Fundamentals of CONE PENETROMETER TEST (CPT) SOUNDINGS

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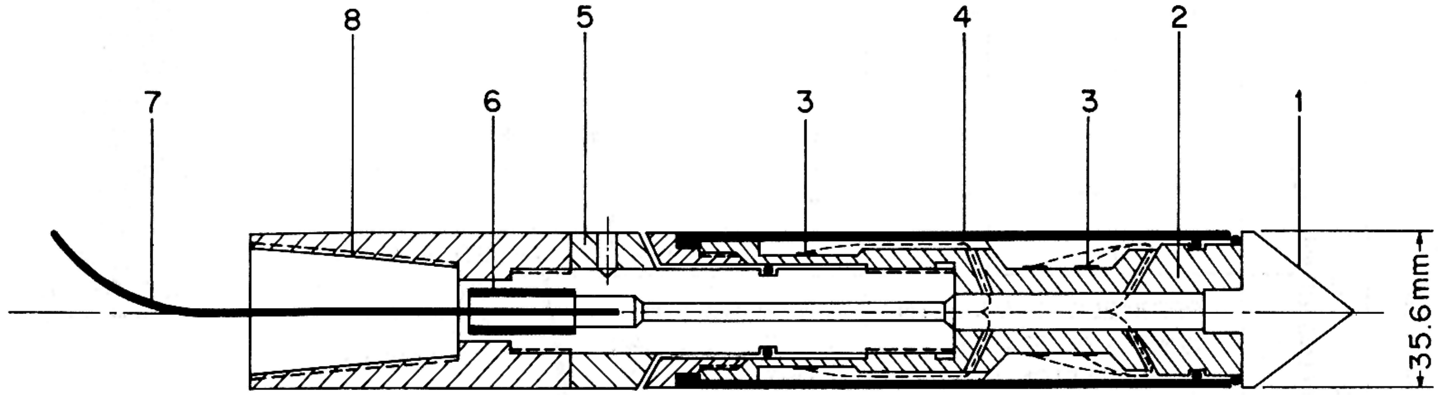
Cone Penetration Test

- **CPT soundings can be very effective in site characterization, especially sites with discrete stratigraphic horizons or discontinuous lenses.**
- **Toda, 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.**



1 Conical point (10 cm^2)
2 Load cell
3 Strain gages
4 Friction sleeve (150 cm^2)
5 Adjustment ring
6 Waterproof bushing
7 Cable
8 Connection with rods

Electric Friction-Cone Penetrometer Tip

- **ASTM adopted the CPT procedure as test D-3441 in 1974.**
- **It 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.**

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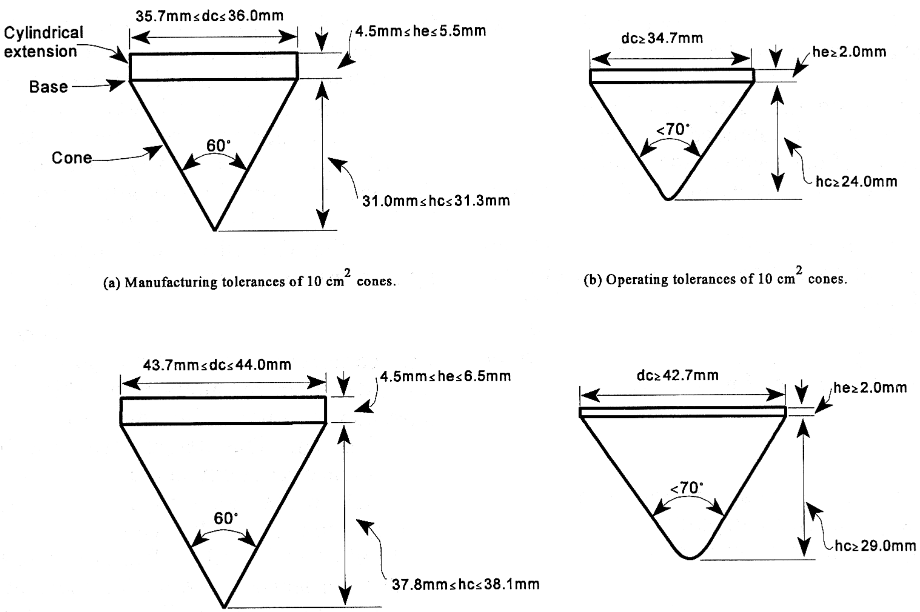
Shape of Cone Tip and rate of advance



(a) Manufacturing tolerances of 10 cm^2 cones.

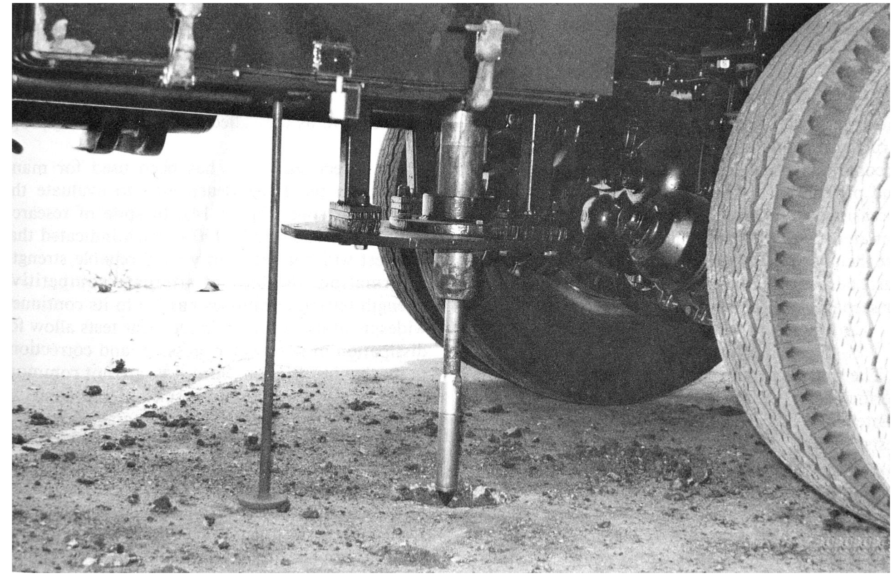
(b) Operating tolerances of 10 cm^2 cones.

(c) Manufacturing tolerances of 15 cm^2 cones.

(d) Operating tolerances of 15 cm^2 cones.

CONE BASE AREA	NOMINAL			TOLERANCE MANUFACTURED (OPERATIONS)		
	BASE DIAMETER	CONE HEIGHT	EXTENSION			
cm^2	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)



- **The standardized cone-penetrometer test (CPT) involves pushing a 1.41-inch diameter 55° to 60° cone through the underlying ground at a rate of *1 to 2 cm/sec*.**

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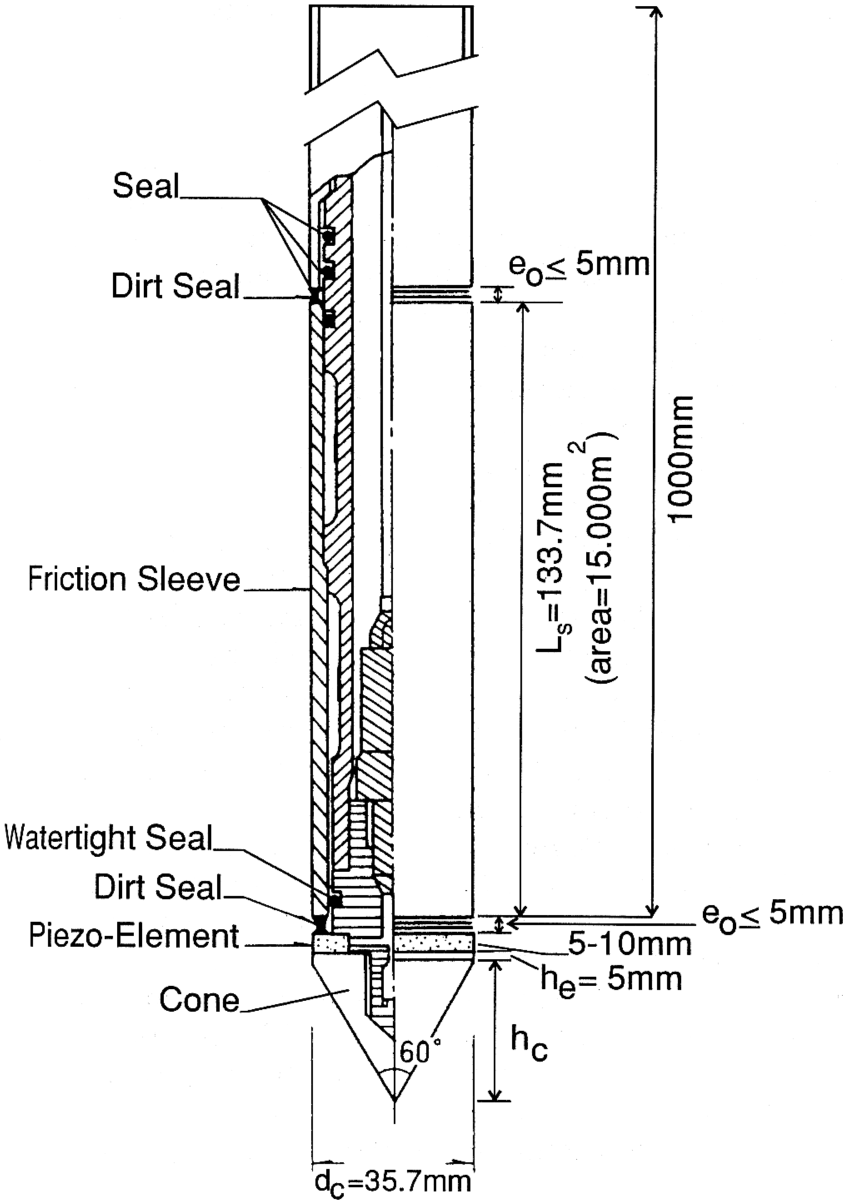
Sleeve vs Tip resistance



Example of a Reference Penetrometer With a Fixed Cone and With Friction Sleeve

- **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 can usually be printed onsite**

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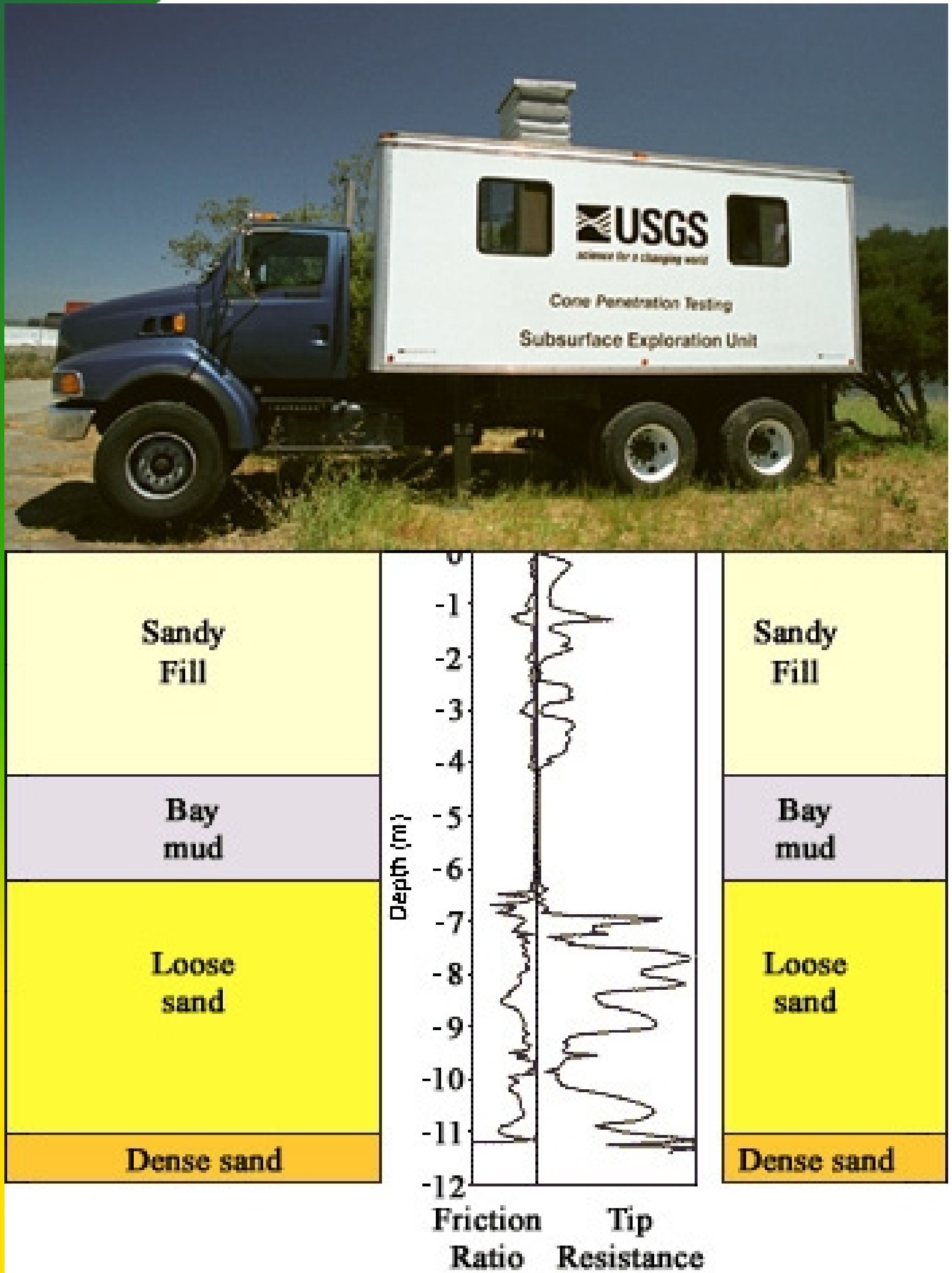

- **CPT rigs** usually employ 1 m long rods.
- They can usually penetrate normally consolidated soils and colluvium, but have also been employed to characterize weathered Quaternary and Tertiary-age strata.
- Cemented or unweathered horizons, such as sandstone, conglomerate or massive volcanic rock can impede advancement of the probe

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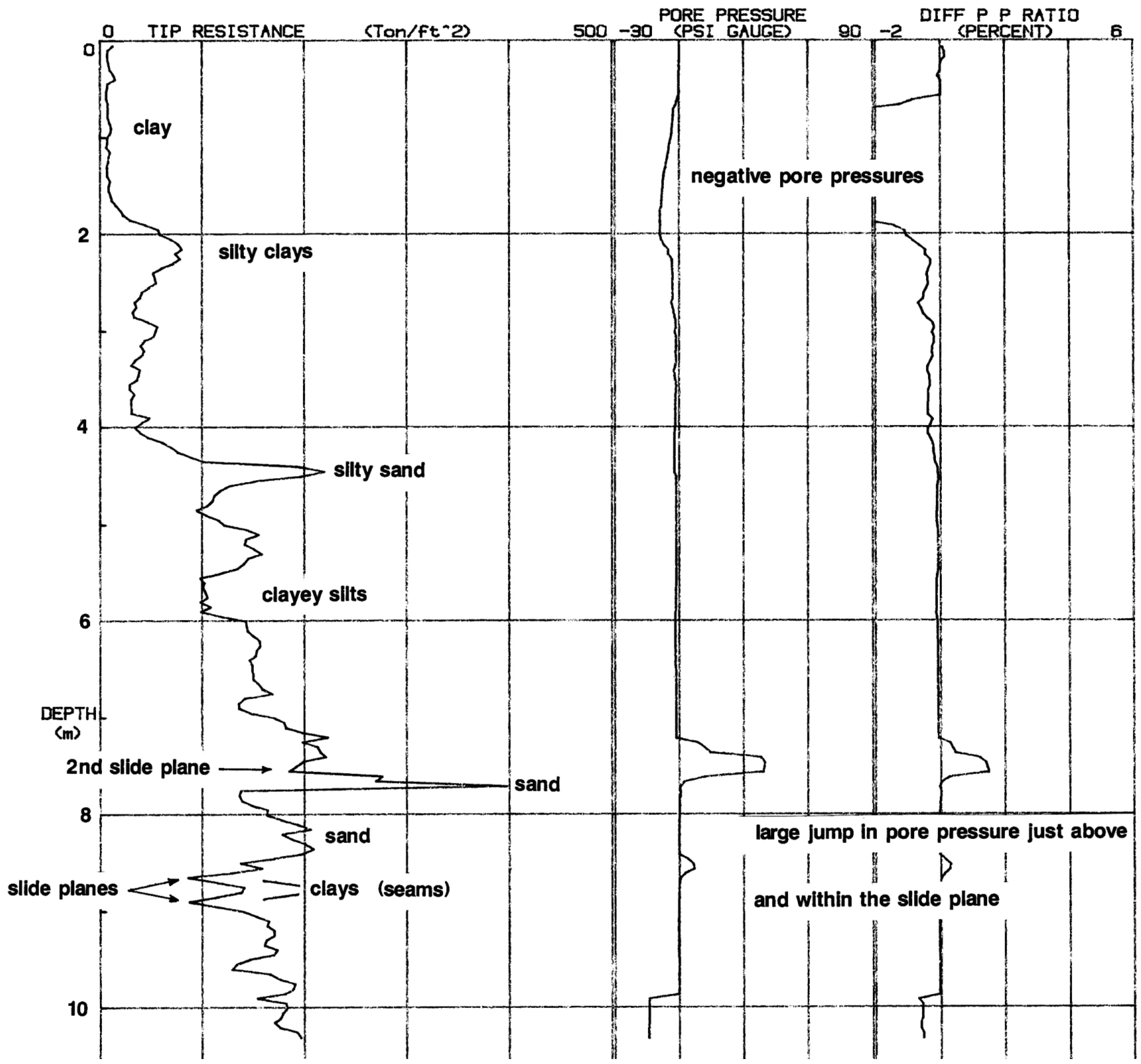

- **The cone is able to delineate even the smallest (0.64 mm/1/4-inch thick) low strength horizons, easily missed in most conventional subsurface sampling programs.**

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Tip Resistance

- The *tip resistance* is measured by load cells located just behind the tapered cone.
- 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.
- 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).

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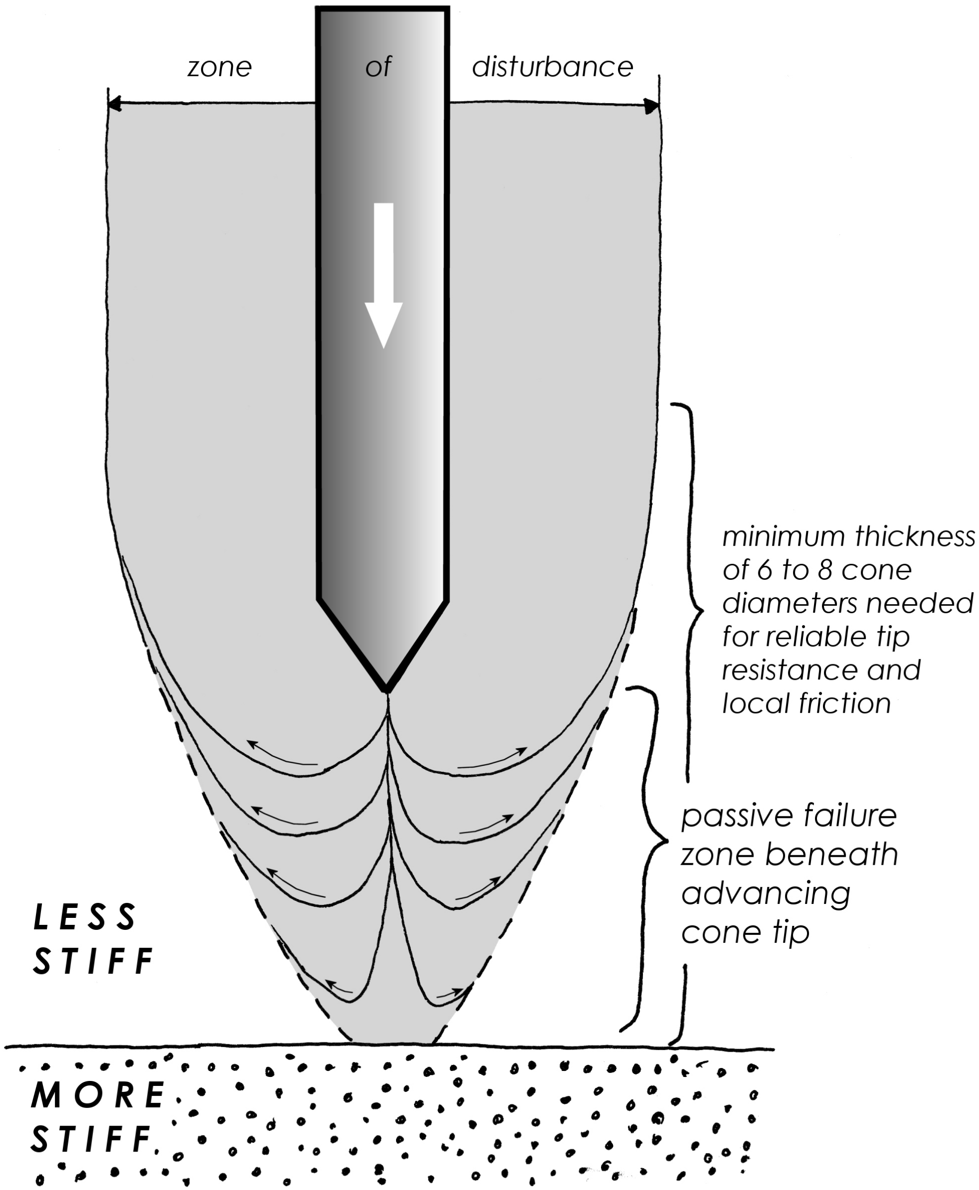

- **The tip of the cone penetrometer senses out ahead of itself as it induces a local bearing failure of the soil it passes through.**
- **The tip resistance recorded by the instrument is an average across this tip influence zone.**
- **Therefore, caution should be exercised when evaluating insitu strength parameters for horizons less than about 8 inches (20 cm) thick**

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Local or Sleeve Friction

- The *local friction* is measured by tension load cells embedded in the sleeve for a distance of 4 inches behind the tip.
- 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.

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Friction Ratio, F_r

- 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 to 20%. Sands are generally identified by exhibiting a ratio < 1%. The exception is buried wood, which can result in F_r values much greater than 20 (and are not interpreted).

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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.
- 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.

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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 five minutes to *equilibrate*, so a quasi-static pore pressure reading can be recorded (this can take 10 to 30 minutes).
- 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.

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Temperature sensor

- A significant 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° F is common at the groundwater interface, even perched horizons within landslides.

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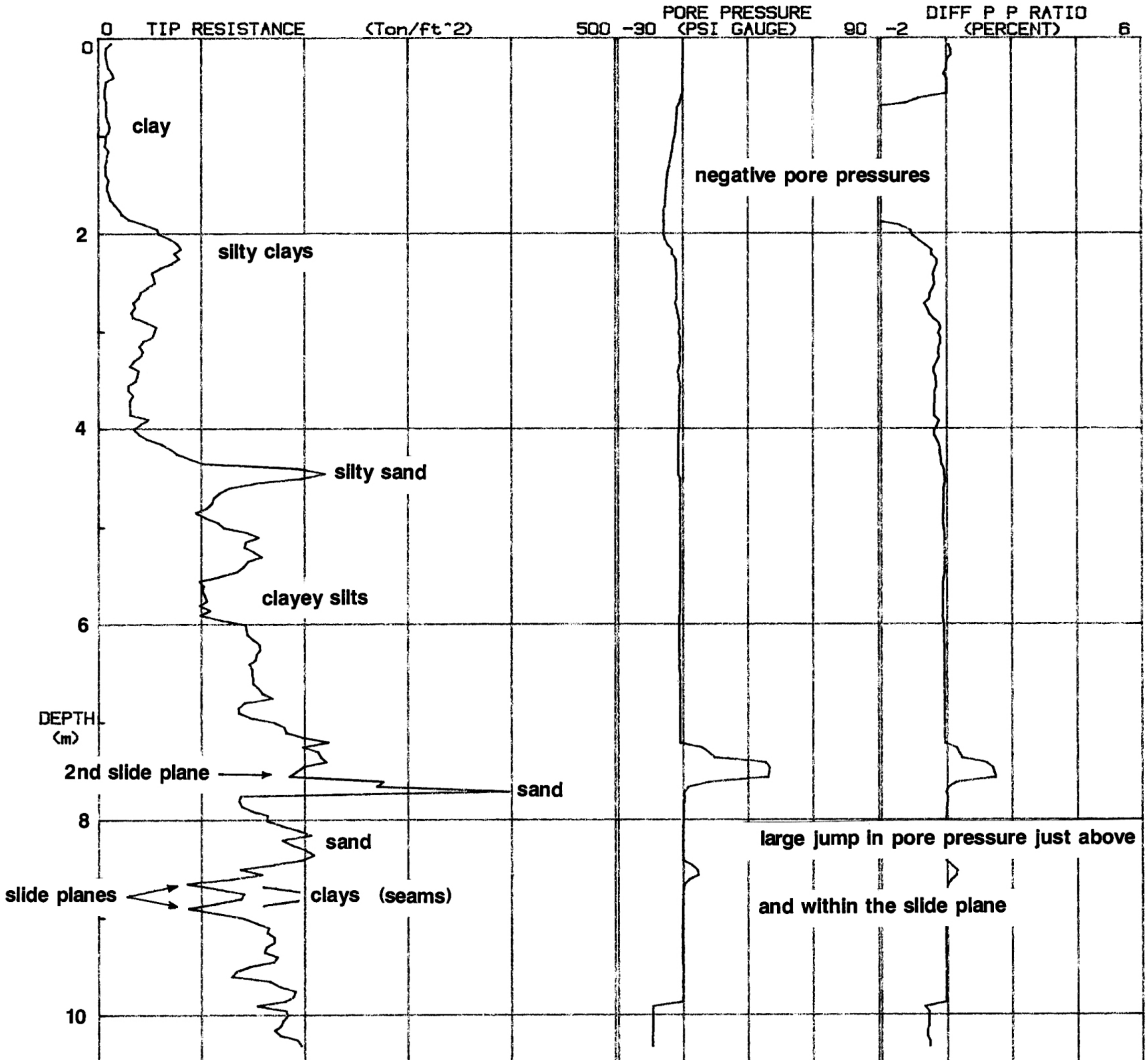

CPT log thru a complex bedrock landslide

Note pore pressure pulses above the slip surfaces

The *tip resistance* values are much higher than the mobilized shear strength because these low strength horizons are just a few inches thick

Corrected, or 'Interpreted' 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 developed by Robinson and Campanella (1986), available from Hogentogler & Co., or from the Natural Sciences and Engineering Research Council of Canada.
- The interpretation programs evaluate all of the measured properties and classify 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.

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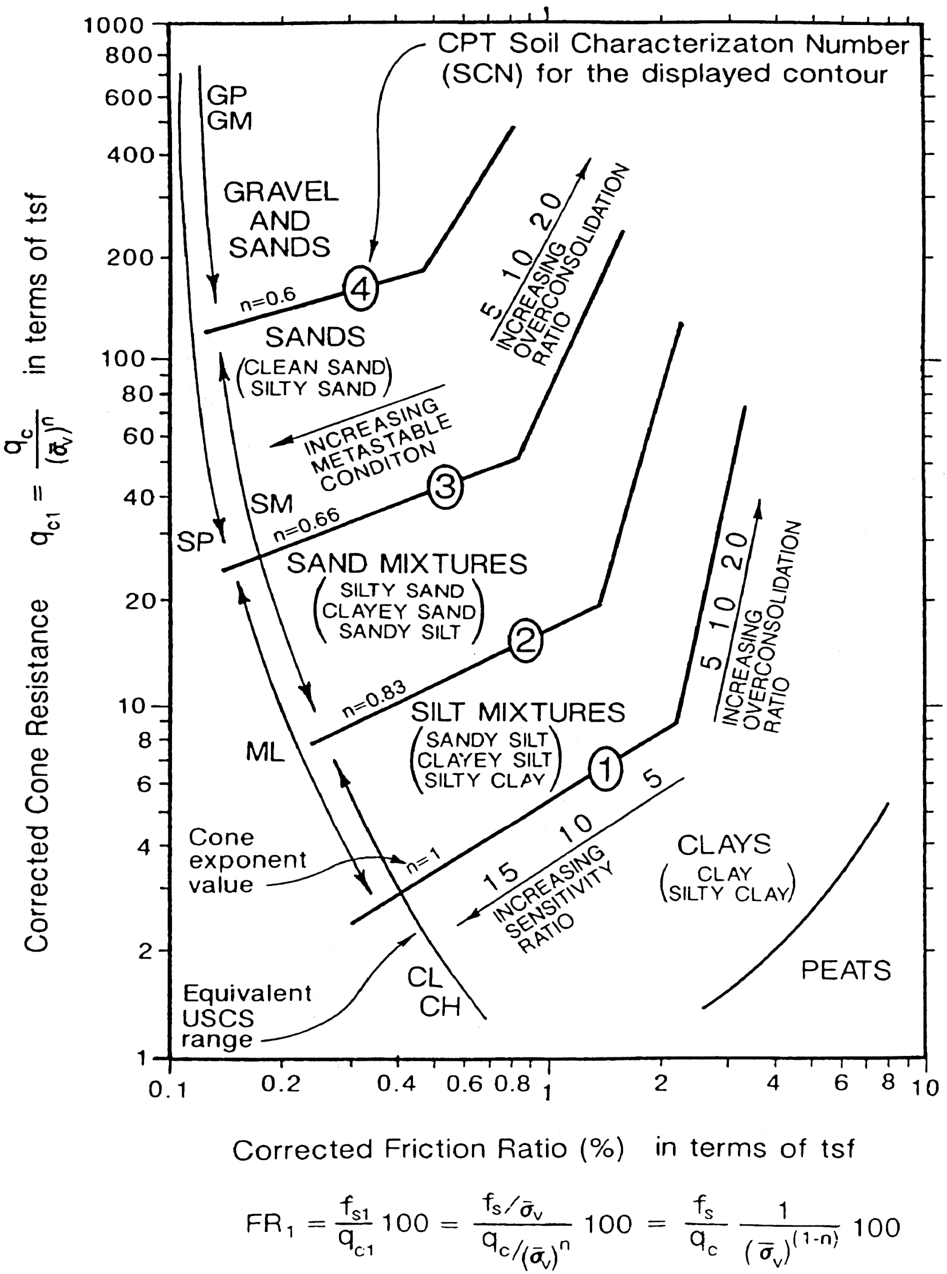

Olsen’s Chart

- A more refined CPT classification chart was developed by Olsen (1988).
- It has been Rogers’ experience that the Olsen chart provides slightly better results than the older charts that preceded it.

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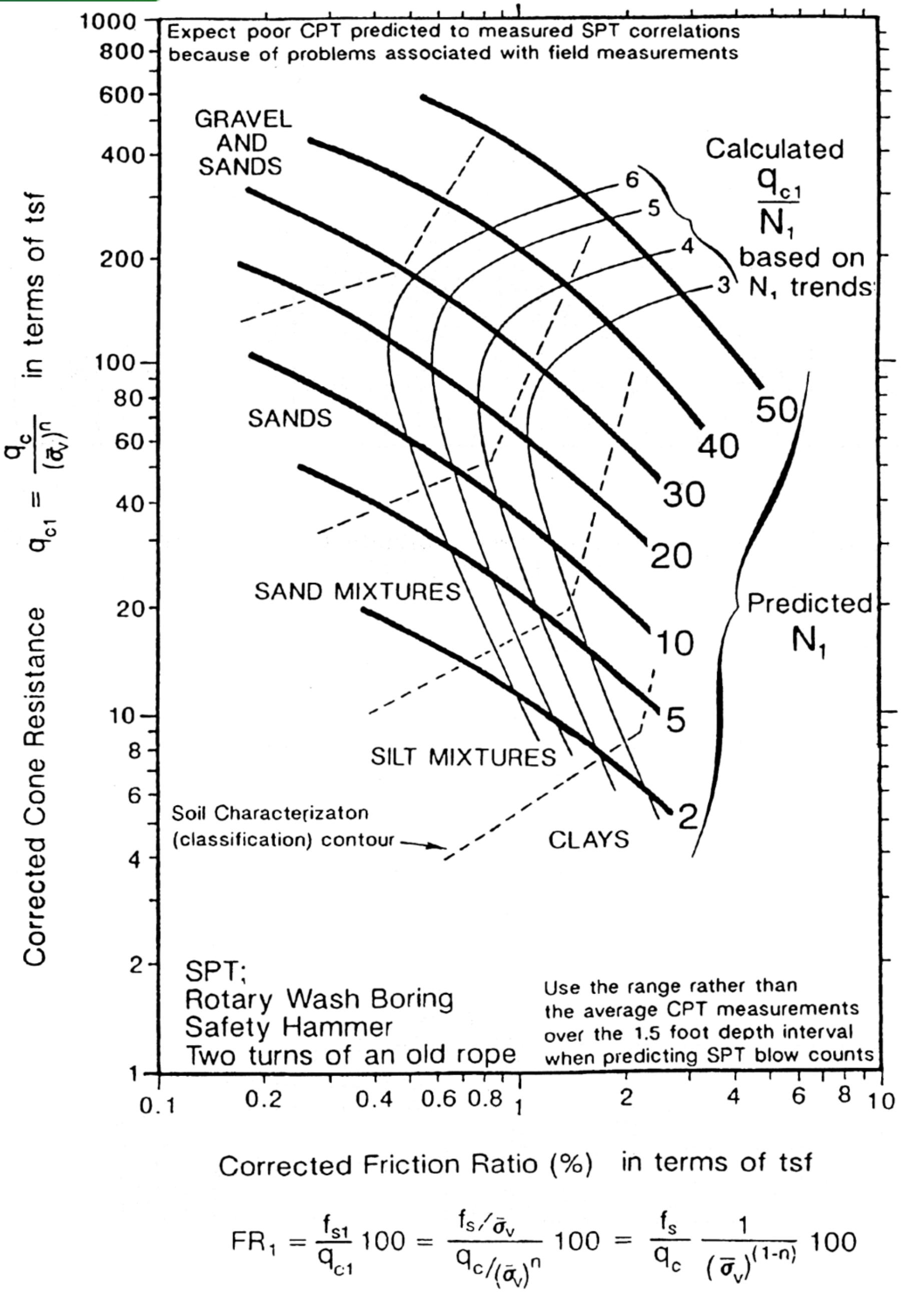
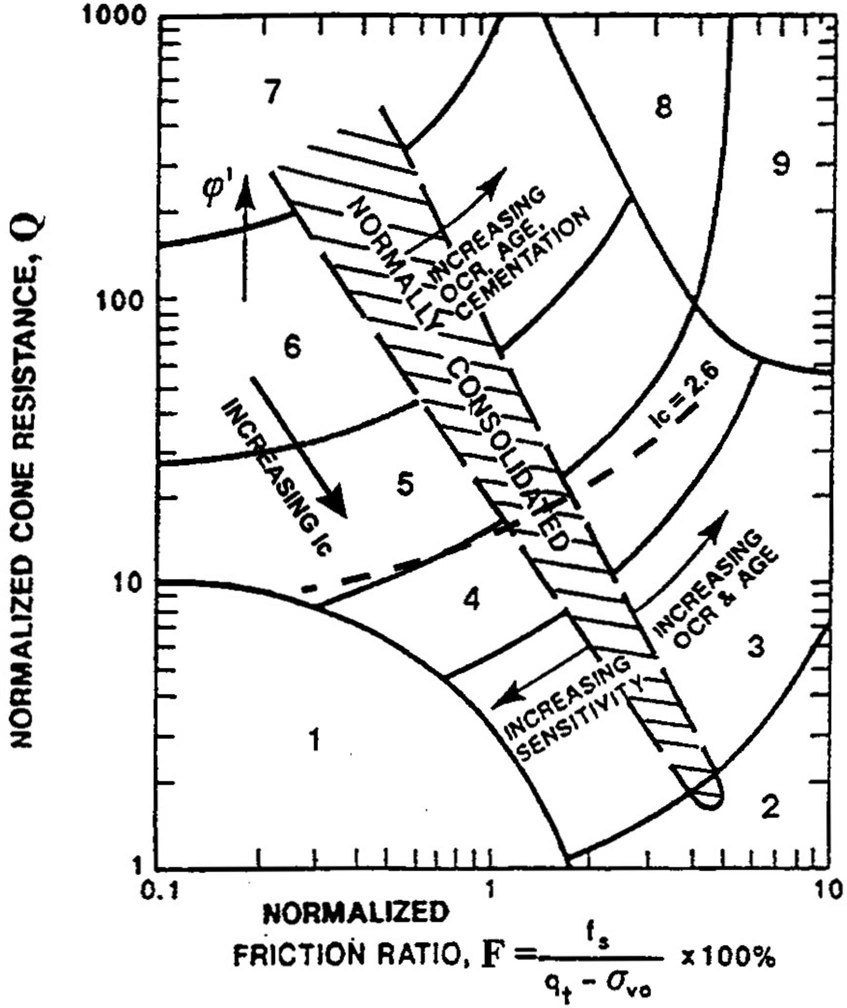
SPt to CPT Conversion Chart



- CPT to SPT Conversion Chart developed by Olsen (1988).
- Useful when attempting to correlate between CPT and older SPT data

Chart relating Impacts of Age, consolidation, and induration



1. Sensitive, fine grained
2. Organic soils - peats
3. Clays - silty clay to clay
4. Silt Mixtures - clayey silt to silty clay
5. Sand Mixtures - silty sand to sandy silt
6. Sands - clean sand to silty sand
7. Gravelly sand to dense sand
8. Very stiff sand to clayey sand*
9. Very stiff, fine grained*

** Heavily overconsolidated or cemented*

- Normalized Cone Penetrometer test (CPT) soil behavior chart proposed by Robinson (1990).
- Important to consider this when evaluating overconsolidated shales or sensitive clay materials

- **Conventional CPT rigs are mounted on diesel truck frames, weighing about 35,000 lbs. The entire weight of the rig is supported on hydraulic rams to increase the normal reaction force pushing the cone downward.**

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Mini CPT Probe

- *GeoProbe* manufactures mini CPT rigs, on small tracked vehicles, vans, or pick-up trucks
- Note the ground screw anchors, used to increase normal force for pushing the cone down into the ground
- Very useful for limited access applications, such as mid-slope benches

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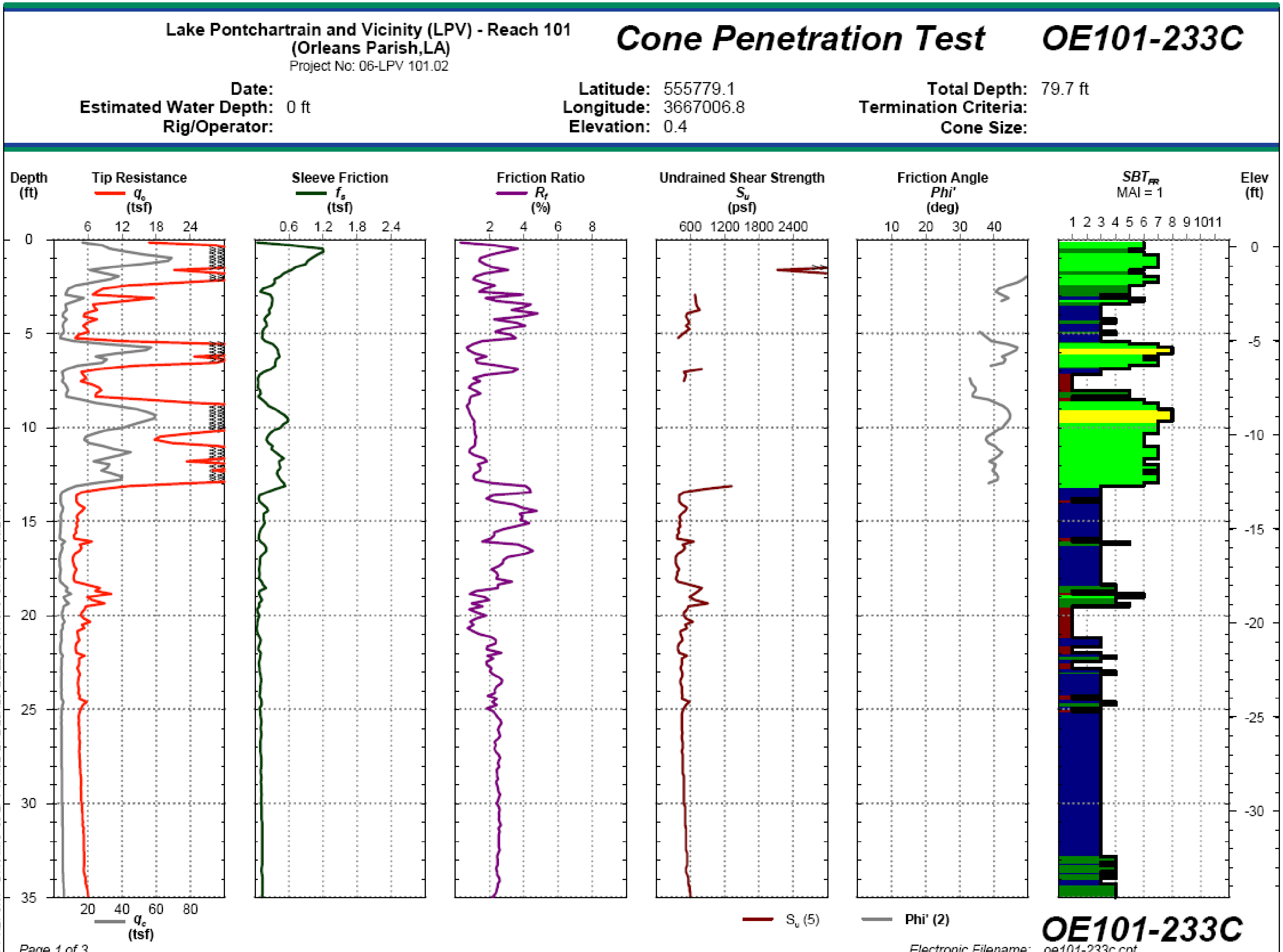
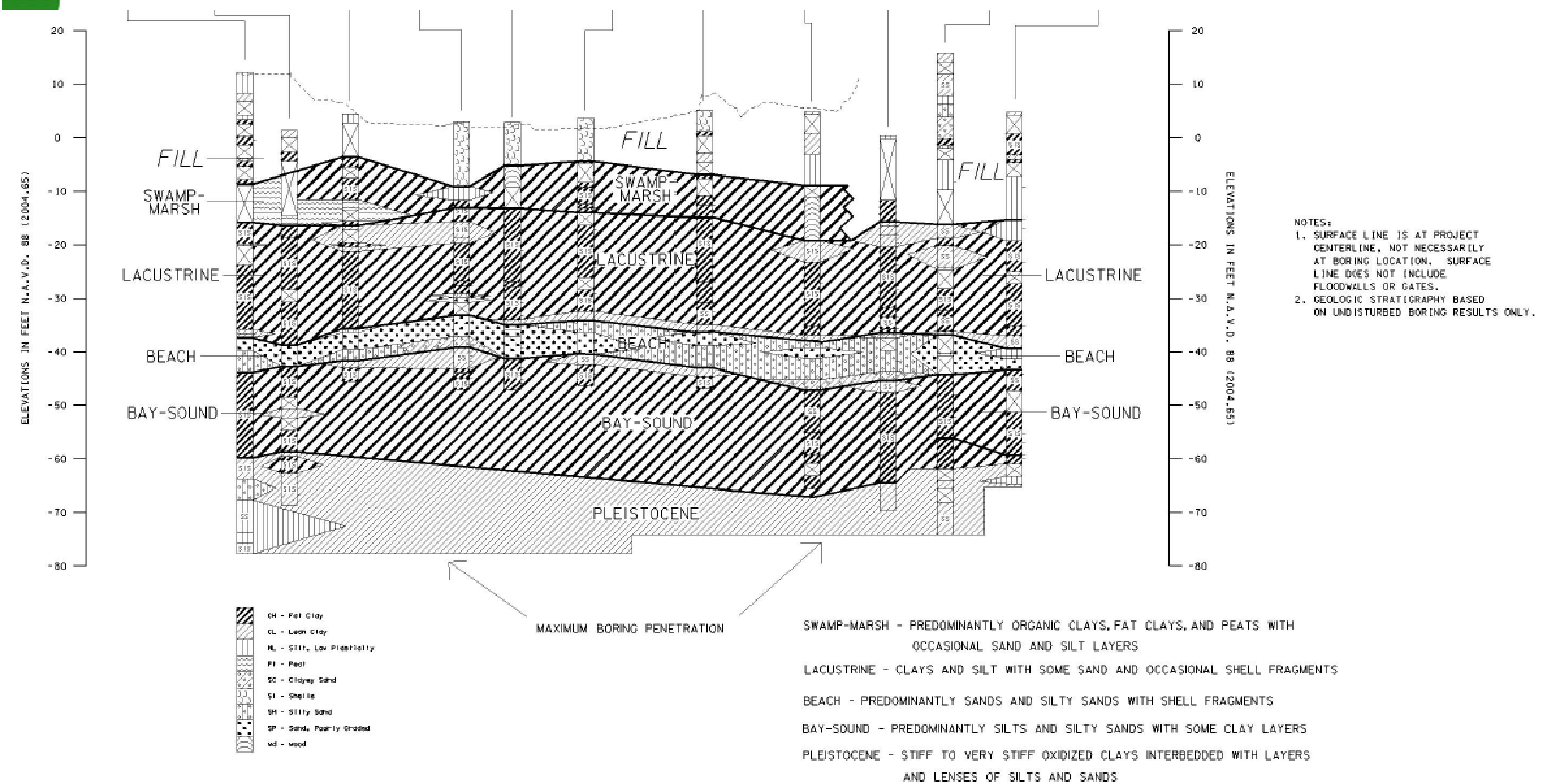
- **CPT rig mounted on an airboat for use in shallow water and marshes along the Gulf Coast. Floating rigs must be anchored securely to stabilize the platform.**

Typical CPT summary logs



Typical Geologic Profile derived from CPT soundings



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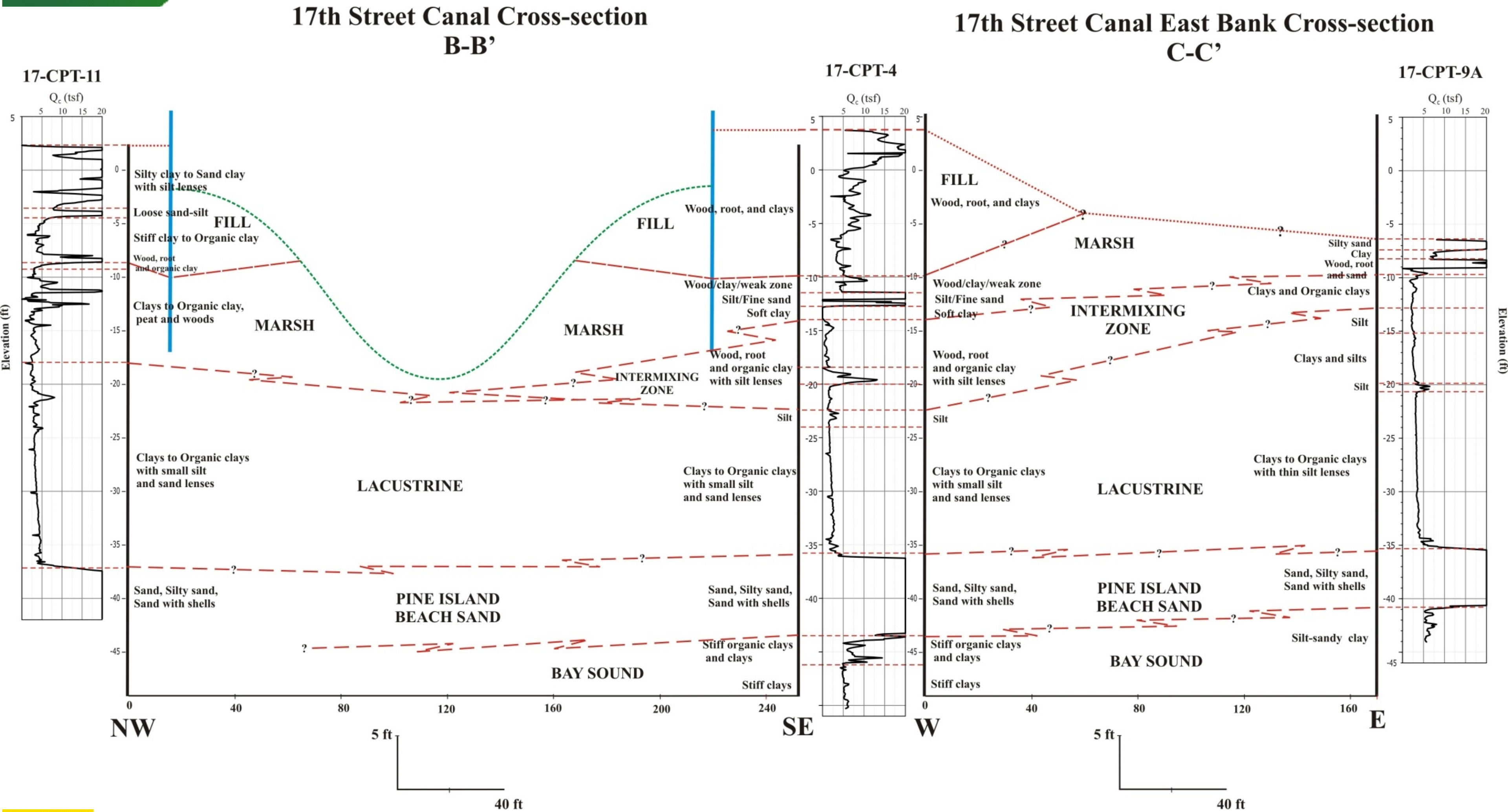

- **CPT logs are extremely valuable for constructing *stratigraphic correlations*, such as the 17th Street Canal failure in new Orleans in 2005, shown here.**

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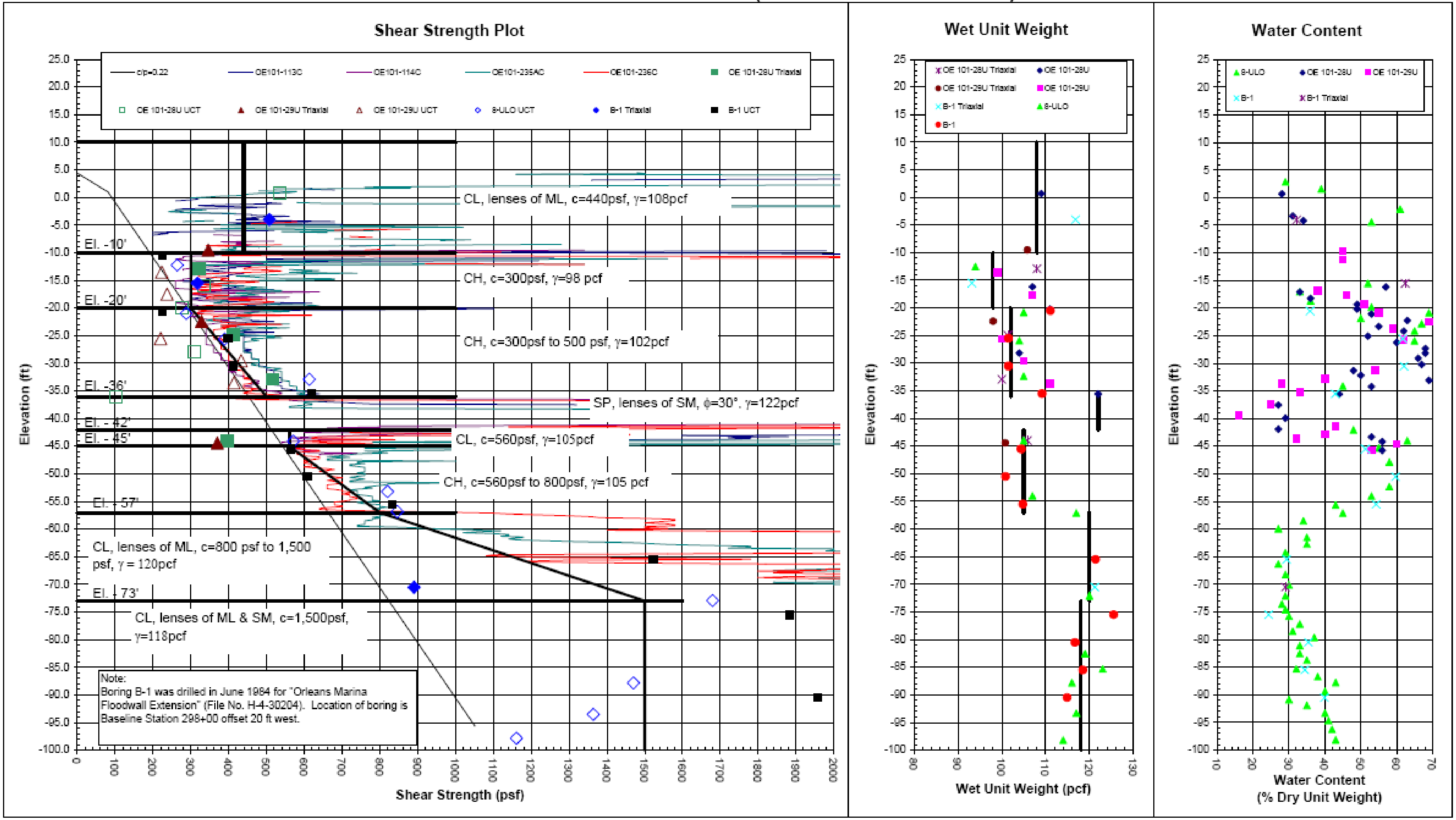
Strengthlines employed for design

Lake Pontchartrain and Vicinity (LPV) Reach 101, Orleans Parish, LA

5-Feb-2008

Baseline Station 297+35 to 303+07 (Wall Station 24+40 to 27+97)



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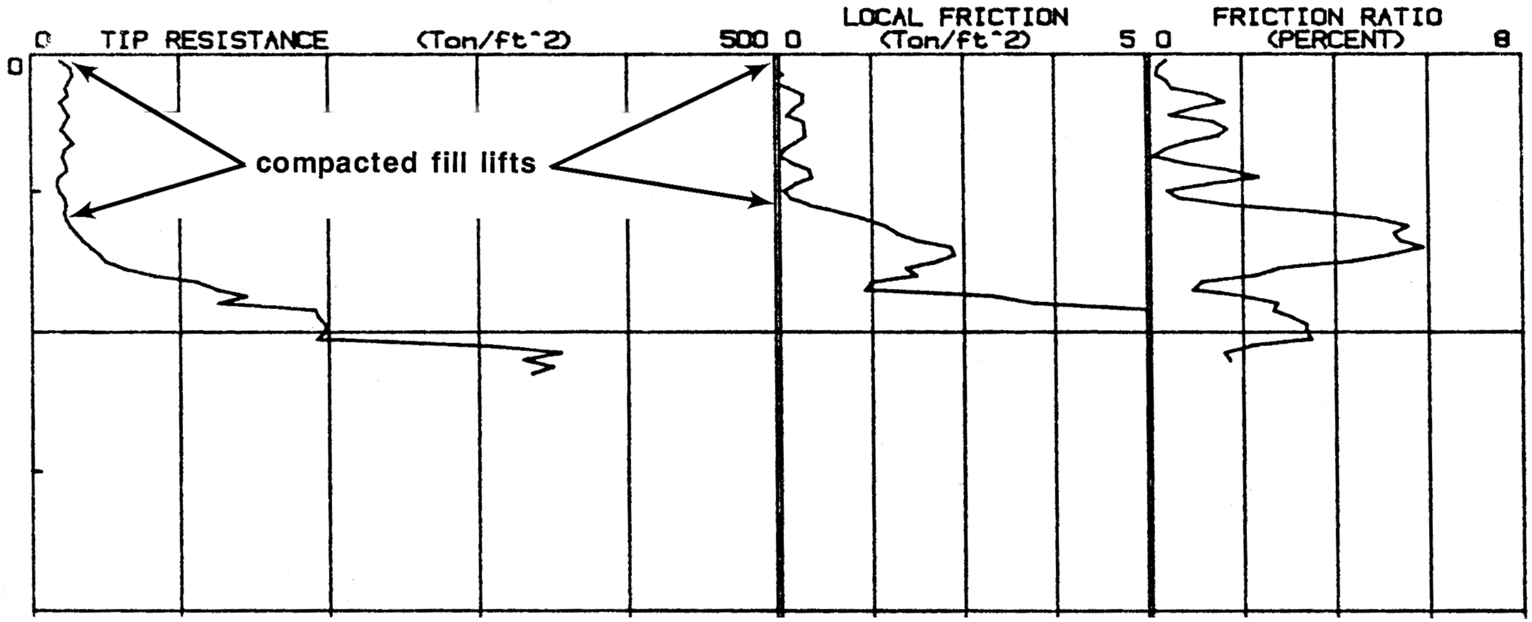
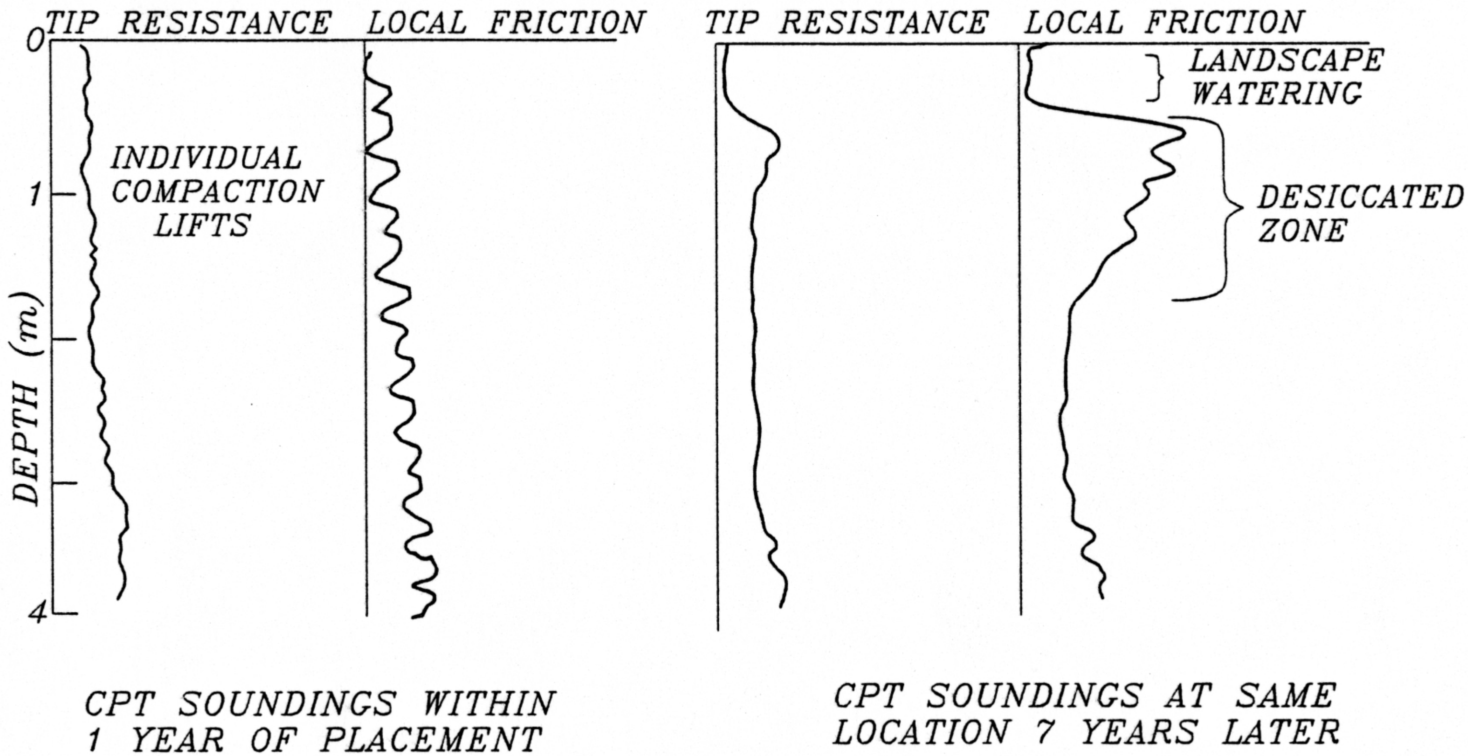


- **The CPT log can discern slight variances in density, stiffness, and shear strength, as shown by these compacted fill lifts**



- **Comparisons of cone penetrometer soundings in expansive silty clay of an engineered fill embankment taken seven years apart.**
- **Note how the initial effects of compaction lifts were erased by moisture absorption, desiccation and swell.**

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Notes of Caution - 1

- 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° 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**, the tip resistance reported on the CPT log may not be a realistic assessment.

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Notes of Caution - 2

- 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 best suited for granular materials, and blow counts in partially saturated cohesive materials must be regarded with some degree of skepticism as they may shift dramatically upon later absorption of moisture.

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CONCLUSIONS - 1

- ***Engineering geologists*** **are most often entrusted with characterizing difficult sites for subsequent analysis by** ***geotechnical engineers*****. Our ability to develop the most effective program of exploration, sampling and testing is built upon each person's unique pedigree of experience.**
- **The most effective means of characterizing complex sites includes a thorough background work-up on the area under investigation, followed by a well-conceived program of subsurface exploration that commonly includes small diameter borings. Cone penetrometer soundings are being employed with increasing regularity, especially in evaluation of soil liquefaction potential.**
- **Engineering geologists should consider employing both techniques whenever possible, because each has slight advantages over the other, but are most powerful when combined on the same sites.**
- **The SPT test allows a first-hand look at subsurface materials which the CPT does not, and can provide crucial "*ground truthing*" as to the type of subsurface material, especially, cohensionless materials with fines.**

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CONCLUSIONS - 2

- **The CPT procedure is capable of detecting *discrete horizons* that would normally be missed using drive samples at specific depth intervals.**
- **But, the absolute values of tip resistance skin (local) friction and pore pressure garnered in CPT soundings must be evaluated with a great degree of judgment, because they can be much higher than actually exists, insitu.**
- **Sites underlain by natural geologic structures should not be approached like a foundation investigation, taking subsurface samples at fixed intervals; they must be attacked individually, with a focused program of exploration that employs a realistic working model of the site's evolution, focused on validating the assumptions used to construct such models.**
- **The greatest danger we face as a profession is the inherent tendency to make the site exploration fit our *pre-conceived notions* of site conditions, then employ insufficient exploration to confirm or deny such assumptions.**

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