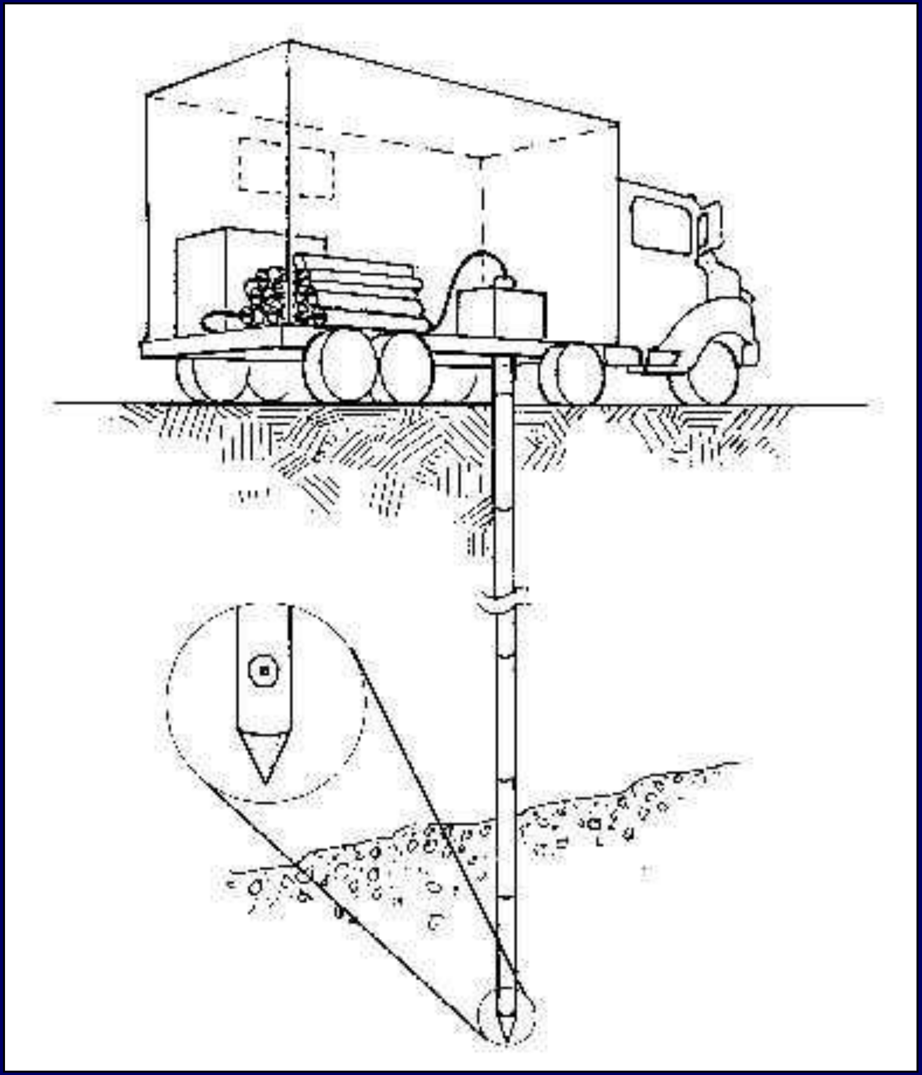
An Introduction to the Cone Penetration Test

Course Goals

1. Become familiar with the methods and limitations of the Cone Penetration Test
2. Learn techniques for presenting and interpreting data
3. Learn the uses of CPT data in geotechnical design
    1. Develop a stratigraphic model of the project site
    2. Estimation of soil engineering properties
    3. Predict the performance of a shallow foundation subject to vertical or inclined loads
    4. Estimate the nominal resistance of a deep foundation subject to a vertical load
    5. Predict the susceptibility of the foundation soils to liquefaction

Advantages of the CPT compared to boreholes



- Rapid
- Continuous
- In-situ measurement of soil response
- Minimal operator influence on the data

What is the most significant difference between a sounding and a borehole?

A brief history of CPT development

- 1931: Dutch push cone with rods
- 1946: Delf Lab manufactures hand operated cone
- 1947: Mantle Cone developed (sleeve resistance)
- 1953: French add hydraulics
- 1964: Fugro Consulting starts commercial use of electric penetrometer
- 1969: Begemann adds friction sleeve
- 1975: French introduce pore pressure transducers
- 1975: ASTM standard D-3441 established
- 1975-present: introduction of the seismic cone, lateral stress cone, piezo-lateral stress cell, vibratory cone, etc.

American Standards

Designation: D 3441 – 98

Standard Test Method for Mechanical Cone Penetration Tests of Soil[1]

This standard is issued under the fixed designation D 3441; 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 Department of Defense.

1. Scope

1.1 This test method covers the determination of end bearing and side friction, the components of penetration resistance that are developed during the steady slow penetration of a pointed rod into soil. This test method is sometimes referred to as the Dutch Cone Test or Cone Penetration Test and is often abbreviated as CPT.

1.2 This test method includes the use of mechanical cone and friction-cone penetrometers. It does not include the use of electric and electronic cones or data interpretation.

1.2.1 The use of electric and electronic cones is covered in Test Method D 5578.

1.3 Mechanical penetrometers of the type described in this test method operate incrementally, using a telescoping penetrometer tip, resulting in no movement of the push rods during the measurement of the resistance components. Design constraints for mechanical penetrometers preclude a complete separation of the end-bearing and side-friction components.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are provided for information only.

1.5 *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:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids

D 5778 Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soil

2.2 *Other Standards:*

USBR D 7020 Performing Cone Penetration Testing of Soils-Mechanical Method *Earth Manual*, Part II, Third Edition, U.S. Department of the Interior, Bureau of Reclamation, U.S. Government Printing Office, 1990

"International Reference Test Procedure for the Cone Penetration Test (CPT)," Proceedings of the First International Symposium for Penetration Testing, ISOPT-1 DeRuiter, ed., Blakema, Rotterdam, ISBN 90 6191 8014, 1988.

3. Terminology

3.1 *Definitions:*

3.1.1 *cone, n*—the cone-shaped point of the penetrometer tip, upon which the end-bearing resistance develops.

3.1.2 *cone penetrometer, n*—an instrument in the form of a cylindrical rod with a conical point designed for penetrating soil and soft rock and for measuring the end-bearing component of penetration resistance.

3.1.3 *cone resistance*, or *end-bearing resistance* q_c, *n*—the resistance to penetration developed by the cone equal to the vertical force applied to the cone divided by its horizontally projected area.

3.1.4 *cone sounding, n*—the entire series of penetration tests performed at one location when using a cone penetrometer.

3.1.5 *friction-cone penetrometer, n*—a cone penetrometer with the additional capability of measuring the local side friction component of penetration resistance.

3.1.6 *friction cone sounding, n*—the entire series of penetration tests performed at one location when using a friction cone penetrometer.

3.1.7 *friction ratio*, R_f, *n*—the ratio of friction resistance to cone resistance, f_s/q_c, expressed in percent.

NOTE 1—The friction ratio for mechanical penetrometers is not comparable to the friction ratio measured by electronic or electrical penetrometer (Test Method D 5778). Users should verify that the application of empirical correlations such as those predicting soil type from R_f are for the correct penetrometer.

3.1.8 *friction resistance*, f_s, *n*—the resistance to penetration developed by the friction sleeve, equal to the vertical force applied to the sleeve divided by its surface area. This resistance consists of the sum of friction and adhesion.

3.1.9 *friction sleeve, n*—a section of the penetrometer tip upon which the local side-friction resistance develops.

3.1.10 *inner rods, n*—rods that slide inside the push rods to extend the tip of a mechanical penetrometer.

3.1.11 *mechanical penetrometer, n*—a penetrometer that uses a set of inner rods to operate a telescoping penetrometer

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

Current edition approved May 10, 1998. Published January 1999. Originally published as D 3441 – 75 T. Last previous edition D 3441 – 94.

Designation: D 5778 – 95 (Reapproved 2000)

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

This standard is issued under the fixed designation D 5778; 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 to penetration of a conical pointed penetrometer as it is advanced into subsurface soils at a slow, steady rate.

1.2 This test method is 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 slow, steady rate.

1.3 This test method applies to friction-cone penetrometers of the electronic type.

1.4 This test method can be used to determine pore pressure development during push of a piezocone penetrometer. Pore pressure dissipation, after a push, can also be monitored for correlation to soil compressibility and permeability.

1.5 Other sensors such as inclinometer, seismic, and temperature sensors may be included in the penetrometer to provide useful information. The use of an inclinometer is highly recommended since it will provide information on potentially damaging situations during the sounding process.

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

1.7 The values stated in SI units are to be regarded as standard. Within Section 13 on Calculations, SI metric units are considered the standard. Other commonly used units such as the inch-pound system are shown in brackets. The various data reported should be displayed in mutually compatible units as agreed to by the client or user. Cone tip projected area is commonly referred to in centimetres for convenience. The values stated in each system are not equivalents; therefore, each system must be used independently of the other.

NOTE 1—This test method does not include hydraulic or pneumatic penetrometers. However, many of the procedural requirements herein could apply to those penetrometers.

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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

E 4 Practice for Force Verification of Testing Machines[3]

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions are in accordance with Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparent load transfer*—apparent resistance measured on either the cone or friction sleeve of an electronic cone penetrometer while that element is in a no-load condition but the other element is loaded. Apparent load transfer is the sum of cross talk, subtraction error, and mechanical load transfer.

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

3.2.3 *cone*—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 projected (horizontal plane) surface area or cone base area of 10 or 15 cm^2, and a cylindrical extension behind the cone base.

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

3.2.5 *cone penetrometer*—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.

3.2.6 *cone resistance*, q_c—the end-bearing component of penetration resistance. The resistance to penetration developed on the cone is equal to the vertical force applied to the cone divided by the cone base area.

3.2.7 *corrected total cone resistance*, q_t—tip resistance

[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.

Current edition approved Sept. 10, 1995. Published January 1996.

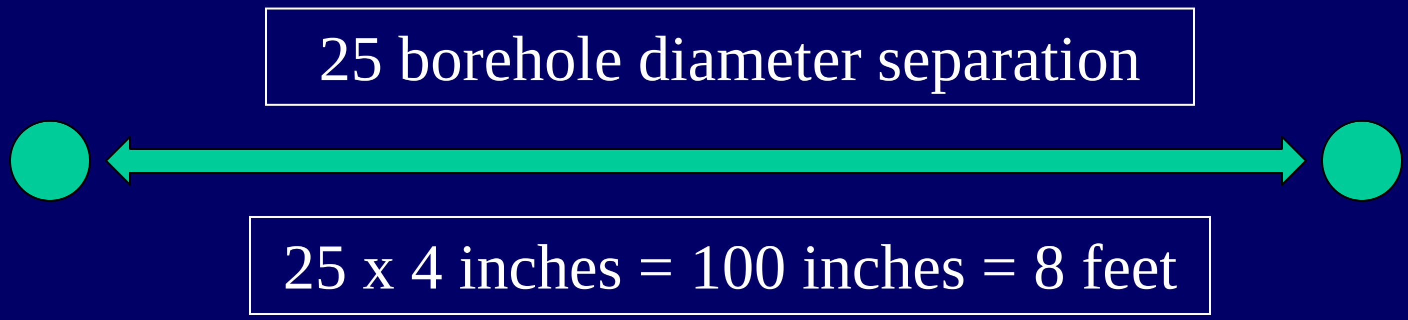
[2] *Annual Book of ASTM Standards*, Vol 04.08

[3] *Annual Book of ASTM Standards*, Vol 03.01.

ASTM Test Method D 3441-98 (Mechanical Cone)

ASTM Test Method D 5778-07 (Electronic Friction Cone and Piezo Cone)

How close can a CPT be to a borehole without effect on the data?



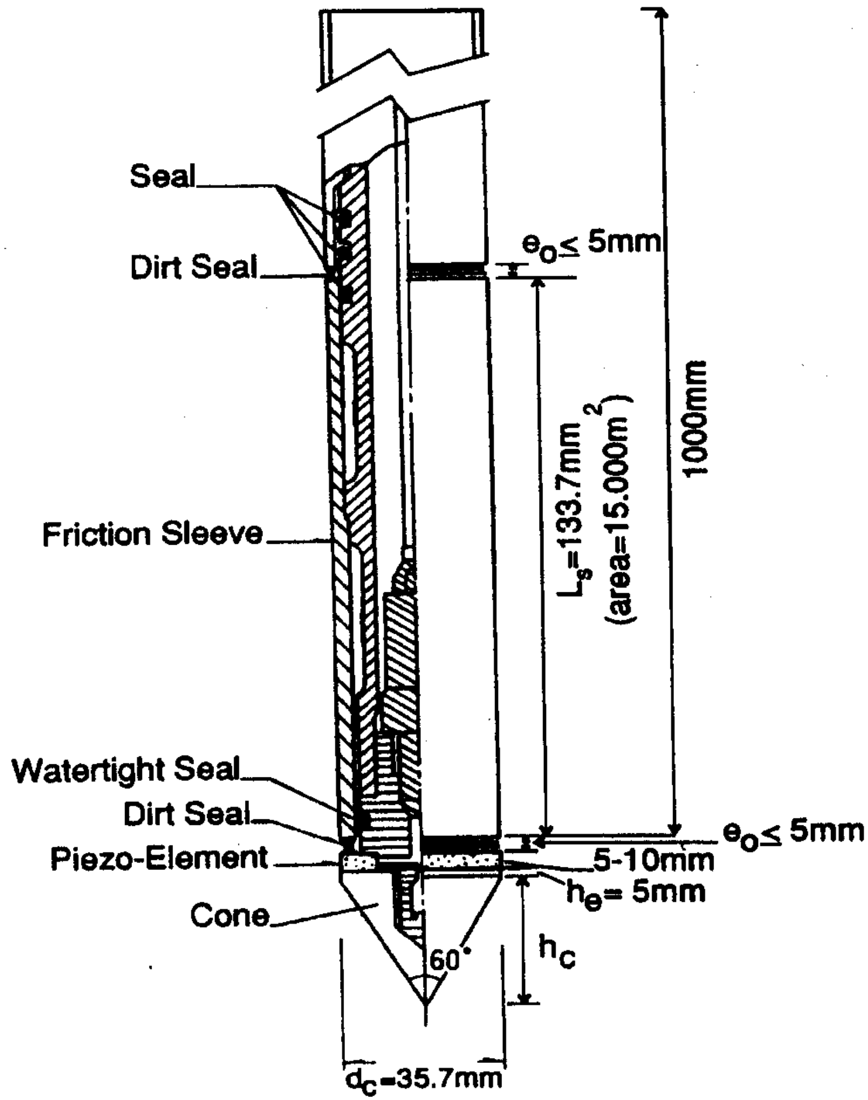
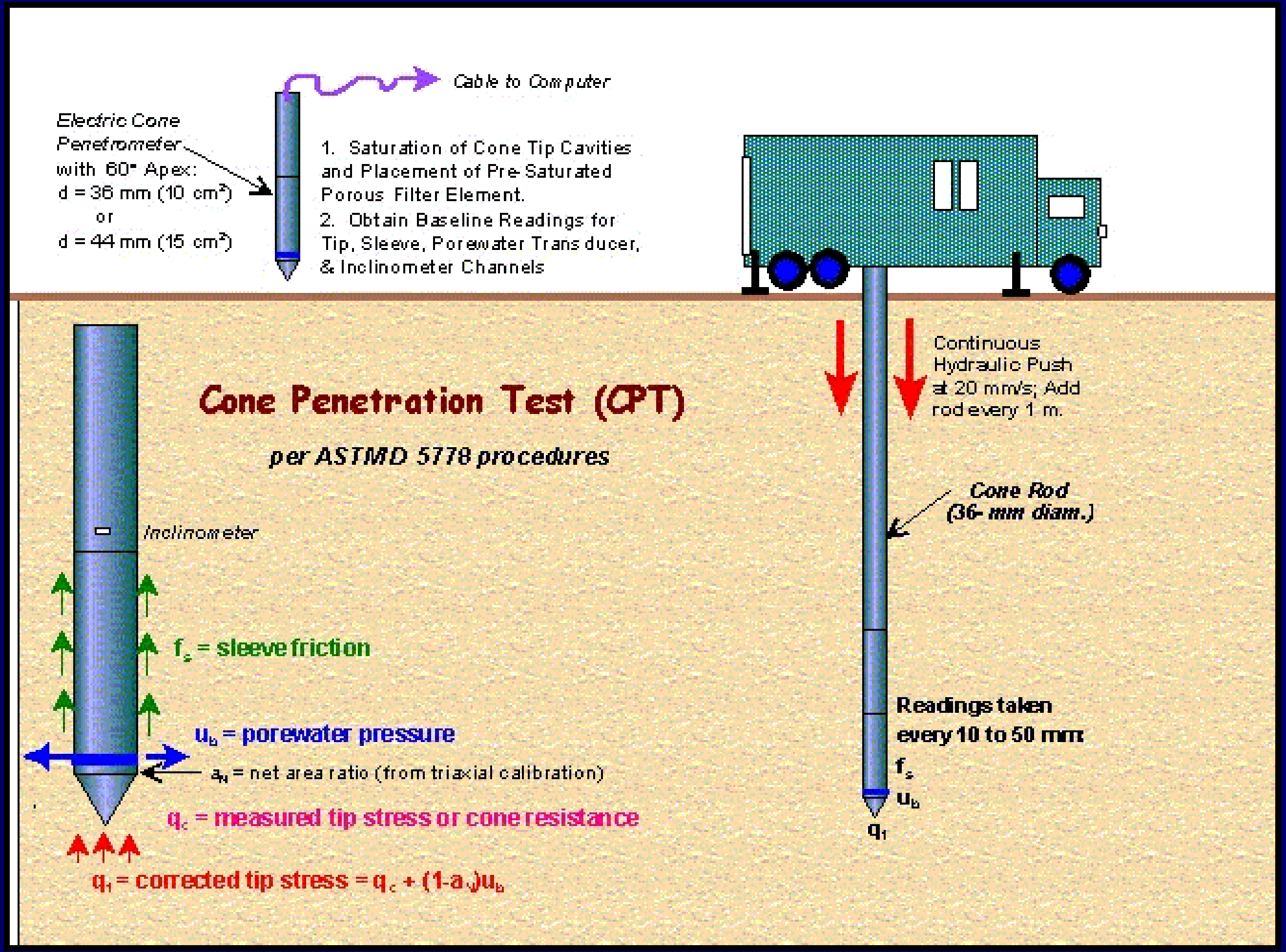


FIG. 3 Example of a Reference Penetrometer With a Fixed Cone and With Friction Sleeve

ASTM Test Method D 5778-07



- CPT and CPTu
- Both Measure:
  - Cone Resistance: $q_c = Q_c / A_c$
  - Friction Resistance: $f_s = Q_s / A_s$

Unsuitable subsurface conditions

- Gravel and gravelly sand
- Weak rock
- Cemented soils
- Strong soils overlain by more than 10 feet of very weak soils

Table 1.2 - Truck with 20 ton push capability

	CLAY			SAND		
Depth (feet)	Soft	Stiff	Hard	Loose	Medium	Dense
15	*	*	*	*	*	*
30	*	*	*	*	*	*
60	*	*	*	*	*	*
90	*	*		*	*	
120	*			*		
150	*			*		
200	*					
250	*					
300						

TABLE 14
SPECIAL TECHNIQUES FOR INCREASED SUCCESS OF CONE PENETRATION IN HARD GEOMATERIALS

Advancing Technique	Reference	Comments/Remarks
Heavy 20-Ton Deadweight CPT Trucks and Track Rigs	Mayne et al. (1995)	Increased weight reaction over standard drill rig
Friction Reducer	van de Graaf and Schenk (1988)	Effective in frictional soils, but not so in very dense sands
Cycling of Rods (up and down)	Shinn (1995, personal communication)	Local encounter in thin hard zones of soil
Large diameter penetrometer (i.e., 44-mm cone; 36-mm rods)	van de Graaf and Schenk (1988)	Works like friction reducer
Guide Casing: Double Set of Rods; Standard 36-mm Rods Supported Inside Larger 44-mm Rods; Prevents Buckling	Peuchen (1988)	Works well in situations involving soft soils with dense soils at depth
Drill Out (downhole CPTs)	NNI (1996)	Alternate between drilling and pushing
Mud Injection	Van Staveren (1995)	Needs pump system for bentonitic slurry
Earth Anchors	Pagani Geotechnical Equipment Geoprobe Systems	Increases capacity for reaction
Static–Dynamic Penetrometer	Sanglerat et al. (1995)	Switches from static mode to dynamic mode when needed
Downhole Thrust System	Zuidberg (1974)	Single push stroke usually limited to 2 m or 3 m
Very Heavy 30- and 40-Ton Rigs	Bratton (2000)	After large 20-ton rig arrives at site, added mass for reaction
ROTAP—Outer Coring Bit	Sterkx and Van Calster (1995)	Special drilling capabilities through cemented zones
CPTWD	Sacchetto et al. (2004)	Cone penetration test while drilling
Sonic CPT	Bratton (2000)	Use of a vibrator to facilitate penetration through gravels and hard zones
EAPS	Farrington (2000); Shinn and Haas (2004); Farrington and Shinn (2006)	Wireline systems for enhanced access penetrometer system

Adapted and modified after Peuchen 1998.
NNI = Nederlands Normalisatie Institute; CPTWD = cone penetration test while drilling; EAPS = enhanced access penetrometer system.

Caltrans dynamic cone penetrometer

Becker Penetration Test

- A suitable tool for gravel and gravelly sand
- Single or double acting diesel hammer
- Double casing is driven
- Closed tip
- Count the number of blows per foot of penetration

Equipment and Testing Procedures

The basic components of the 1.75 inch (44.45 mm) diameter cone penetrometer tip

Also known as a 15 cm^2 cone.

- Cone tip
- Friction sleeve
- Inclinometer

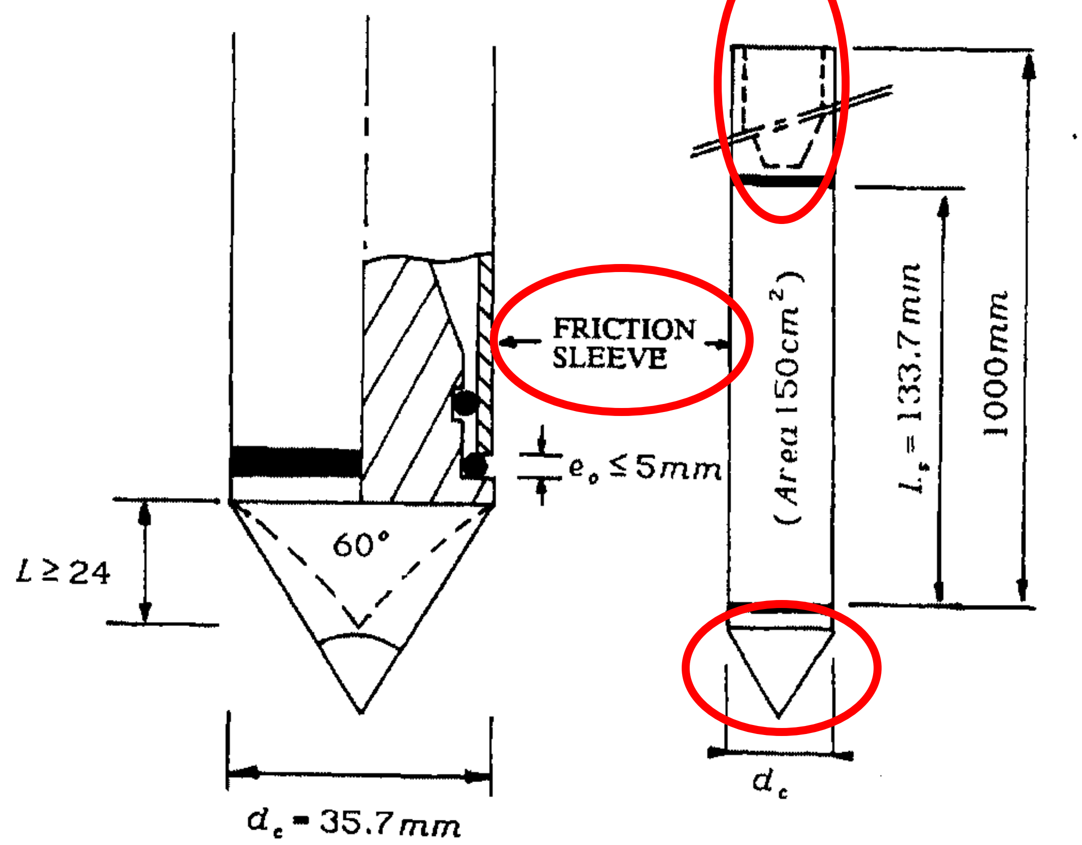


FIG. 2.3. Standard Dimensions of the Electric Penetrometer Tip

All CPT tips contain a 2 channel inclinometer

- Resolution of 0.1 degrees
- Full scale output is 15 degrees
- Heading of cone penetrometer tip never known
- Sudden changes in heading are caused by:
  - rocks
  - boundaries of underlying harder layers

The cone penetrometer tips used by Caltrans and made by Vertek are:

- Caltrans owns 3 multi-channel digital cones:
  - Cone tip resistance
  - Local friction resistance
  - Pore pressure behind the cone tip
  - Temperature
  - Inclination

$7500 each

- Caltrans owns 2 digital cones which also have:
  - Seismic compression or shear wave receiver

$8500 each

Alternate locations for the porous element of a piezocone

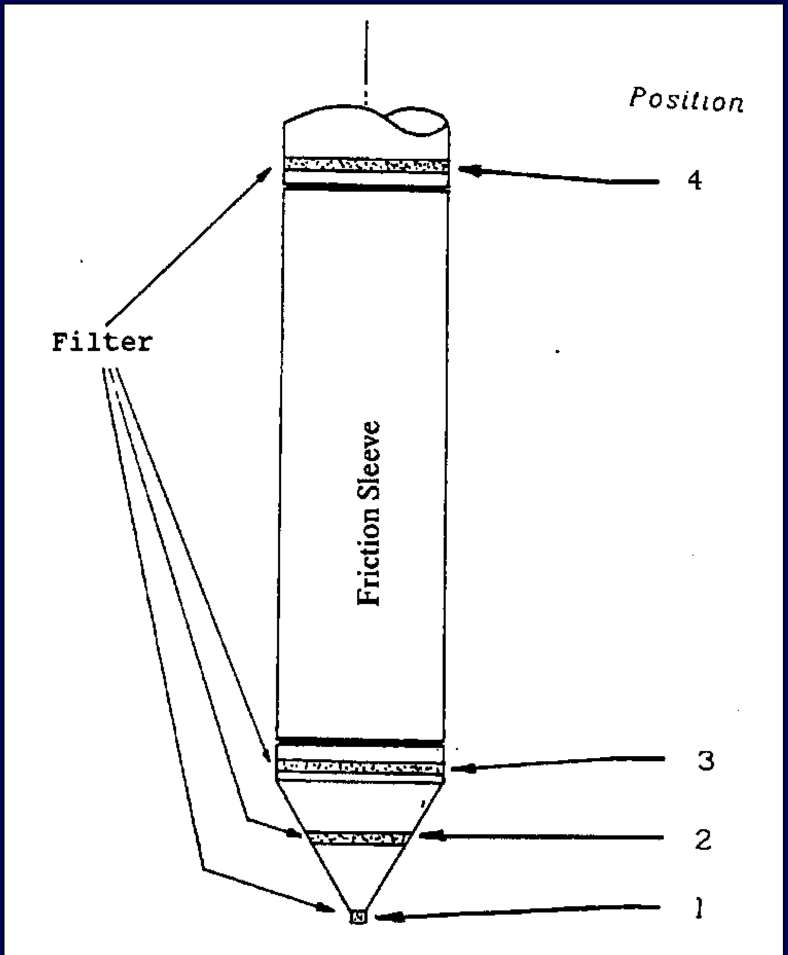
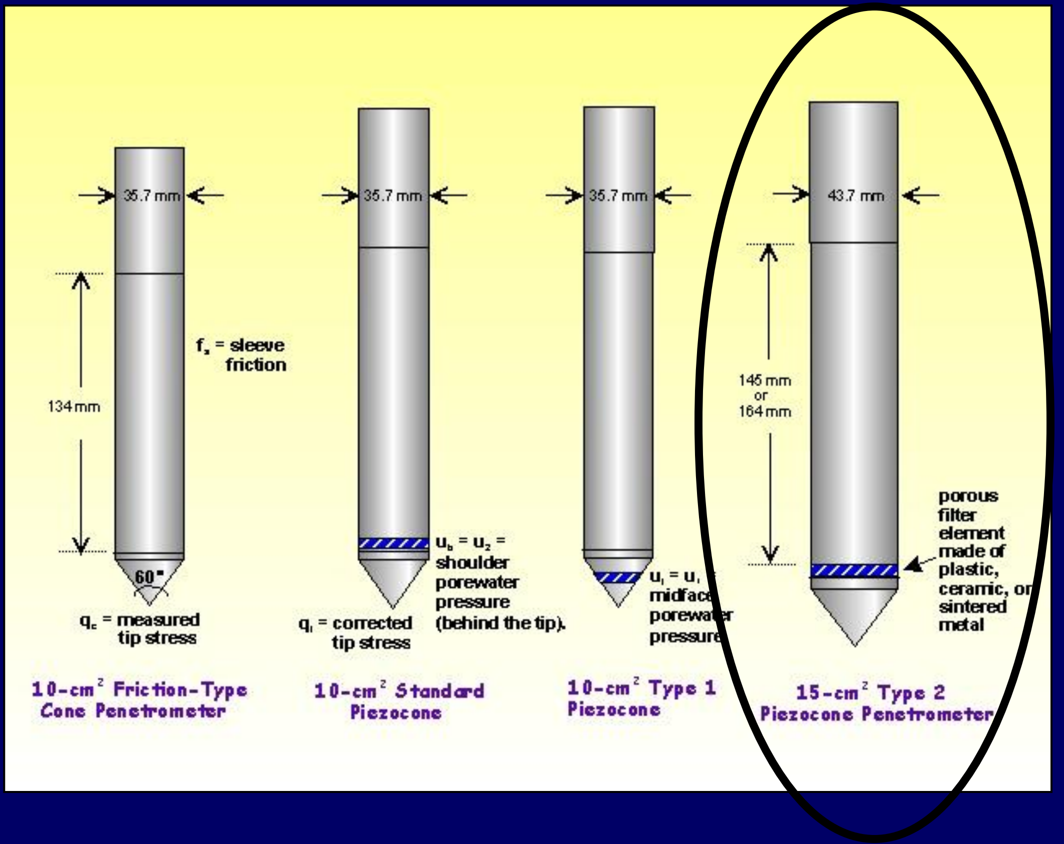


FIG. 2.6. Location of the Porous Filter



The porous element installed in the cone "shoulder" location of a Type 2 cone tip.

Other cone penetrometer tip instruments

- Vision or optical
- Electrical resistivity
- Ultra violet induced fluorescence
- Gamma
- Piston sampler
- Grout

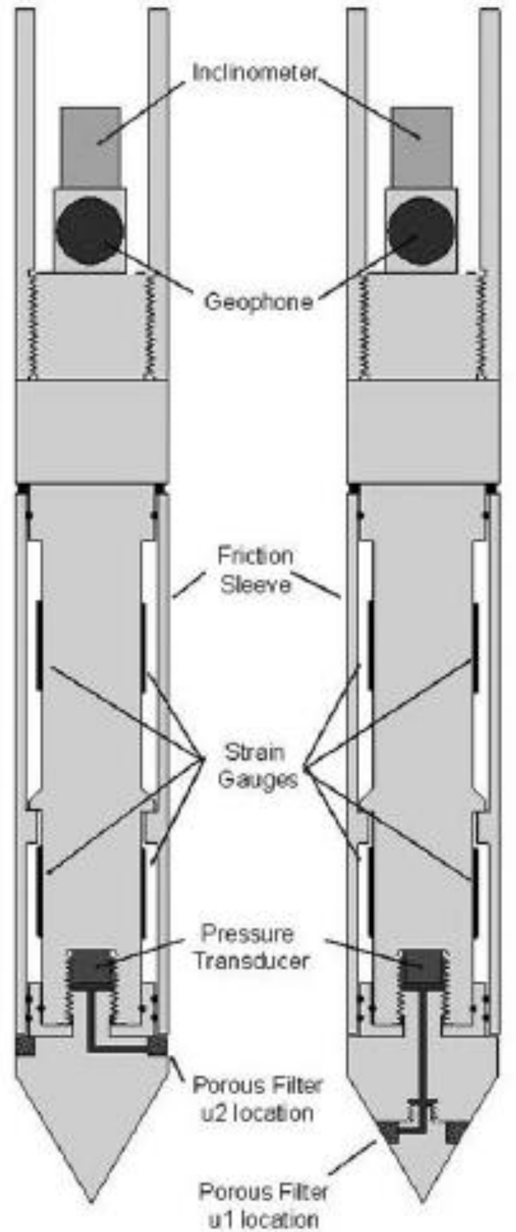
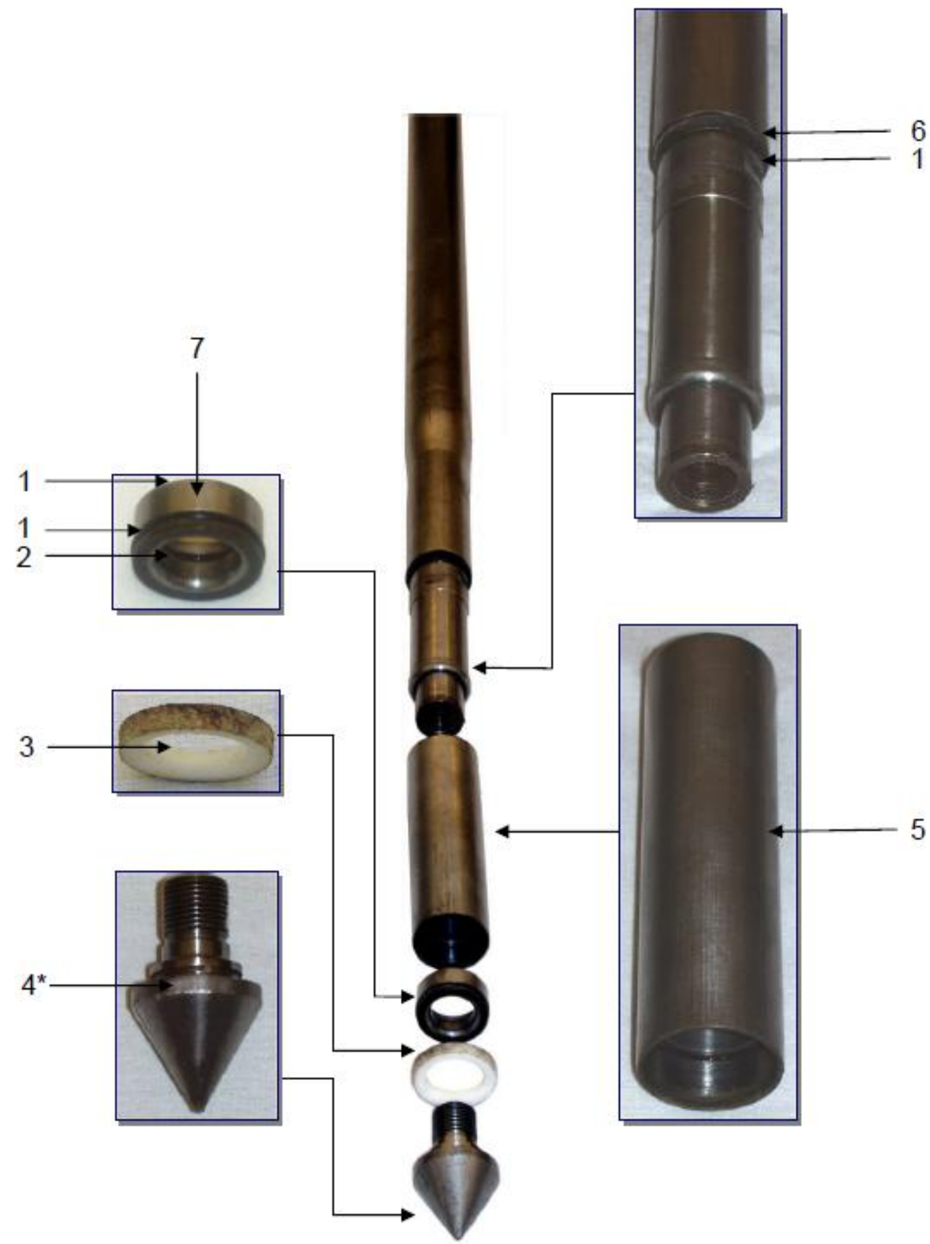


FIGURE 9 Basic internal schematic of an electric cone penetrometer.

DIGITAL CONE EXPLODED DIAGRAM

(Components not shown to scale.)



The interior of "subtraction" cones

Push rods

- One meter long
- Tapered threads
- Hollow with data cable threading through
- 40 rods on the rack

CPT carrier vehicle configurations

- GVW 46,000 pounds
- 25 feet long
- 8 feet wide
- 12.5 feet high for travel
- 13.5 feet high when testing

Weights and pressures for the Caltrans cone penetrometer

• Truck Weight:	23 tons?
• Maximum Axial Rod Load:	20 ton?
• Hydraulic Ram Load at Bypass:	10 tons?
• Cone penetrometer tip max. load:	11.5 tons
• Cone penetrometer tip max. stress:	1065 tsf

Cone penetrometer tips can be manufactured to have different maximum load capacities

Soil Strength	**Tip Capacity**	**Rating of Available Cone Penetrometer**
Very soft	1 to 2.5 tons	2 tons
Soft to medium	2.5 to 5 tons	5 tons
Medium to hard	5 to 10 tons	10 tons
Dense sand	15 tons or more	20 tons

Cone Penetrometer Test (CPT) Request Form

Caltrans

E-Mail to: *Ronnie_Gu@dot.ca.gov*
Geotechnical Instrumentation (GI) Branch
Geotechnical Services
Fax #: (916) 227-1084
Phone #: (916) 227-1064

Project Name:____________________ Request By:____________________

Dist/Co/Rte/PM:____________________ Phone No.:____________________

EA No. & Activity Code:____________________ Date of Request:____________________

Bridge No (if Applicable):____________________ Thomas Brothers Guide/Page #:__________

Requested Start Date and estimated number of days to complete work:____________________

Please attach a vicinity map and general site plan identifying proposed hole locations and significant site features. Please reference locations to latitude/longitude or Dist/Co/Rte/PM station and offset, if possible.

Type of Cone Penetration Test (CPT) Required:

_____ Standard Cone Estimated Number of Holes:________ Estimated Depth per Hole:__________

_____ Seismic Cone Estimated Number of Holes:________ Estimated Depth per Hole:__________

_____ Piezometric Cone Estimated Number of Holes:________ Estimated Depth per Hole:__________

PCC or AC Coring Required?______________ If yes, coring must be scheduled with the appropriate pavement coring personnel following notification that the CPT request has been scheduled. Scheduling of coring is the responsibility of the requesting engineer or geologist; the GI Branch will assist in providing a contact name and phone number to schedule coring, if requested.

Lane Closures Or Other Traffic Control Required?_____ If Yes, how many holes per lane closure?_______ Scheduling of lane closures or other traffic control is the responsibility of the requesting engineer or geologist.

Time Constraints On When CPT Can Be Performed (nights/weekends)?____________________

____

____

____

____

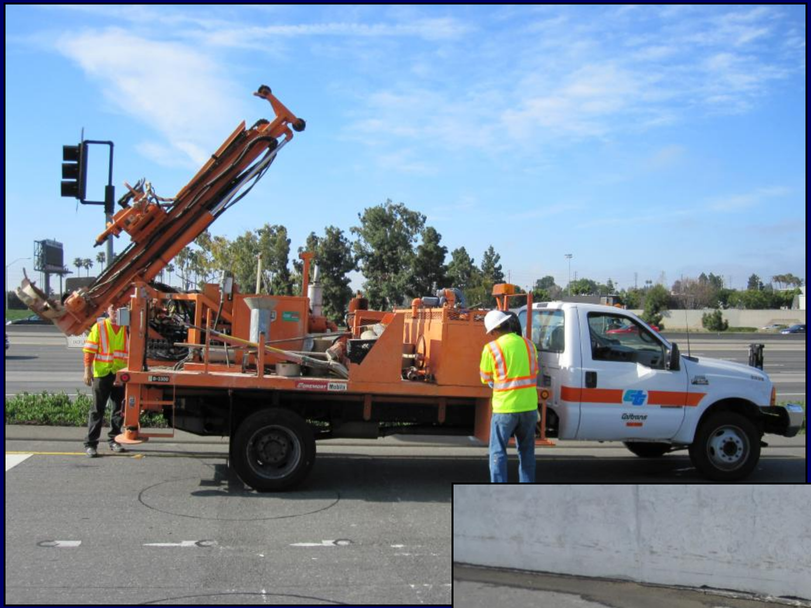
No CPT work will be performed without Underground Service Alert (USA) clearances.

For GI Use Only

Tracking Number	GI Rep	Date Tested	Date of Report	Deadline
Comments:				

Performing a cone penetration sounding with the Caltrans equipment

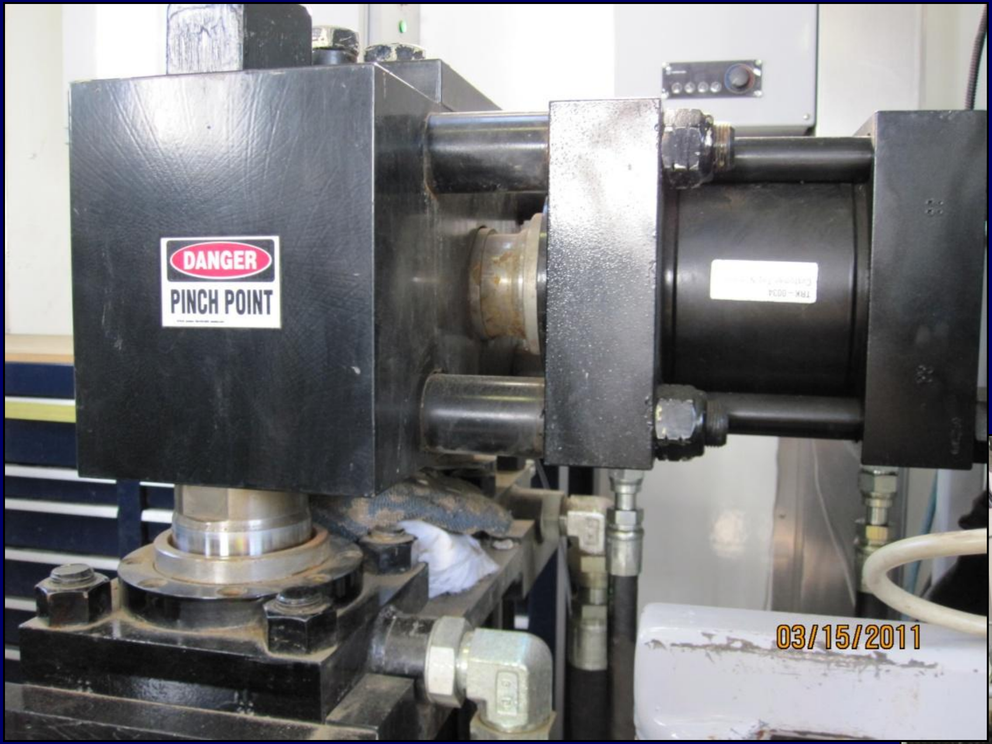
Starting a sounding where there are surface obstructions



- Asphalt Concrete
- Portland Cement Concrete

Guide tube and hydraulic thrust cylinders

There are 2 rod clamping mechanisms



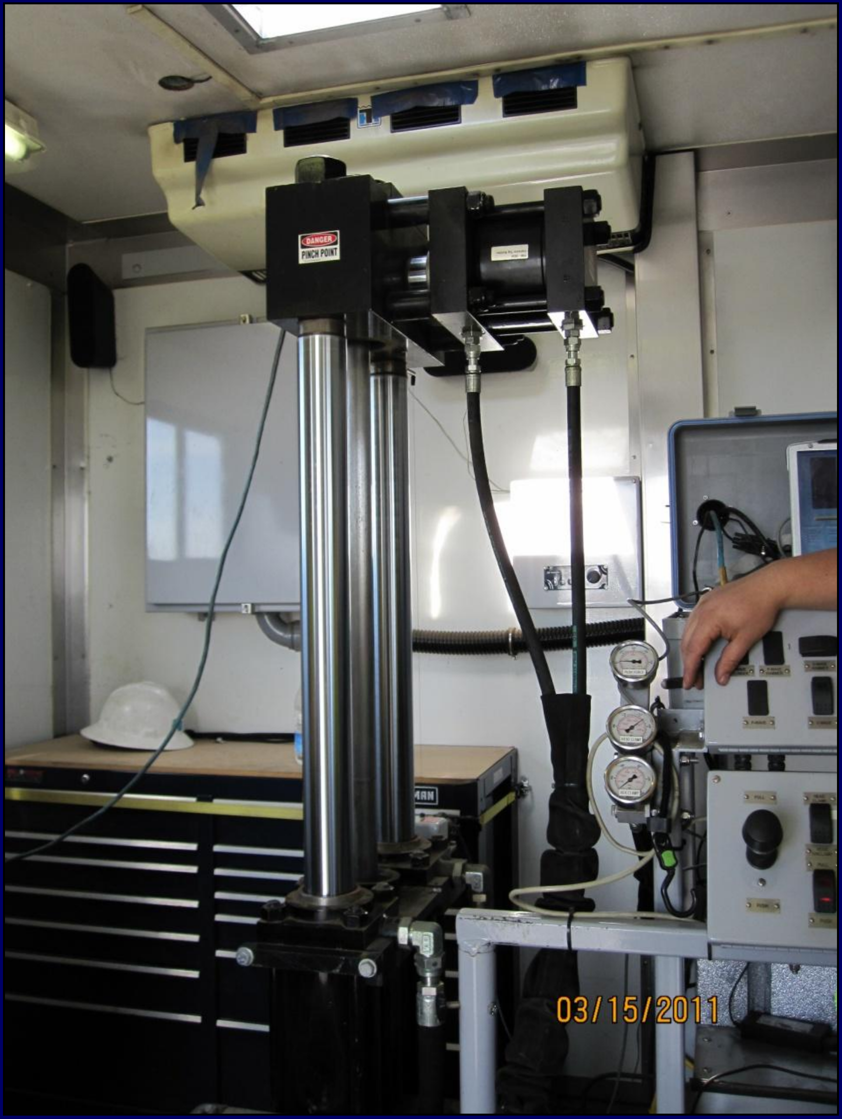
The data acquisition system

Depth encoding gage captures data approximately every 50 mm.

The CPT test procedure

20 mm/sec push rate

The CPT test procedure



Interpreting the name of the field data file

CPT15M103C

CPT FILE NAMING SCHEME

DESCRIPTION	POSITION	NOTE #
Rig ID	1ST	1
Date of Month	2ND	
Month Code	3RD	2
Last 2 Digits of Year	4TH	
Test Number That Day	5TH	
Test Type	6TH	3
Extension	3 DIGITS AFTER "."	4

NOTES:

1 Rig ID — User defined identification of the Push Rig.

2 Month Code — The first unused letter of the current month. January, February, March, April, May, June, July, August, September, October, November, December.

3 Test Type — A unique, single character identification code for the type of data file.

CPT Data - "C".
Dissipation Data - "P"
Seismic Data - "S"

4 Extension — The depth (ft) is used as the extension for all files EXCEPT CPT files that use ".DAT".

Reasons to terminate a CPT sounding

- Reaction force or thrust capacity exceeded
- Push rod buckling
- Inclination exceeds the maximum tolerable limit
- Inclination changes a large amount in a short penetration distance
- Magnitude of cone tip readings exceeds the maximum tolerable limit
- Magnitude of friction sleeve readings exceeds the maximum tolerable limit

Routine maintenance of the cone tip

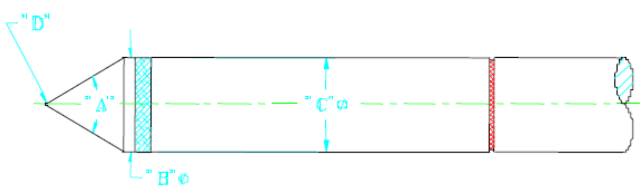
ASTM INSPECTION SHEET

DATE:

CONE SERIAL NUMBER:

INSPECTION PERFORMED BY:

GAGE SERIAL NUMBER:



10 CM^2 CONE

DIMENSION	"A"	"B"	"C"	"D"
ASTM MAX.	65°	1.422 in. (36.1 mm)	"B" + 0.024 in. ("B" + 0.5 mm)	0.125 R. (3.2 mm R.)
ASTM MIN.	55°	1.390 in. (35.3 mm)	"B" + 0.000 in. ("B" + 0.0 mm)	0.000 R. (0.0 mm R.)
ACTUAL				

15 CM^2 CONE

DIMENSION	"A"	"B"	"C"	"D"
ASTM MAX.	65°	1.732 in. (44.0 mm)	"B" + 0.024 in. ("B" + 0.5 mm)	0.125 R. (3.2 mm R.)
ASTM MIN.	55°	1.700 in. (43.2 mm)	"B" + 0.000 in. ("B" + 0.0 mm)	0.000 R. (0.0 mm R.)
ACTUAL				

ASTM Specification D3441 requires that all cone assemblies and cone penetration testing conform to the above specifications taken from the 1995 ASTM Standards Specification.

1-A

- cone tips and cone sleeves are gradually reduced in size when penetrating sandy and gravelly soils
- cone tips and cone sleeves can be chipped or dented when pushed through gravel, boulders and man-made debris
- routine replacement of the soil seals prevent soil from intruding into the cone tip

Tip replacement cost: $100
Sleeve replacement cost: $200
Piezo element cost: $10
Annual device calibration: $300

Questions?