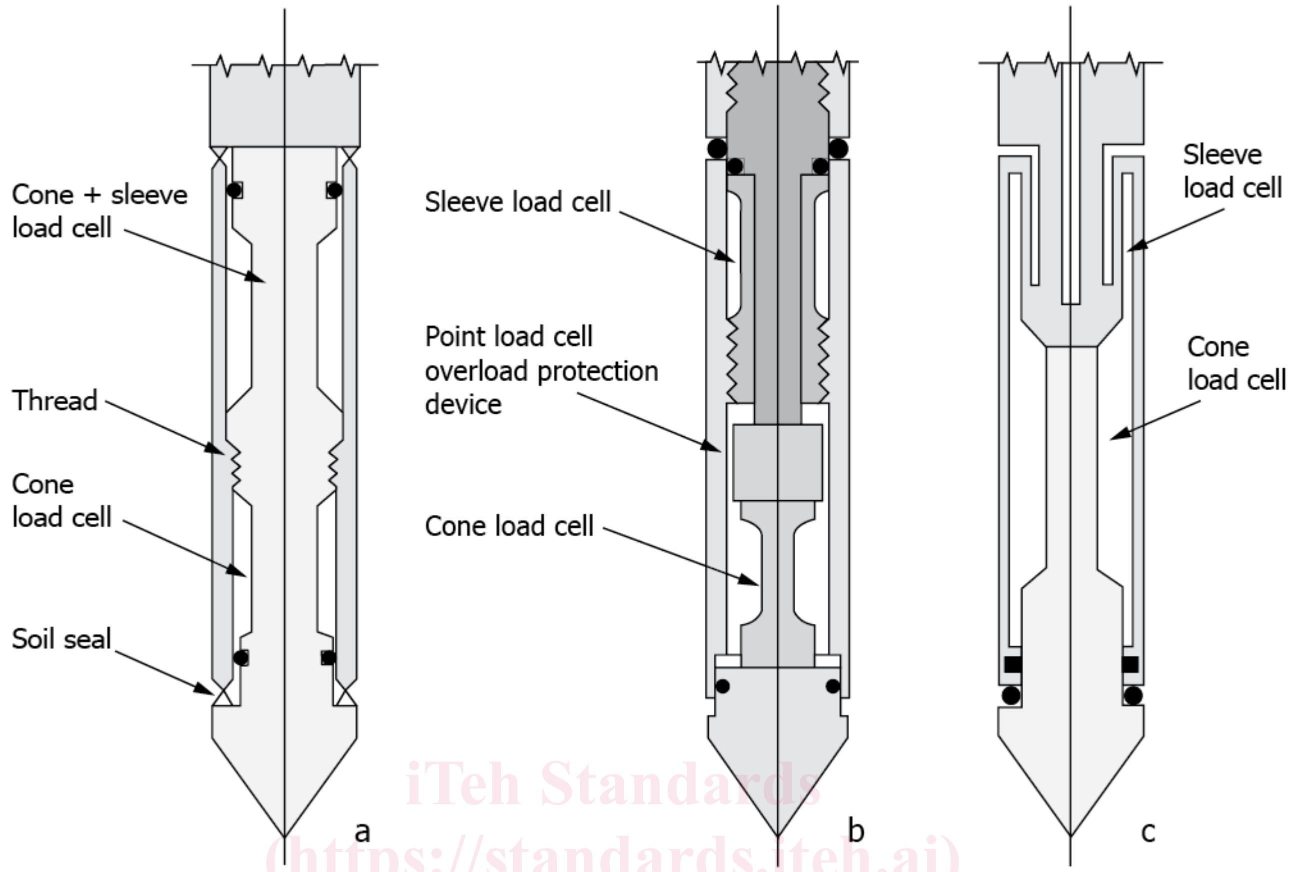

FIG. 2 Configurations for Electric Friction-Cone Penetrometers (1) Showing: (a) Subtraction type, (b) Compression type, and (c) Tension type (courtesy ConeTec Data Services)

measurement, but may be more susceptible to damage under extreme loading conditions.

7.1.3 Designs are also available where both the cone tip and sleeve load cells are separate, but where the load cell for the friction sleeve operates in tension (Fig. 2c).

7.1.4 Typical general purpose electronic cones are manufactured to full scale outputs (FSO) equivalent to net loads of 100 to 200 kN. Often, weak soils are the most critical in an investigation program, and to gain better resolution, the FSO can be lowered. However, this may place electrical components at risk if overloaded in stronger soils, in which case pre-boring may be required to avoid damage. The selection of cone type and resolution should consider such factors as practicality, availability, calibration requirements, cost, risk of damage, and preboring requirements.

7.2 *Cone Tip*—Nominal dimensions, with manufacturing and operating tolerances, for the cone are shown on Fig. 3.

NOTE 3—In some applications it may be desirable to scale the cone diameter down to a smaller projected area. Cones with 5 cm^2 projected area find use in the field applications and even smaller sizes (1 cm^2) are used in the laboratory for research purposes. These cones should be designed with dimensions adjusted proportionally to the square root of the diameter ratio. In thinly layered soils, the diameter affects how accurately the layers may be sensed. Smaller diameter cones may sense thinner layers more accurately than larger cones.

7.2.1 The cone tip is made of high strength steel of a type and hardness suitable to resist wear due to abrasion by soil. Cone tips that have worn to the operating tolerance shown in Fig. 3 shall be replaced.

7.3 *Friction Sleeve*—The outside diameter of the manufactured friction sleeve and the operating diameter are equal to the diameter of the base of the cone with a tolerance of +0.35 mm and –0.0 mm, but not more than 36.1 mm for a 10-cm^2 cone and 44.2 mm for a 15-cm^2 cone. The friction sleeve is made from high strength steel of a type and hardness to resist wear due to abrasion by soil. Chrome-plated steel is not recommended due to differing frictional behavior. The surface area of the friction sleeve is 150 cm^2 ± 2 % for a 10-cm^2 cone and 225 cm^2 ± 2 % for a 15-cm^2 cone. If it has been demonstrated that comparable results are obtained, the surface area of the friction sleeve for a 15-cm^2 cone can be adjusted to a minimum of 200 cm^2 ± 2 %.

NOTE 4—If the cone base area is altered to other values, as provided for in Note 2, the surface area of the friction sleeve should be adjusted proportionally to the cone base area ratio.

7.3.1 The top diameter of the sleeve must not be smaller than the bottom diameter or significantly lower sleeve resistance will occur. The top and bottom of the sleeve should be periodically checked for wear with a suitable tool. Normally, the top of the sleeve will wear faster than the bottom. Friction sleeves that have worn to the operating tolerance shall be replaced.

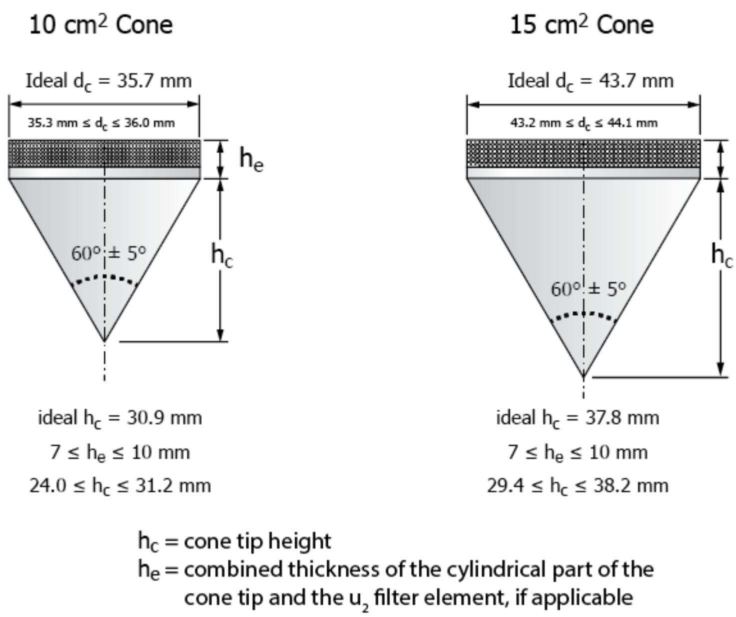

FIG. 3 Manufacturing and Operating Tolerances of Cone Tips (5) (courtesy ConeTec Data Services)

7.3.2 Friction sleeves must be designed with equal end areas, which are exposed to water pressures (**1**, **5**, **6**, **7**, **8**). This will remove the tendency for unbalanced end forces to act on the sleeve. Sleeve design must be checked in accordance with A1.6 to ensure proper response.

7.4 *Gap*—The gap (annular space) between the cylindrical extension of the cone tip base and the other elements of the cone shall be kept to the minimum necessary for operation of the sensing devices and shall be designed and constructed in such a way to prevent the entry of soil particles. These gap requirements also apply to the gaps at either end of the friction sleeve and to other elements of the cone.

7.4.1 The gap between the cylindrical extension of the cone tip and other elements of the cone must not be larger than 5 mm.

7.4.2 If a seal is placed in the gap, it should be properly designed and manufactured to prevent entry of soil particles. It must have a deformability at least two orders of magnitude greater than the material comprising the load transferring components of the sensing devices in order to prevent load transfer from the cone tip to the sleeve.

7.5 *Diameter Requirements*—The cone shall have the same diameter as the cone tip (that is, equal to the diameter of the base of the cone with a tolerance of +35 mm and –0.0 mm, but not more than 36.1 mm for a 10-cm^2 cone and 44.2 mm for a 15-cm^2 cone) for the complete length of the cone (**5**, **9**, **10**).

7.5.1 For some cone designs, it may be desirable to increase the diameter of the cone body to house additional sensors or reduce friction along push rods. These diameter changes are acceptable if they do not have significant influence on tip and sleeve data, and therefore these diameter changes shall be at least 400 mm from the cylindrical extension of the cone tip base for a 10-cm^2 cone and 500 mm for a 15-cm^2 cone. If the cone diameter is not constant, information on diameters of the complete cone shall be reported.

NOTE 5—The effects caused by cone diameter changes on tip and sleeve resistance are dependent on the magnitude of diameter increase, location, and soil conditions. If there is question regarding a specific design with diameter increases, comparison studies can be made to a cone with constant diameter. Most practitioners feel that diameter increases equivalent to addition of a friction reducer with area increases of 15 to 20 % should be restricted to a location at least eight to ten cone diameters behind the friction sleeve.

7.6 *Cone Axis*—The axis of the cone tip, the friction sleeve, and the remainder of the cone must be coincident.

7.7 *Force Sensing Devices*—The typical force sensing device is a strain gauge load cell that contains temperature compensated bonded strain gauges. The configuration and location of strain gauges should be such that measurements are not influenced by possible eccentricity of loading.

7.7.1 The transducers shall have an accuracy of at least ±100 kPa or 5 % of the reading (whichever is larger), except if the transducer is dedicated to measuring the friction sleeve resistance, in which case the precision shall be at least 15 kPa or 15 % of the reading (whichever is larger).

7.8 *Electronic Piezocone*—A piezocone can contain porous filter element(s), pressure transducer(s), and fluid filled ports connecting the elements to the transducer to measure pore water pressure. Fig. 4 shows some common design types used in practice for 10-cm^2 and 15-cm^2 piezocones (with ideal dimensions).

7.8.1 The pore water pressure measurement location of the porous element shall be either in the cone tip (Type 1 or u_1), immediately behind the cone tip (Type 2 or u_2) or immediately behind the friction sleeve (Type 3 or u_3). Some piezocones used for research purposes may have multiple measurement locations. The Type 2 piezocone is preferred to allow correction of tip resistances. Moreover, this type is less subject to damage and abrasion, and shows fewer compressibility effects (**1**, **8**). However, Type 2 cones may be subject to cavitation at shallow depths in dense soils because the zone behind the

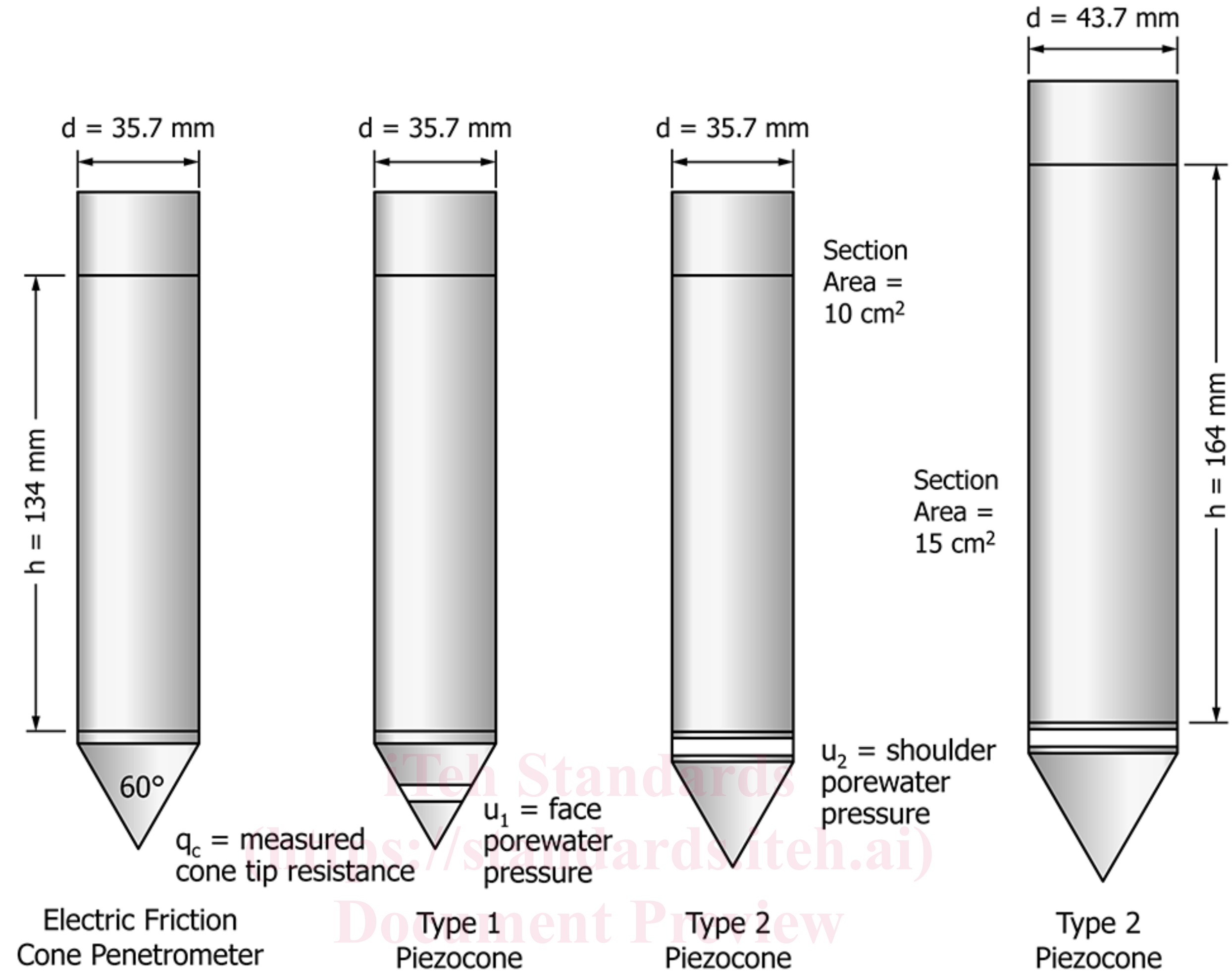

FIG. 4 Cone Design Configurations: (a) Electronic Friction-type, (b) Type 1 Piezocone, (c) Standard 10-cm² Type 2 Piezocone, and (d) 15-cm² Type 2 Version (7) (courtesy ConeTec Data Services)

height of cylindrical extension is a zone of dilation in drained soils. Similar response can occur in stiff fissured clays and crusts (**1**). Pore water pressure measurements obtained at the u_1 location are more effective for dissipation readings, compressibility determinations and layer detection, particularly in fissured soils and materials prone to cause cavitation of Type 2 piezocones, but are more subject to wear and damage (**4, 11**).

7.8.2 Numerous design and configuration aspects can affect the measurement of pore water pressures. Variables such as the element location, design and volume of ports, and the type and degree of saturation of the fluids, cavitation of the element fluid system and resaturation lag time, depth and saturation of soil during testing all affect the pore water pressure measured during testing and dissipation tests of pore water pressures (**2, 3, 4, 8**). It is beyond the scope of the procedure to address all of these variables. As a minimum, complete information shall be reported as to the design, configuration, and the preparation of the piezocone system that is used for the particular sounding.

7.8.3 Measurement of equilibrium pore water pressures during pauses in testing are more straightforward. The presence of air entrained in the system only affects dynamic response. In high permeability soils (for example, clean sands or gravel), the pore water pressure will equalize the equilibrium pore pressure within seconds or minutes. In low permeability materials such as high plasticity clays, equalization can take many hours. If the goal of the exploration program is only to acquire equilibrium pore water pressures in sands, some of the preparation procedures for pore water pressure measuring can be relaxed, such as deairing fluids. However, such relaxation shall be reported in detail, including on each pore pressure graph generated with such relaxed preparation procedures.

7.8.4 The pressure transducer is normally housed near the cone tip. For dynamic pressure measurements, the filter and ports are filled with deaired fluid and the volume of connecting ports to the transducer should be minimized. The transducer shall have an accuracy of at least 25 kPa or 3 % of the reading (whichever is larger).

7.8.5 *Element*—The element is a fine porous filter made from plastic, sintered steel or bronze, or ceramic. The pore size should be less than 100 micron. Different materials have different advantages. Smearing of metallic element openings by hard soil grains may reduce dynamic response of the system, thus these elements are normally not used for Type 1 cones, but best suited for Type 2 or Type 3 cones. Ceramic elements are very brittle and may crack when loaded, but perform well for Type 1 cones as they reduce compressibility concerns. Polypropylene plastic elements are most commonly used in practice, particularly for Type 2 and Type 3 cones, but they may be inappropriate for environmental type CPTs where contaminant detection is sought.

7.8.6 *Fluids for Saturation*—Pure glycerine or silicone oil is most often applied for deairing elements that are used to measure the dynamic response. These stiff viscous oils have less tendency to cavitate, although cavitation may be controlled by the effective pore size of the element mounting surfaces. Water or water mixtures can be used for the fluid if the entire sounding will be submerged, or if the dynamic response is not important. The fluids are deaired using procedures described in 11.1.

7.9 *Data Acquisition System*—The signals from the cone transducers are to be displayed at the surface during testing as a continuously updated plot against penetration length. The data are also to be recorded electronically on the same data acquisition system for subsequent processing.

7.9.1 The electronic data files shall include project, location, operator, and data format information (for example, channel, units, corrected or uncorrected, etc.) so that the data can be understood when reading the file with a text editor.

7.10 *Push Rods*—Steel rods are required having a cross sectional area adequate to sustain, without buckling, the thrust required to advance the cone. For systems that use cables, the cable is prestrung through the rods prior to testing. Push rods are typically supplied in 1-meter lengths, although other lengths are used as well. The push rods must be secured together to bear against each other at the joints and form a rigid-jointed string of push rods. Before a test is carried out, the linearity of the push rods should be checked. If any indications of bending appear, the use of the rods should be suspended.

7.10.1 For the 10-cm^2 cone steel push rods are typically 36-mm outside diameter, 16-mm inside diameter, and have a mass per unit length of 6.65 kg/m. For 15-cm^2 cones, the test is typically performed with 44.5-mm outside diameter rods or with standard rods used for the 10-cm^2 cones, although other diameters are used as well.

7.11 *Friction Reducer*—Friction reducers are normally used on the push rods to reduce rod friction. If a friction reducer is used, it shall be located on the push rods no closer than 400 mm behind the cone tip base of the 10-cm^2 cone and 500 mm behind the cone tip base of a 15-cm^2 cone. Friction reducers, that increase push rod outside diameter by approximately 25 %, are typically used for 10-cm^2 cones. If a 15-cm^2 cone is advanced with 36-mm push rods there may be no need for friction reducers since the cone itself will open a larger hole. The type, size, amount, and location of friction reducer(s) used during testing must be reported.

7.12 *Thrust Machine and Reaction*—The thrust machine will 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 cone and push rods at a smooth, constant rate (see 12.1.2) 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 cone and does not move relative to the soil surface during thrust.

NOTE 6—Cone penetration soundings usually require thrust capabilities ranging from 100 to 200 kN for full capacity. High mass ballasted vehicles can cause soil surface deformations, which may affect cone resistance(s) measured in near surface layers. Anchored or ballasted vehicles, or both, may induce changes in ground surface reference level. If these conditions are evident, they should be noted in reports.

7.13 *Other Sensing Devices*—Other sensing devices can be included in the cone to provide additional information during the sounding. These instruments are normally read at the same continuous rate as tip, sleeve, and pore water pressure sensors, or alternatively, during pauses in the push (often at 1-m rod breaks). Typical sensors are inclinometer, temperature, resistivity (or its reciprocal, electrical conductivity), or seismic sensors. The use of an inclinometer is highly recommended since it will provide information on potentially damaging situations during the sounding process. An inclinometer can provide a useful depth reliability check because it provides information on verticality. In addition, it will allow for correction of the penetration length to the penetration depth during post-processing of the data.

8. Reagents and Materials

8.1 *O-Ring Compound*—A petroleum or silicon compound for facilitating seals with O-rings. Use of silicon compounds may impede repair of strain gages if the strain gauge surface is exposed to the compound.

8.2 *Silicone Oil, Glycerine, or water,* for use in pore water pressure measurement systems.

NOTE 7—Detailed comparisons and discussions on the use of these fluids can be found elsewhere (**8, 11**).

9. Hazards

9.1 *Technical Precautions—General:*

9.1.1 Use of components that do not meet required tolerances or show visible signs of non-symmetric wear can result in erroneous cone resistance data.

9.1.2 The application of thrust in excess of rated capacity of the equipment can result in damage to equipment (see Section 6).

9.1.3 A cone sounding must not be performed any closer than 10 borehole diameters from any existing unbackfilled or uncased bore hole.

9.1.4 When performing cone penetration testing in prebored holes, the depth and diameter of the prebored hole shall be reported and shown on the sounding plot.

NOTE 8—Usually it is assumed that the soil is disturbed at least three borehole diameters below the bottom of the borehole, and this should be taken into account when evaluating the penetration resistance data.

9.1.5 If obstructions are encountered and normal advance of the sounding is stopped to bore through the obstructions, the depth and thickness of obstructions shall be recorded.

9.1.6 Significant bending of the push rods can influence penetration resistance data. The use of a tubular rod guide is