NOTES on the CONE PENETROMETER TEST

Introduction

The standardized cone-penetrometer test (CPT) involves pushing a 1.41-inch diameter 55^o to 60^o cone (Figs. 1 thru 3) through the underlying ground at a rate of 1 to 2 cm/sec. CPT soundings can be very effective in site characterization, especially sites with discrete stratigraphic horizons or discontinuous lenses. Cone penetrometer testing, or CPT (**ASTM D-3441**, adopted in 1974) is a valuable method of assessing subsurface stratigraphy associated with soft materials, discontinuous lenses, organic materials (peat), potentially liquefiable materials (silt, sands and granule gravel) and landslides. Cone rigs can usually penetrate normally consolidated soils and colluvium, but have also been employed to characterize d weathered Quaternary and Tertiary-age strata. Cemented or unweathered horizons, such as sandstone, conglomerate or massive volcanic rock can impede advancement of the probe, but the author has always been able to advance CPT cones in materials of Tertiary-age sedimentary rocks. The cone is able to delineate even the smallest (0.64 mm/1/4-inch thick) low strength horizons, easily missed in conventional (small-diameter) sampling programs. Some examples of CPT electronic logs are attached, along with hand-drawn lithologic interpretations.

Most of the commercially-available CPT rigs operate electronic friction cone and piezocone penetrometers, whose testing procedures are outlined in **ASTM D-5778**, adopted in 1995. These devices produce a computerized log of tip and sleeve resistance, the ratio between the two, induced pore pressure just behind the cone tip, pore pressure ratio (change in pore pressure divided by measured pressure) and lithologic interpretation of each 2 cm interval are continuously logged and printed out.

Tip Resistance

The tip resistance is measured by load cells located just behind the tapered cone (Figure 4). The tip resistance is theoretically related to undrained shear strength of a saturated cohesive material, while the sleeve friction is theoretically related to the friction of the horizon being penetrated (Robinson and Campanella, 1986, *Guidelines for Use and Interpretation of the Electric Cone Penetration Test, 3rd Ed.*: Hogentogler & Co., Gaithersburg, MD, 196 p.). The tapered cone head forces failure of the soil about 15 inches ahead of the tip and the resistance is measured with an embedded load cell in tons/ft^2 (tsf).

Local Friction

The local friction is measured by tension load cells embedded in the sleeve for a distance of 4 inches behind the tip (Figure 4). They measure the average skin friction as the probe is advanced through the soil. If cohesive soils are partially saturated, they may exert appreciable skin friction, negating the interpretive program.

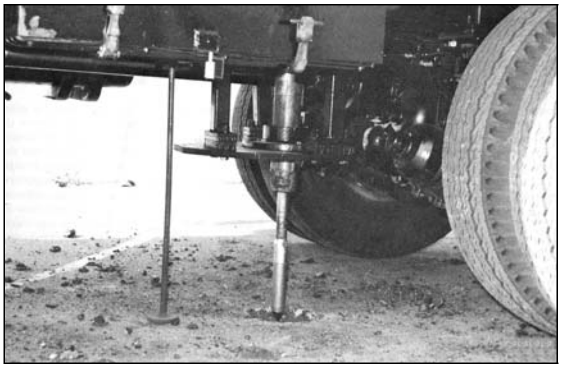


Figure 1 (left) – *Cone tip exposed beneath truck, just before being advanced into the ground at a rate between 1 and 2 cm/sec. The cone has an area of either 10 or 15 cm^2 and is typically advanced in 1 m increments because the rods are of that length.*

Figure 2 (right) – *Hogentogler CPT rig operated by Ertec in Long Beach, CA. Cone rigs weigh about 18 tons, so are capable of exerting considerable normal force on the advancing rod. The cone tip includes a plumb meter to warn of out-of-vertical penetration.*

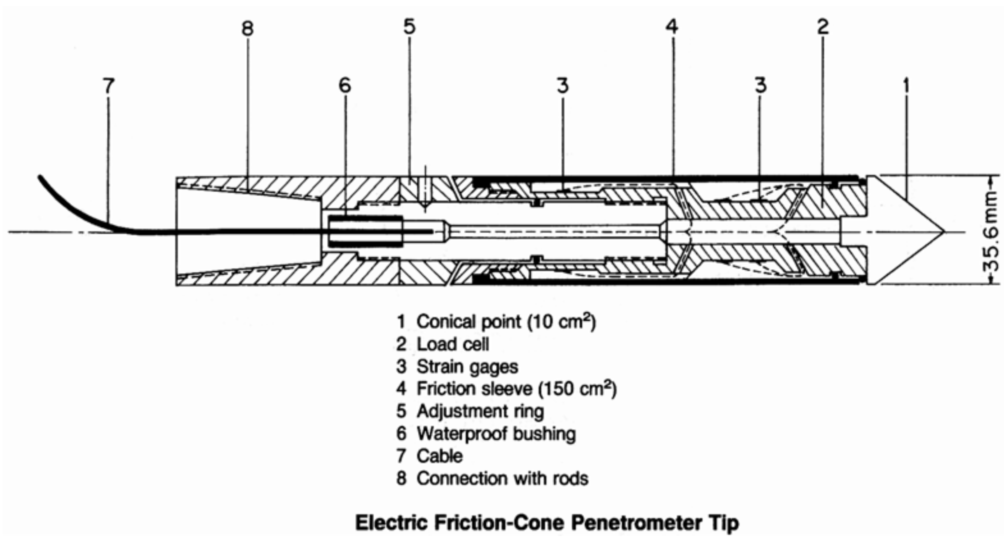
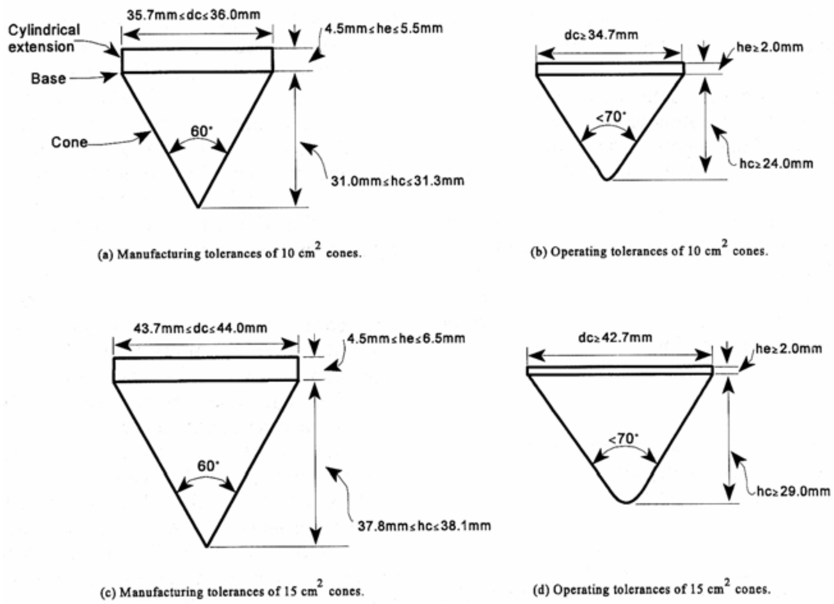


Figure 3 – *Manufacturing and operating tolerances of cones, taken from ASTM D5778***.**



CONE BASE AREA	NOMINAL			TOLERANCE MANUFACTURED (OPERATIONS)		
	BASE DIAMETER	CONE HEIGHT	EXTENSION			
cm²	dc mm	hc mm	he mm	dc mm	hc mm	he mm
10	35.7	31.0	5.0	+0.3 - 0.0 (≥34.7)	+0.3 - 0.0 (≥24.0)	+0.0 - 0.5 (≥2.0)
15	43.7	37.8	5.0 - 6.0	+0.3 - 0.0 (≥42.7)	+0.3 - 0.0 (≥29.0)	+0.0 - 0.5 (≥2.0)

Manufacturing and Operating Tolerances of Cones (2)

Figure 4 – *Schematic section through an electric friction-cone penetrometer tip, taken from ASTM D3441.*

Friction ratio

The friction ratio is given in percent. It is the ratio of skin friction divided by the tip resistance (both in tsf). It is used to classify the soil, by its behavior, or reaction to the cone being forced through the soil. High ratios generally indicate clayey materials (high c, low Ø) while lower ratios are typical of sandy materials (or dry desiccated clays). Typical skin friction to tip friction ratios are 1 % to 10%. The ratio seldom, if ever, exceeds 15%. Sands are generally identified by exhibiting a ratio < 1%.

Pore Pressure

Piezocones also measure insitu pore pressure (in psi), in either dynamic (while advancing the cone) or static (holding the cone stationary) modes. Piezocones employ a porous plastic insert just behind the tapered head that is made of hydrophilic polypropylene, with a nominal particle size of 120 microns (Figure 5). The piezocell must be saturated with glycerin prior to its employment. The filter permeability is about 0.01 cm/sec (1 x 10^{-2} cm/sec). When using the cone to penetrate dense layers, such as cemented siltstone, sandstone or conglomerate, the piezo filter element can become compressed, thereby inducing high positive pore pressures. But, the plastic filters do not exhibit this tendency, though they do become brittle with time and may need to be replaced periodically. In stiff over-consolidated clays the pore pressure gradient around the cone may be quite high. This pore pressure gradient often results in dissipations recorded behind the CPT tip that initially increase before decreasing to the equilibrium value.

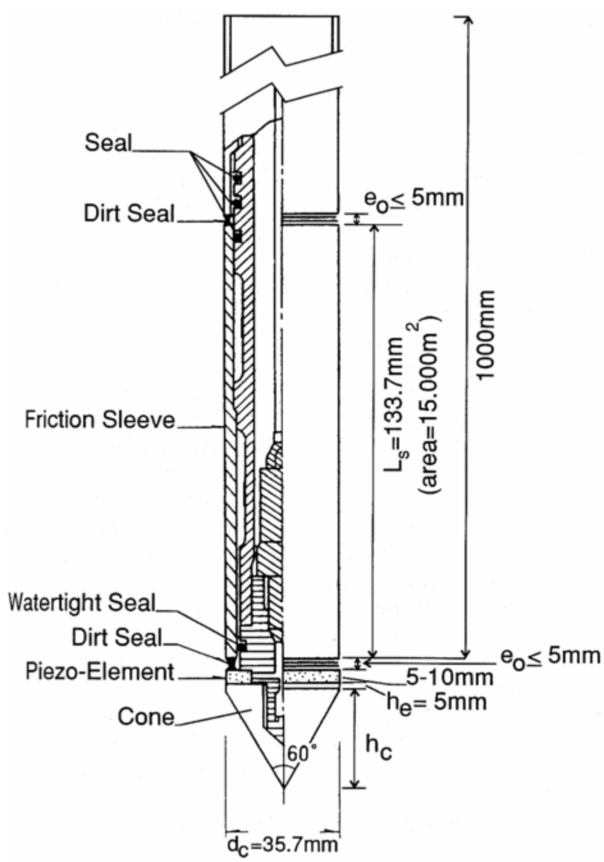


Figure 5- *Schematic section through a piezocone head, showing the piezo-element and friction sleeve. Taken from ASTM D5778.*

Differential Pore Pressure

The Differential Pore Pressure Ratio is used to aid in soil classification according to the Unified Soil Classification System (USCS). When the cone penetrates dense materials like sand, the sand dilates and the pore pressure drops. In clayey materials high pore pressures may be induced by the driving of the cone head. If transient pore pressures are being recorded that seem non-hydrostatic, most experienced operators will ask that the penetration be halted and allowed at least 5 minutes to equilibrate, so a quasi-static pore pressure reading can be recorded. Sometimes equilibration can take 10 to 30 minutes, depending on the soil. In practice experienced operators try to stop the advance and take pore pressure measurements in recognized aquifers and just above or adjacent to indicated aquacludes.

Temperature sensor

One great advantage of the electric cone is the temperature sensor. This has been found to be very useful in assessing the precise position of the zone, or zones, of saturation, which is of great import in slope stability and consolidation studies. **A temperature shift of about 6^{o} F is common at the groundwater interface**, even perched horizons within landslides.

Corrected Logs

Most CPT rigs are equipped with one or several automated interpretation programs, which classify 1 cm horizons according to the Unified Soil Classification System. The most widely employed routine has been that originally developed by Robinson and Campanella, available from Hogentogler & Co., of Gaithersburg, MD or from the Natural Sciences and Engineering Research Council of Canada. An alternative interpretation program was developed by Dr. Richard Olsen (available through www.liquefaction.com).

The interpretation programs evaluates all of the measured properties and classifies the horizon according to its behavior (in lieu of petrology). For instance, when classifying a clayey material the interpretive programs consider undrained shear strength, tip resistance and differential pore pressure. A high differential pore pressure is assumed diagnostic of more clayey materials.

Importance of "ground-truthing"

Like geophysical techniques, CPT soundings are most meaningful when "ground-truthed" with established lithologic horizons. The easiest method to "ground truthing" CPT data is to advance a sounding next to a bucket auger or conventional boring, from which subsurface samples are collected. In this way the electronic "signature" of the sounding can be compared with the various lithologies already identified in the substory. This comparison can prove especially valuable in identifying potentially liquefiable materials and old landslide slip surfaces. Once the CPT sounding is "ground-truthed", the rig can traverse the job site, commonly advancing 10 or 12 soundings in a single day. This allows for an expanded data set, which allows superior three-dimensional characterization of the site under evaluation, and allows construction of reliable geologic cross sections through the area.

Notes of Caution

Some notes of caution are advised when applying the CPT method to evaluating discrete **low-strength horizons** or partings, such as landslide slip surfaces. The 60^{o} tip of the cone forces a passive failure of the ground in front of the advancing tip. The instrumented tip senses soil resistance about 21cm (8.4 in) ahead of the advancing tip.

This means that the tip resistance reported as “undrained shear strength” is actually an average value, taken over the zone within 21 cm of the cone tip. If the tip penetrates low strength horizons less than 21 cm thick, such as a landslide slip surface, the tip resistance reported on the CPT log may be much higher than actually exists on the discrete plane of slippage, which maybe only a fraction of an inch thick.

Another problem with the CPT method is that cone soundings advanced through desiccated clay will often be interpreted as sand or silt mixtures (by the computerized lithologic interpretation routine) because of recorded sleeve friction. The opposite problem occurs when reporting Standard Penetration Test (SPT) blow counts after advancing drive samples through clayey horizons! The SPT test is only intended for granular materials, and blow counts in such materials must be regarded with some degree of skepticism as they may shift dramatically upon later absorption of moisture.

Sample CPT logs

The attached logs are representative of the features common to electronic friction cones. They include raw data sensed by the cone as it is pushed through the ground. This data includes: Friction Ratio, Local Friction, Tip Resistance, Pore Pressure, Differential Pore Pressure Ratio and an interpreted lithologic profile (often printed out on a separate sheet, depending on which interpretation program is being utilized).

V B I

Operator : VIRGIL A. BAKER | CPT Date : 03/23/90 12:53 | Sounding : 53 Pg 1 / 1

Location : CPT-2 | Cone Used : 330 | Job No. : EW0463.1T

Depth Increment : .05 m

Max Depth : 33.79 ft

V B I

Operator : VIRGIL A. BAKER CPT Date : 03/23/90 13:26 Sounding : 54 Pg 1 / 1
Location : CPT-3 Cone Used : 330 Job No. : EW0483.1T

Depth Increment : .05 m Max Depth : 31.33 ft

V B I

Operator : VIRGIL A. BAKER CPT Date : 03/23/90 16:13 Sounding : 58 Pg 1 / 1
Location : CPT-7 Cone Used : 330 Job No. : EW0483.1T

Depth Increment : .05 m Max Depth : 38.22 ft