Designation: D6067 – 10

Standard Practice for Using the Electronic Piezocone Penetrometer Tests for Environmental Site Characterization[1]

This standard is issued under the fixed designation D6067; 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 The electronic cone penetrometer test often is used to determine subsurface stratigraphy for geotechnical and environmental site characterization purposes (**1**).[2] The geotechnical application of the electronic cone penetrometer test is discussed in detail in Test Method D5778, however, the use of the electronic cone penetrometer test in environmental site characterization applications involves further considerations that are not discussed. For environmental site characterization, it is highly recommended to use the Piezocone (PCPT or CPTu) option in Test Method D5778 so information on hydraulic conductivity and aquifer hydrostatic pressures can be evaluated.

1.2 The purpose of this practice is to discuss aspects of the electronic cone penetrometer test that need to be considered when performing tests for environmental site characterization purposes.

1.3 The electronic cone penetrometer test for environmental site characterization projects often requires steam cleaning the push rods and grouting the hole. There are numerous ways of cleaning and grouting depending on the scope of the project, local regulations, and corporate preferences. It is beyond the scope of this practice to discuss all of these methods in detail. A detailed explanation of grouting procedures is discussed in Guide D6001.

1.4 The electronic cone penetrometer may be be combined with other direct push sampling and testing methods. Estimated soil types can be confirmed by soil sampling (Guide D6282). Cone penetrometer tests are often used to locate aquifers for installation of wells (Practice D5092, Guide D6274). Cone penetrometers can be equipped with additional sensors for groundwater quality evaluations (Practice D6187). Location of other sensors must conform to requirements of Test Method D5778.

1.5 This practice is applicable only at sites where chemical (organic and inorganic) wastes are a concern and is not intended for use at radioactive or mixed (chemical and radioactive) waste sites.

1.6 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.7 *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.*

1.8 *Standard Practice—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 means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C150 Specification for Portland Cement

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

D5088 Practice for Decontamination of Field Equipment Used at Waste Sites

D5092 Practice for Design and Installation of Groundwater Monitoring Wells

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

[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

Current edition approved May 1, 2010. Published June 2010. Originally approved in 1996. Last previous edition approved in 2003 as D6067–96(2003) DOI: 10.1520/D6067-10.

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

[3] 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**

D6001 Guide for Direct-Push Groundwater Sampling for Environmental Site Characterization
D6187 Practice for Cone Penetrometer Technology Characterization of Petroleum Contaminated Sites with Nitrogen Laser-Induced Fluorescence
D6274 Guide for Conducting Borehole Geophysical Logging - Gamma
D6282 Guide for Direct Push Soil Sampling for Environmental Site Characterizations

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms related to this standard, refer to Terminology D653.

3.1.2 *hydraulic conductivity (in field aquifer tests), n*—the volume of water at the existing kinematic viscosity that will move in a unit time under a hydraulic gradient through a unit area measured at right angles to the direction of flow.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *baseline, n*—a set of zero load readings, expressed in terms of apparent resistance, that are used as reference values during performance of testing and calibration.

3.2.2 *bentonite, n*—the common name for drilling fluid additives and well construction products consisting mostly of naturally occurring sodium montmorillonite. Some bentonite products have chemical additives that may affect water quality analyses.

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

3.2.4 *cone resistance, q_c, n*— the end bearing component of penetration resistance.

3.2.5 *cone sounding, n*—a series of penetration readings performed at one location over the entire depth when using a cone penetrometer.

3.2.6 *dissipation test, n*—test where the dissipation of excess pore water pressure generated during push is monitored to evaluate depth specific hydraulic conductivity and final pressure head of the soil when penetration is stopped.

3.2.6.1 *Discussion*—Either complete or 50 % dissipation is monitored. Complete dissipation can be used to determine equilibrium pore water pressure and thus hydrostatic head at a point in the aquifer. The time required for dissipation depends on the soil type.

3.2.7 *electronic cone penetrometer, n*—a friction cone penetrometer that uses force transducers, such as strain gage load cells, built into a nontelescoping penetrometer tip for measuring within the penetrometer tip, the components of penetration resistance.

3.2.8 *electronic piezocone penetrometer, n*— an electronic cone penetrometer equipped with a low-volume fluid chamber, porous element, and pressure transducer for determination of pore pressure at the porous element soil interface.

3.2.9 *end bearing resistance, n*—same as cone resistance or tip resistance, q_c.

3.2.10 *equilibrium pore water pressure, u_o, n*—at rest water pressure at depth of interest. Same as hydrostatic head. **D653**

3.2.11 *excess pore water pressure, u–u_o, n*—the difference between pore pressure measured as the penetratoin occurs, u, and estimated equilibrium pore water pressure, u_o. Excess pore pressure can be either positive or negative.

3.2.12 *friction ratio, R_f, n*— the ratio of friction sleeve resistance, f, to cone resistance, q_c, measured with the middle of the friction sleeve at the same depth as the cone point. It is usually expressed as a percentage.

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

3.2.14 *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.

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

3.2.16 *local friction, n*—same as friction sleeve resistance.

3.2.17 *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.

3.2.18 *penetrometer tip, n*—the terminal body (end section) of the penetrometer which contains the active elements that sense the components of penetration resistance.

3.2.19 *piezocone, n*—same as electronic piezocone penetrometer.

3.2.20 *piezocone pore pressure, u, n*—fluid pressure measured using the piezocone penetration test.

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

3.2.22 *sleeve friction or resistance, n*—same as friction sleeve resistance, f.

3.2.23 *stratigraphy, n*—a classification of soil behavior type that categorizes soils of lateral continuity (**2**).

3.3 *Acronyms:*

3.3.1 *CPT*—Cone Penetration Test.

3.3.2 *PCPT or CPTu*—Piezocone Penetration Test. **D5778**

3.4 *Abbreviations:*

3.4.1 t_{50}—time for dissipation of 50 percent of the excess excess pore water pressure during dissipation tests.

4. Significance and Use

4.1 Environmental site characterization projects almost always require information regarding subsurface soil stratigraphy and hydraulic parameters related to groundwater flow rate and direction. Soil stratigraphy often is determined by various drilling procedures and interpreting the data collected on borehole logs. The electronic piezocone penetrometer test is another means of determining soil stratigraphy that may be faster, less expensive, and provide greater resolution of the soil units than conventional drilling and sampling methods. For environmental site characterization applications, the electronic piezocone also has the additional advantage of not generating contaminated cuttings that may present other disposal problems (**3**, **4**, **2**, **5**, **6**, **7**, **8**, **9**). Investigators may obtain soil samples from adjacent borings for correlation purposes, but prior information or experience in the same area may preclude the need for borings (**1**). Most cone penetrometer rigs are equipped with direct push soil samplers (Guide D6282) that can be used to confirm soil types.

4.2 The electronic piezocone penetration test is an in situ investigation method involving:

4.2.1 Pushing an electronically instrumented probe into the ground (see Fig. 1 for a diagram of a typical cone penetrometer). The position of the pore pressure element may vary but is typically located in the u_2 position (Test Method D5778).

4.2.2 Recording force resistances, such as tip resistance, local friction, and pore water pressure.

4.2.3 Data interpretation.

4.2.3.1 The most common use of the interpreted data is stratigraphy based on soil behavior types. Several charts are available. A typical CPT soil behavior type classification chart is shown in Figs. 2 and 3 (**10**). The first step in determining the extent and motion of contaminants is to determine the subsurface stratigraphy. Since the contaminants will migrate with groundwater flowing through the more permeable strata, it is impossible to characterize an environmental site without valid stratigraphy. Cone penetrometer data has been used as a stratigraphic tool for many years. The pore pressure channel of the cone can be used to determine the depth to the water table or to locate perched water zones.

4.2.3.2 Hydraulic conductivity can be estimated based on soil behavior type (Figs. 4 and 5). These estimates span two to three orders of magnitude. Alternately, pore pressure data (4.5) can be used for refined estimates of hydraulic conductivity.

4.3 When attempting to retrieve a soil gas or water sample, it is advantageous to know where the bearing zones (permeable zones) are located. Although soil gas and water can be retrieved from on-bearing zones such as clays, the length of time required usually makes it impractical. Soil gas and water samples can be retrieved much faster from permeable zones, such as sands. The cone penetrometer tip and friction data generally can identify and locate the bearing zones and nonbearing zones less than a foot thick very accurately.

4.4 The electronic cone penetrometer test is used in a variety of soil types. Lightweight equipment with reaction weights of less than 10 tons generally are limited to soils with relatively small grain sizes. Typical depths obtained are 20 to 40 m, but depths to over 70 m with heavier equipment

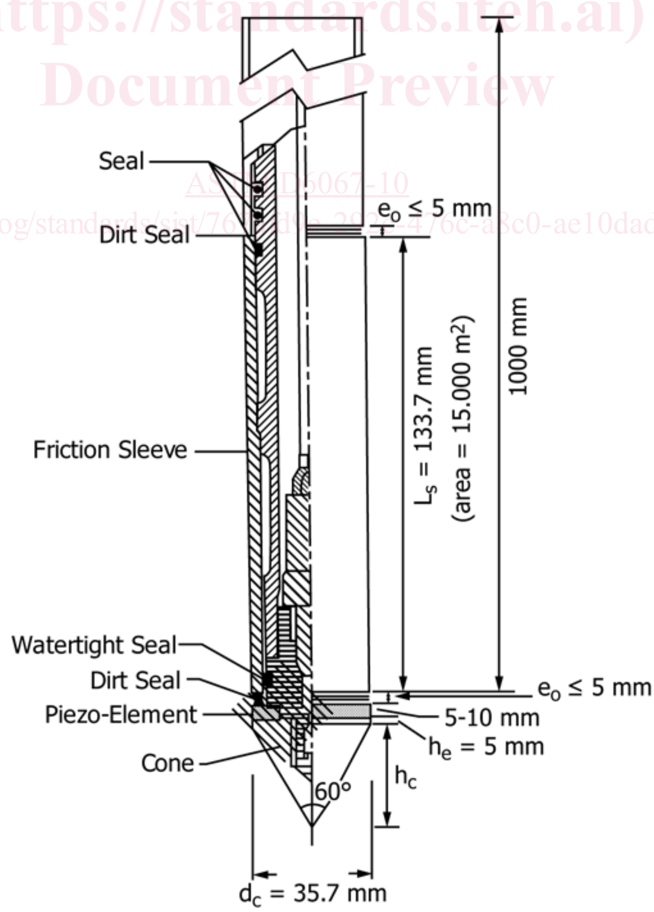
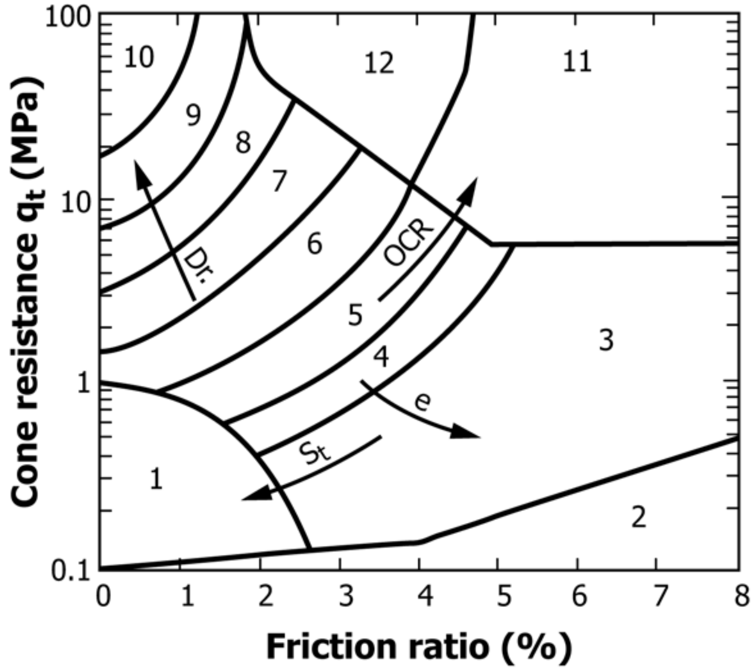


FIG. 1 Electronic Cone Penetrometer (Test Method D5778-07)



Zone	Soil Behavior Type
1	Sensitive fine grained
2	Organic material
3	Clay
4	Silty Clay to clay
5	Clayey silt to silty clay
6	Sandy silt to clayey silt
7	Silty sand to sandy silt
8	Sand to silty sand
9	Sand
10	Gravelly sand to sand
11	Very stiff fine grained*
12	Sand to clayey sand*

** Overconsolidated or cemented*

FIG. 2 Simplified Soil Classification Chart for Standard Electric Friction Cone (Robertson and Campanella 1986) (10)

weighing 20 tons or more are not uncommon. Since penetration is a direct result of vertical forces and does not include rotation or drilling, it cannot be utilized in rock or heavily cemented soils. Depth capabilities are a function of many factors including:

4.4.1 The force resistance on the tip,

4.4.2 The friction along the push rods,

4.4.3 The force and reaction weight available,

4.4.4 Rod support provided by the soil, and

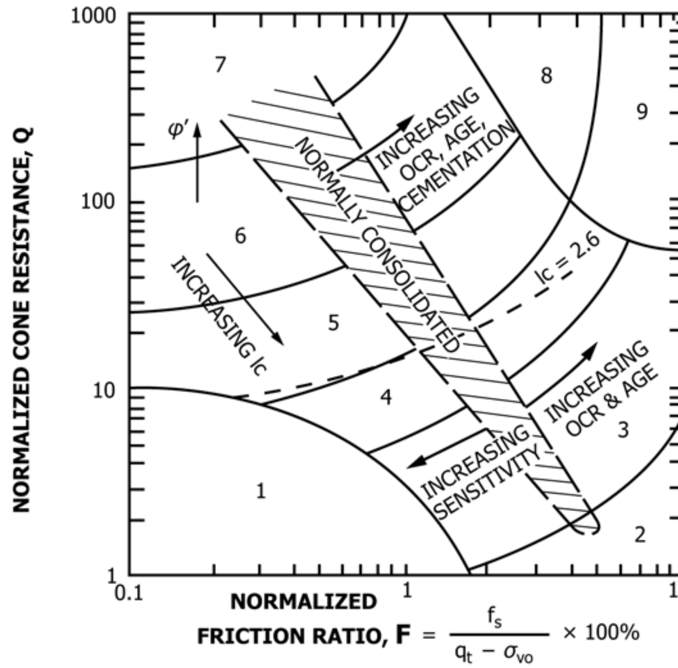
4.4.5 Large grained materials causing nonvertical deflection or unacceptable tool wear.

4.4.6 Depth is always site dependent. Local experience is desirable.

4.5 *Pore Pressure Data:*

4.5.1 Excess pore water pressure data often are used in environmental site characterization projects to identify thin soil layers that will either be aquifers or aquitards. The pore pressure channel often can detect these thin layers even if they are less than 20 mm thick.

4.5.2 Excess pore water pressure data taken during push are used to provide an indication of relative hydraulic conductivity. Excess pore water pressure is generated during an electronic cone penetrometer test. Generally, high excess pore water pressure indicates the presence of aquitards (clays), and low excess pore water pressure indicates the presence of aquifers (sands). This is not always the case, however. For example, some silty sands and over-consolidated soils generate negative pore pressures if monitored above the shoulder of the cone tip. See Fig. 1. The balance of the data, therefore, also must be evaluated. There have been methods proposed to estimate hydraulic conductivity from excess pore water pressure measurements (**11**, **12**, **13**).



Zone	Soil Behavior Type	I_c
1	*Sensitive, fine grained*	N/A
2	*Organic soils – peats*	>3.6
3	*Clays – silty clay to clay*	2.95–3.6
4	*Silt mixtures – clayey silt to silty clay*	2.60–2.95
5	*Sand mixtures – silty sand to sandy silt*	2.05–2.6
6	*Sands – clean sand to silty sand*	1.31–2.05
7	*Gravelly sand to dense sand*	<1.31
8	*Very stiff sand to clayey sand**	N/A
9	*Very stiff, fine grained**	N/A

**Heavily overconsolidated or cemented*

FIG. 3 Normalized Soil Classification Chart for Standard Electric Friction Cone (Robertson 1990) (10)

Zone	*Soil Behavior Type (SBT)*	*Range of Permeability k (m/s)*
1	Sensitive fine grained	3×10^{-9} to 3×10^{-8}
2	Organic soils	1×10^{-8} to 1×10^{-6}
3	Clay	1×10^{-10} to 1×10^{-9}
4	Silty clay to clay	1×10^{-9} to 1×10^{-8}
5	Clayey silt to silty clay	1×10^{-8} to 1×10^{-7}
6	Sandy silt to clayey silt	1×10^{-7} to 1×10^{-6}
7	Silty sand to sandy silt	1×10^{-5} to 1×10^{-6}
8	Sand to silty sand	1×10^{-5} to 1×10^{-4}
9	Sand	1×10^{-4} to 1×10^{-3}
10	Gravelly sand to dense sand	1×10^{-3} to 1
11	Very stiff fine-grained soil	1×10^{-8} to 1×10^{-6}
12	Very stiff sand to clayey sand	3×10^{-7} to 3×10^{-4}

FIG. 4 Estimation of Hydraulic Conductivity from Non-Normalized CPT SBT Chart (10)

Zone	*Soil Behavior Type (SBT_N)*	*Range of Permeability k (m/s)*
1	Sensitive fine grained	3×10^{-9} to 3×10^{-8}
2	Organic soils	1×10^{-8} to 1×10^{-6}
3	Clay	1×10^{-10} to 1×10^{-9}
4	Silt mixtures	3×10^{-9} to 1×10^{-7}
5	Sand mixtures	1×10^{-7} to 1×10^{-5}
6	Sands	1×10^{-5} to 1×10^{-3}
7	Gravelly sands to dense sands	1×10^{-3} to 1
8	Very stiff sand to clayey sand	1×10^{-8} to 1×10^{-6}
9	Very stiff fine-grained soil	1×10^{-8} to 1×10^{-6}

FIG. 5 Estimation of Hydraulic Conductivty from Normalized CPT VSBT Chart (10)

4.5.3 *Dissipation Tests:*

4.5.3.1 In general, since the groundwater flows primarily through sands and not clays, modeling the flow through the sands is most critical. The pore pressure data also can be monitored with the sounding halted. This is called a pore pressure dissipation test. A rapidly dissipating pore pressure indicates the presence of an aquifer while a very slow dissipation indicates the presence of an aquitard. Fig. 6 shows one proposed relationship between dissipation time, soil type, and hydraulic conductivity (**14**).

4.5.3.2 A pore pressure decay in a sand is almost instantaneous. The permeability (hydraulic conductivity), therefore, is very difficult to measure in a sand with a cone penetrometer. As a result, until recently the cone penetrometer was not used very often for measuring the permeability of sands in environmental applications. Newly developed hardware and software now allow for high resolution data collection even in rapidly dissipating sand formations (**15**).

4.5.3.3 A thorough study of groundwater flow also includes determining where the water cannot flow. Cone penetrometer pore pressure dissipation tests can be used very effectively to study the permeability of aquitards (**16**).

4.5.3.4 The pore pressure data also can be used to estimate the depth to the water table or identify perched water zones. This is accomplished by allowing the excess pore water pressure to equilibrate and then subtract the appropriate head pressure. Due to high excess pore pressures being generated, typical pore pressure transducers are configured to measure pressures up to 3.5 MPa. Since transducer accuracy is a function of maximum range, this provides a relative depth to water level accuracy of about ±150 mm. Better accuracy can be achieved if the operator allows sufficient time for the transducer to dissipate the heat generated while penetrating dry soil above the water table. Lower pressure transducers are sometimes used just for the purpose of determining the depth to the water table more accurately. For example, a 175-KPa transducer would provide accuracy that is better than 10 mm. Incorporation of a temperature transducer and appropriate calibration allows for high precision and rapid data collection. Caution must be used, however, to prevent these transducers from being damaged due to a quick rise in excess pressure. Some newer systems allow for large burst pressure protection without hysteresis, which enables users to collect data in highly stratified environments without as much concern for transducer damage.

4.5.3.5 When coupled with appropriate models, three dimensional gradient can be derived from final pressure values collected from multiple CPT locations. Once gradient distributions have been derived, and hydraulic conductivity and effective porosity distributions have been generated, seepage velocity distributions can be derived and visualized. This type of information is critical to environmental investigations and remediation design. If contaminant concentration distributions are known, the same software can be used to derive three dimensional distributions of contaminant mass flux.

4.6 For a complete description of a typical geotechnical electronic cone penetrometer test, see Test Method D5778.

4.7 This practice tests the soil in situ. Soil samples are not obtained. The interpretation of the results from this practice provides estimates of the types of soil penetrated. Investigators may obtain soil samples from adjacent borings for correlation purposes, but prior information or experience in the same area may preclude the need for borings.

4.8 Certain subsurface conditions may prevent cone penetration. Penetration is not possible in hard rock and usually not possible in softer rocks, such as claystones and shales.

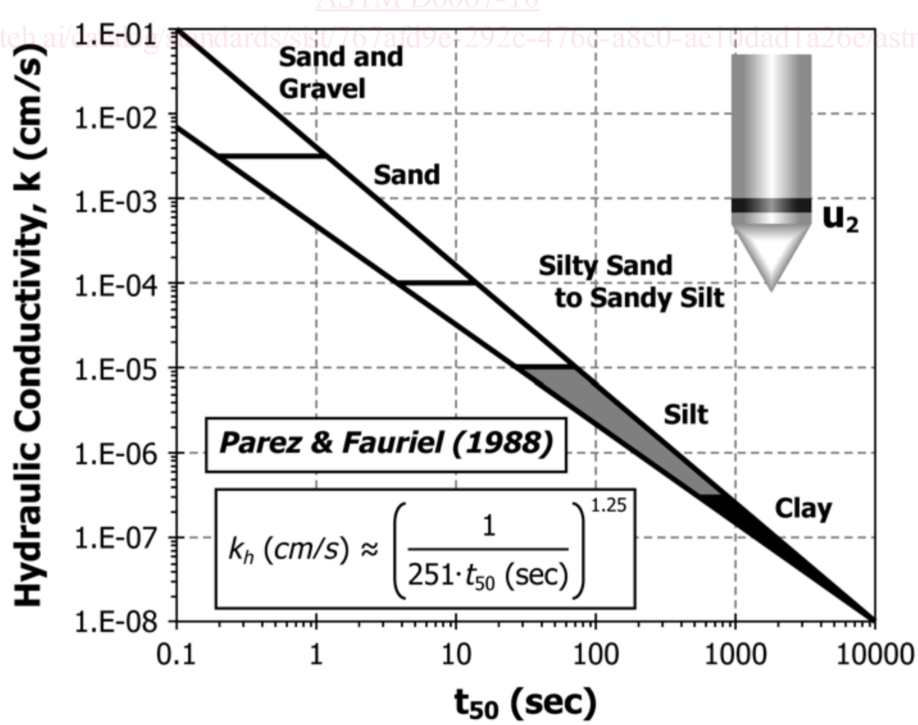


FIG. 6 Proposed Relationship between T50 Dissipation Time, Soil Type, and Hydraulic Conductivity (15)