

بسمه تعالی

دانشگاه شهید باهنر کرمان

دانشکده فنی و مهندسی

بخش مهندسی معدن

بررسی ساختگاهی

ترم اول ۱۳۹۷

(۹)

سعید کریمی نسب

Site Investigation Course-1397
Kariminasab

dynamic cone penetration test
ASTM D-1586

dynamic cone penetration test

If the test is to be carried out in gravelly soils the driving shoe (in SPT) is replaced by a solid 60 cone and the test is usually called a **dynamic cone penetration test**.

dynamic cone penetration test

There is evidence that slightly higher results are obtained in the same material when the normal driving shoe is replaced by the 60 cone.

Note: For more details of the test refer to **ASTM D-1586**.

Disturbance of a soil sample

Disturbance of a soil sample

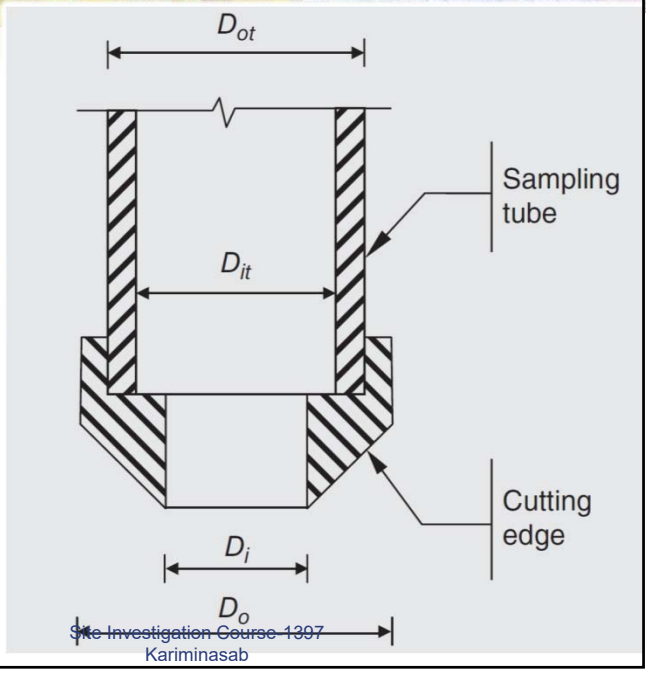
What are the factors on which disturbance of a soil sample depends?

(b) The cutting edge of a sampling tube has outside diameter D_o = 50.8 mm and inside diameter D_i = 47.6 mm, while the sampling tube has D_{ot} = 50.03 mm and D_{it} = 48.50 mm. Is the tube sampler well designed?

Disturbance of a soil sample

Disturbance of a soil sample, during the sampling process, depends on many factors such as rate of penetration of the sampling tube, method of applying the penetrating force (by pushing or driving), the presence of gravel, the area ratio A_r, the inside and outside clearances and proper working of the check valve inside the sampler head.

Sampling tube and the inside and outside diameters



Disturbance of a soil sample

In obtaining undisturbed soil samples, the sample disturbance can be greatly reduced by: pushing the sampler with a moderate rate of penetration, using stainless steel tube with inside protective coating as required by ASTMD 1587,

Disturbance of a soil sample

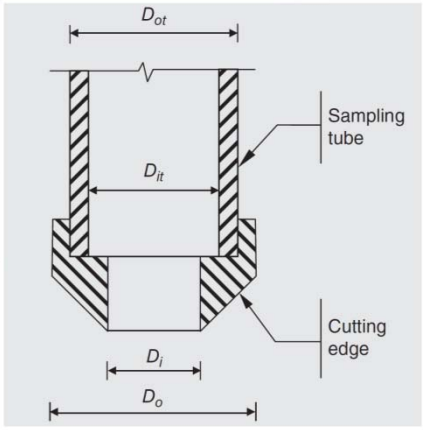
frequent cleaning the sampler head so that the check valve works properly, and using sampler of A_r<10% with its inside clearance C_i = 0.5–3.0% and outside clearance C_o = 0–2%.

The factors **A_r, C_i** and **C_o** are usually expressed as:

$$A_r = \frac{D_o^2 - D_i^2}{D_i^2} \times 100$$

$$C_i = \frac{D_{it} - D_i}{D_i} \times 100$$

$$C_o = \frac{D_o - D_{ot}}{D_{ot}} \times 100$$



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$$A_r = \frac{D_o^2 - D_i^2}{D_i^2} \times 100 = \frac{50.8^2 - 47.63^2}{47.63^2} \times 100 = 13.75\%$$

$$C_i = \frac{D_{it} - D_i}{D_i} \times 100 = \frac{48.50 - 47.63}{47.63} \times 100 = 1.83\%$$

$$C_o = \frac{D_o - D_{ot}}{D_{ot}} \times 100 = \frac{50.80 - 50.03}{50.03} \times 100 = 1.54\%$$

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Problem

A thin-walled tube sampler was pushed into soft clay at the bottom of a borehole a distance of 600 mm.

When the tube was recovered, a measurement down inside the tube indicated a recovered sample length of 585 mm. What is the soil recovery ratio SRR, and what (if anything) happened to the sample? If Do and the Di (outside and inside

diameters) of the sampling tube were 76.2 and 73.0 mm respectively, what is the probable sample quality?

Soil Recovery Ratio, SRR

Similar to the rock recovery ratio, there is also soil recovery ratio, SRR, which can be used in estimating degree of disturbance of soil samples, where

$$SRR = \frac{\text{Actual length of recovered soil sample}}{\text{Total length of sampler in soil}}$$

Soil Recovery Ratio, SRR

A recovery ratio of **1** indicates, theoretically, that the sample did not become compressed during sampling.

A recovery ratio **less than 1** indicates compressed sample in a disturbed state. Also, when a recovery ratio is **greater than 1**, the sample is disturbed due to loosening from rearrangement of stone fragments, roots, removal of overburden, or other factors.

$$SRR = \frac{585}{600} = 0.98 < 1$$

So soil is slightly compressed sample

- The sample is compressed from friction on the tube and, or from pressure of entrapped air above the sample due to incapable head check valve.

$$A_r = \frac{D_o^2 - D_i^2}{D_i^2} \times 100$$

$$C_i = \frac{D_{it} - D_i}{D_i} \times 100$$

$$C_o = \frac{D_o - D_{ot}}{D_{ot}} \times 100$$

$$A_r = \frac{D_o^2 - D_i^2}{D_i^2} \times 100 = \frac{76.2^2 - 73.0^2}{73.0^2} \times 100 = 8.96\,\% < 10\%$$

$$C_i = \frac{D_{it} - D_i}{D_i} \times 100 = \frac{73.0 - 73.0}{73.0} \times 100 = 0\% < (0.5\text{–}3.0\%)$$

$$C_o = \frac{D_o - D_{ot}}{D_{ot}} \times 100 = \frac{76.2 - 76.2}{76.2} \times 100 = 0\%$$

SPT Example

At the site the variation of the SPT number (N_{60}) with depth in a deposit of normally consolidated sand is as given below:

Depth, m:	1.5	3.0	4.5	6.0	7.5	9.0
N_{60}:	6	8	9	8	13	14

CONE PENETRATION TESTING (CPT)

- The cone penetration test is quickly becoming the most popular type of in-situ test because it is fast, economical, and provides continuous profiling of geostratigraphy and soil properties evaluation.

CONE PENETRATION TESTING (CPT)

- The test is performed according to ASTM D-3441 (mechanical systems) and ASTM D 5778 (electric and electronic systems) and consists of pushing a cylindrical steel probe into the ground at a constant rate of 20 mm/s and measuring the resistance to penetration.

CONE PENETRATION TESTING (CPT)

- The standard penetrometer has a conical tip with 60° angle apex, 35.7-mm diameter body (10-cm^2 projected area), and 150-cm^2 friction sleeve.

CONE PENETRATION TESTING (CPT)

- The measured point or tip resistance is designated qc and the measured side or sleeve resistance is fs.
- The ASTM standard also permits a larger 43.7-mm diameter shell (15-cm^2 tip and 200-cm^2 sleeve).

CONE PENETRATION TESTING (CPT)

- The CPT can be used in very soft clays to dense sands, yet is not particularly appropriate for gravels or rocky terrain.

CONE PENETRATION TESTING (CPT)

- As the test provides more accurate and reliable numbers for analysis, yet no soil sampling, it provides an excellent complement to the more conventional soil test boring with SPT measurements.

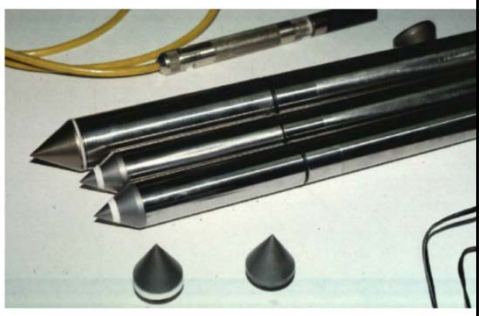
CONE PENETRATION TESTING
ADVANTAGES

- Fast and continuous profiling
- Economical and productive
- Results not operator-dependent
- Strong theoretical basis in interpretation
- Particularly suitable for soft soils

CONE PENETRATION TESTING
DISADVANTAGES

- High capital investment
- Requires skilled operator to run
- Electronic drift, noise, and calibration.
- No soil samples are obtained.
- Unsuitable for gravel or boulder deposits





Cone Penetrometers





- Electronic Steel Probes with 60° Apex Tip
- ASTM D 5778 Procedures
- Hydraulic Push at 20 mm/s
- No Boring, No Samples, No Cuttings, No Spoil
- Continuous readings of stress, friction, pressure

Cone Penetration Tests (CPT)

Cone Trucks







Mobile 25-tonne rigs with enclosed cabins to allow testing under all weather conditions

CONE PENETRATION TESTING

- Most electric/electronic cones require a cable that is threaded through the rods to connect with the power supply and data acquistion system at the surface.

CONE PENETRATION TESTING

- An analog-digital converter and pentium notebook are sufficient for collecting data at approximate 1-sec intervals.

CONE PENETRATION TESTING

- Depths are monitored using either a potentiometer (wire-spooled LVDT), depth wheel that the cable passes through, or ultrasonics sensor.

CONE PENETRATION TESTING

- Systems can be powered by voltage using either generator (AC) or battery (DC), or alternatively run on current.

Corrections to CPT

- Tip Stress correction for porewater pressures on unequal areas – Important in Intact Clays & Silts
- Sleeve Friction correction for porewater pressures – Use equal end areas on friction sleeve
- Baseline corrections – Obtain before & after sounding

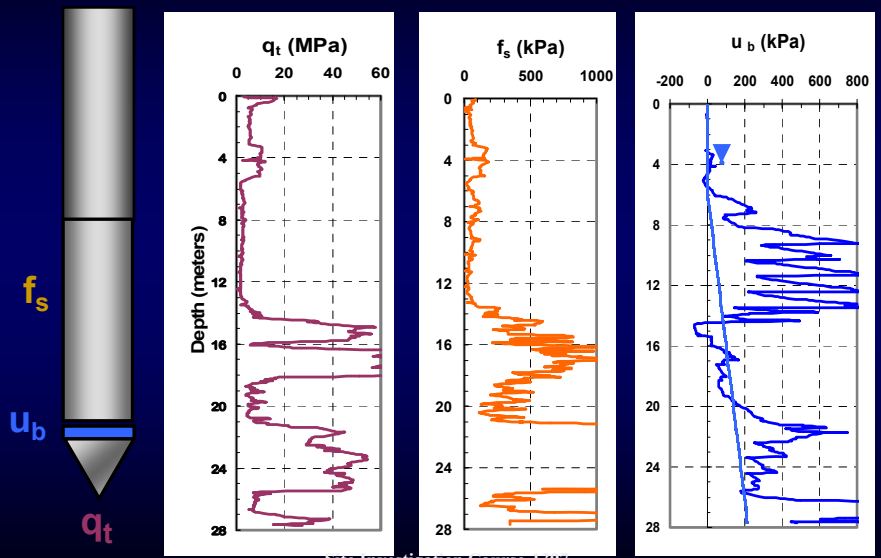
Anchored Cone Rig

Mud Island, Downtown Memphis, TN

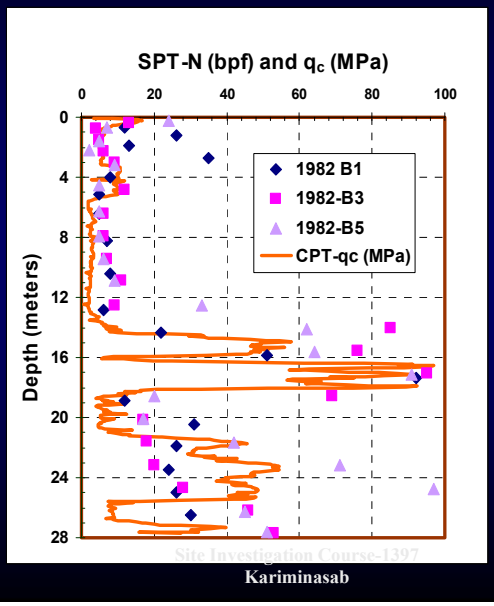


- 6-tonne Geostar truck with 20-tonne hydraulic pushing system
- No special license
- Twin earth anchors
- Has penetrated to depths over 32+ meters at sites in SC, AL, MO, TN, & AL

CPT Profile, Downhole Memphis



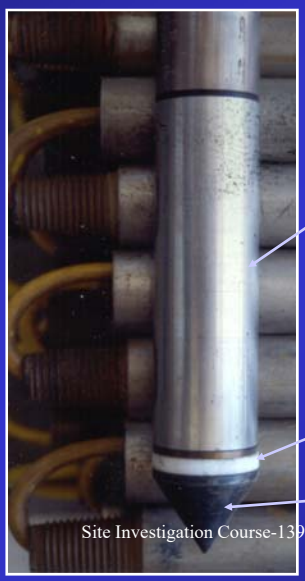
Comparison CPT and SPT Downtown Memphis





Basic Cone Parameters





Sleeve Friction
$f_s = {}^{load}/_{2\pi rh}$

Pore Pressure, u_2

Tip Resistance
$q_c = {}^{load}/_{\pi r^2}$

Robertson, 2015

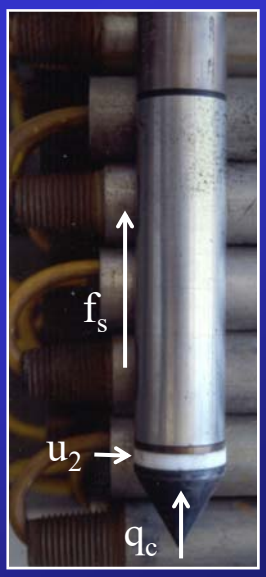
Cone Penetration Test (CPT)

ADVANTAGES:

- Fast and continuous profiling
- Repeatable data
- Economical and productive
- Strong theoretical basis for interpretation
- More than one measurement (q_c, f_s, u)
- Additional sensors (e.g. seismic V_s & V_p)

LIMITATIONS:

- Somewhat high capital investment
- Somewhat skilled operators
- No soil sample (during CPT)*
- Penetration restricted in gravels/cemented layers (same as SPT)



Typical approach using CPT

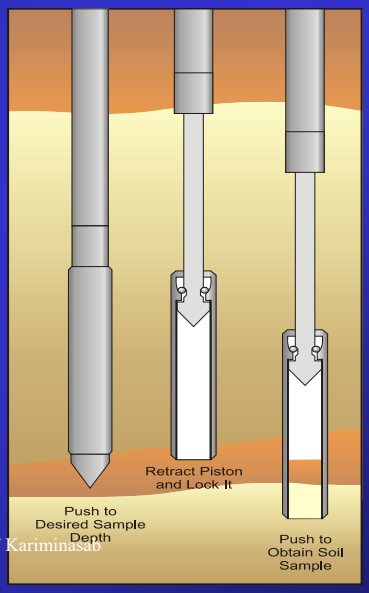
- CPT first
  - Reliable and fast (~600 ft/day)
  - Continuous profile (vert. & horiz. variability)
  - Preliminary interpretation (stratigraphy and parameters)
  - Small number of disturbed samples using CPT (classification purposes)
- Small number of boreholes to obtain good quality samples
  - Small number of good quality samples in layers that are critical to project

Example CPT Soil Sampling

CPT (Piston-Type) Sampler

- Simple single-tube system
- 30cm (12”) long by 25mm (1 ”) diameter
- Similar size as SPT sampler
- Good for classification purposes





Ground Investigation

To investigate ground and groundwater conditions in and around site consistent with project requirements

- Nature, sequence and variability of strata
- Groundwater conditions
- Physical, chemical and mechanical characteristics of strata

Field work designed to test and evaluate geologic model

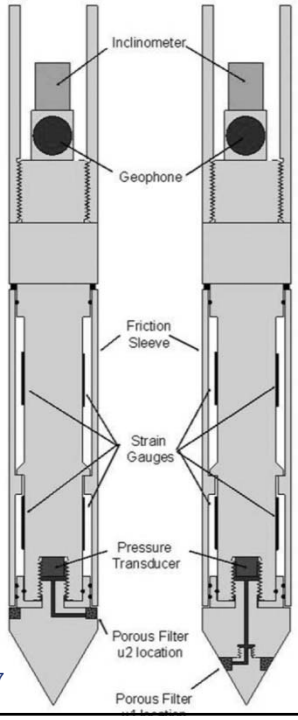
BASIC TYPES OF CONE PENETRATION TESTS AVAILABLE FOR SITE CHARACTERIZATION

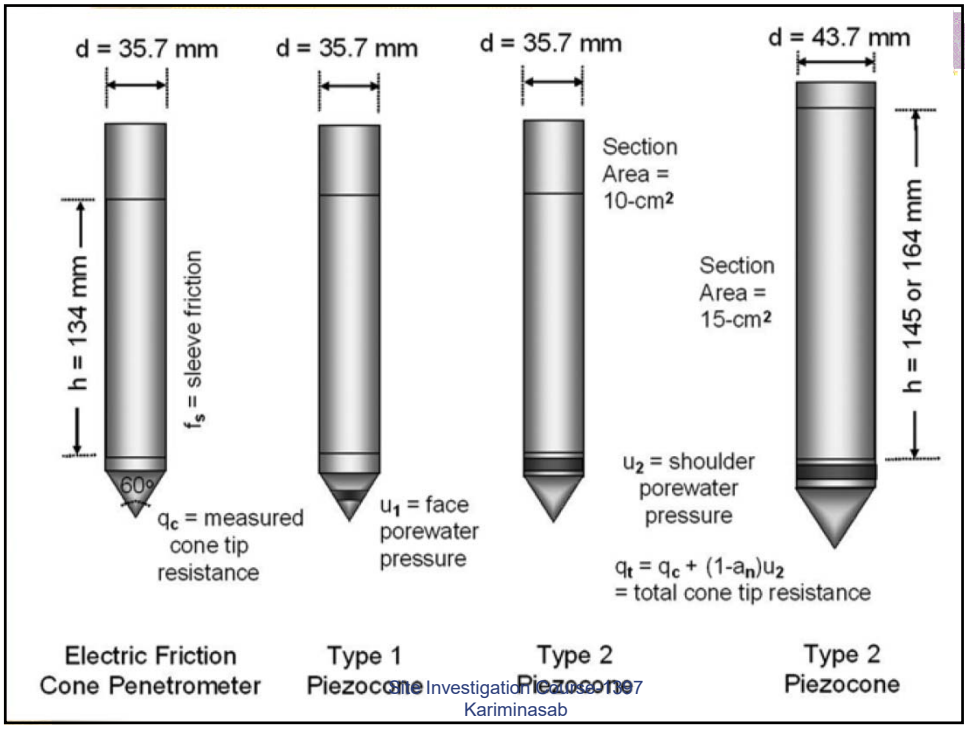
Type of CPT	Acronym	Measurements Taken	Applications
Mechanical Cone Penetration Test	MCPT	q_c (or q_c and f_s) on 20-cm intervals. Uses inner and outer rods to convey loads uphole	Stratigraphic profiling, fill control, natural sands, hard ground
Electric Friction Cone	ECPT	q_c and f_s (taken at 1- to 5-cm intervals)	Fill placement, natural sands, soils above the groundwater table
Piezocone Penetration Test	CPTu and PCPT	q_c, f_s, and either face u_1 or shoulder u_2 (taken at 1- to 5-cm intervals)	All soil types. Note: Requires u_2 for correction of q_c to q_t
Piezocone with Dissipation	CPTù	Same as CPTu with timed readings of u_1 or u_2 during decay	Normally conducted to 50% dissipation in silts and clays
Seismic Piezocone Test	SCPTu	Same as CPTu with downhole shear waves (V_s) at 1-m intervals	Provides fundamental soil stiffness with depth: $G_{max} = \rho_t V_s^2$
Resistivity Piezocone Test	RCPTu	Same as CPTu with electrical conductivity or resistivity readings	Detect freshwater–salt water interface. Index to contaminant plumes

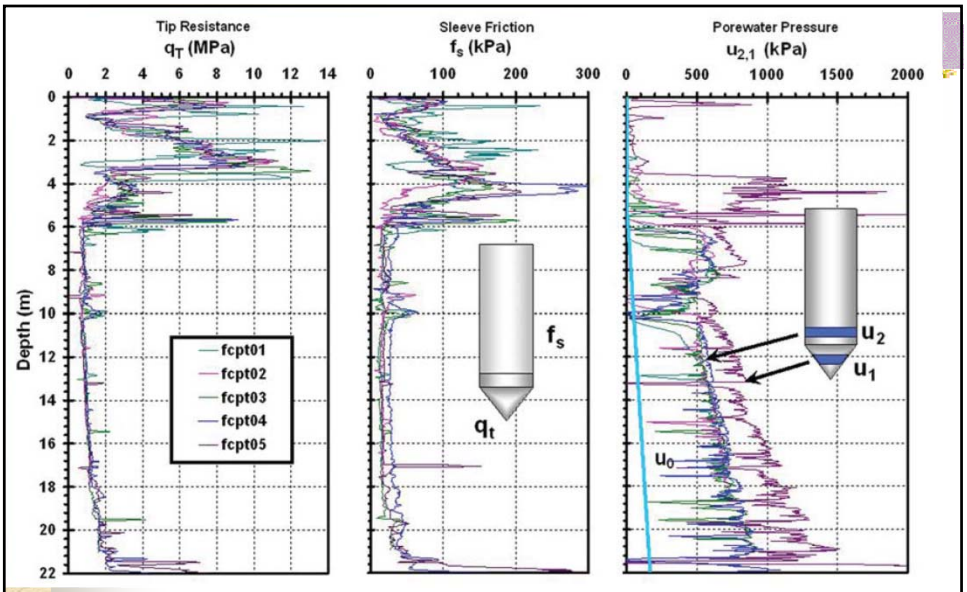
BASIC TYPES OF CONE PENETRATION TESTS AVAILABLE FOR SITE CHARACTERIZATION

- **Notes: q_c = measured point stress or cone tip resistance,**
- ***fs* = measured sleeve friction,**
- ***u* = penetration pore water pressure (u_1 at face; u_2 at shoulder),**
- **q_t = total cone resistance,**
- ***Vs* = shear wave velocity.**

- Basic internal schematic of an electric cone penetrometer







- Series of piezocone penetration tests

CPT
TESTING PROCEDURES

- **TESTS AT INTERMITTENT DEPTHS**

At each one-meter rod break, there is an opportunity to conduct intermittent testing before the next succession of pushing

as the next rod is added.

Two common procedures include: (1) dissipation testing, and (2) downhole shear wave velocity measurements.

Porewater Dissipation Tests

Dissipation testing involves the monitoring of pore water pressures as they decay with time.

The installation of a full displacement device such as a cone penetrometer results in the generation of excess pore water pressures (Δu) locally around the axis of perturbation.

Porewater Dissipation Tests

In clean sands, the Δu will dissipate almost immediately because of the high permeability of sands,

whereas in clays and silts of low permeability the measured Δu will require a considerable time to equilibrate.

Porewater Dissipation Tests

Given sufficient time in all soils, the penetrometer pore water channel will eventually record the ambient hydrostatic condition corresponding to u_0.

Thus, the measured pore water pressures (u_m) are a combination of transient and hydrostatic pressures, such that:

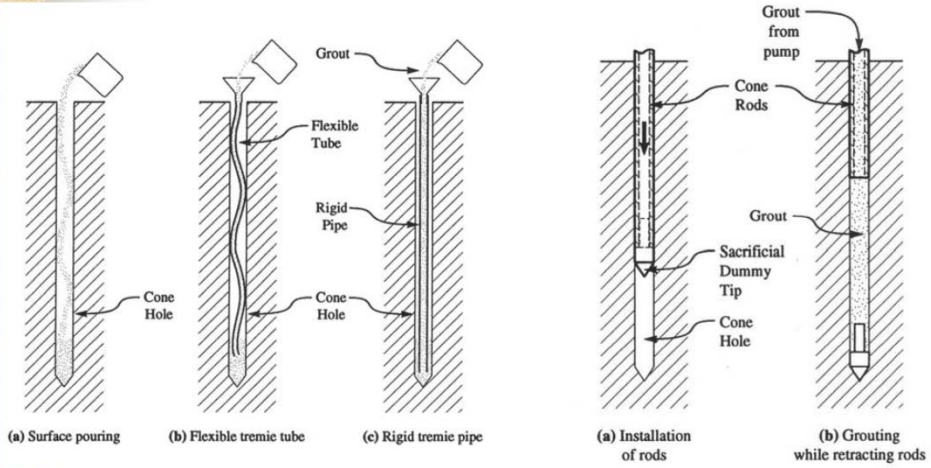
$$u_m = \Delta u + u_0$$

HOLE CLOSURE

After the sounding is completed, a number of possible paths may be followed during or after extraction:

- CPT hole is left open.
- Hole is backfilled using native soils or pea gravel or sand.
- Cavity is grouted during withdrawal using a special “loss tip” or retractable portal.
- After withdrawal, hole is reentered using a separategrouting system.

HOLE CLOSURE



Piezocone Penetration Testing (PCPT or CPTu)

- Piezocones are cone penetrometers with added transducers to measure penetration pore water pressures during the advancement of the probe.
- In clean sands, the measured penetration pore pressures are nearly hydrostatic because the **high permeability of the sand permits immediate dissipation**.

Piezocone Penetration Testing (PCPT or CPTu)

- In clays, however, the undrained penetration results in the development of high excess pore water pressures above hydrostatic. These excess **u** can be either positive or negative, depending upon the specific location of the porous element (filter stone) along the cone probe.

Piezocone Penetration Testing (PCPT or CPTu)

- If the penetration is arrested, the decay of pore water pressures can be monitored with time and used to infer the rate of consolidation and soil permeability.

Geotechnical Risk

Sum of:

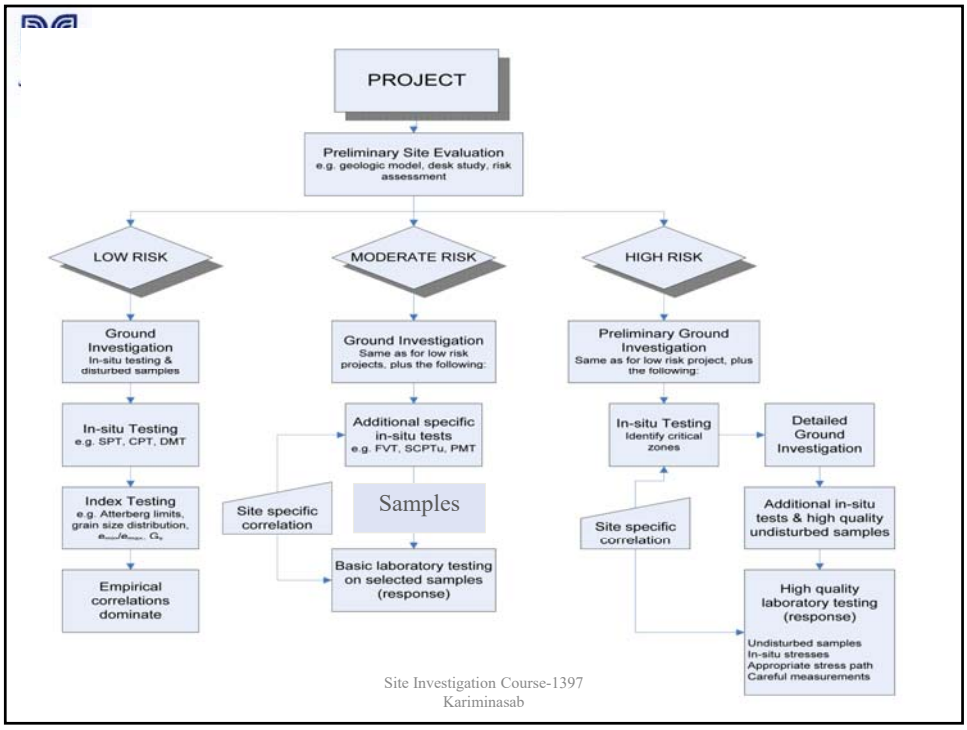
- Hazards (What can go wrong?)
  - including geologic complexity
- Probability of occurrence (How likely is it?)
- Consequences (What are the consequences?)
- Experience of engineer (What is local experience?)

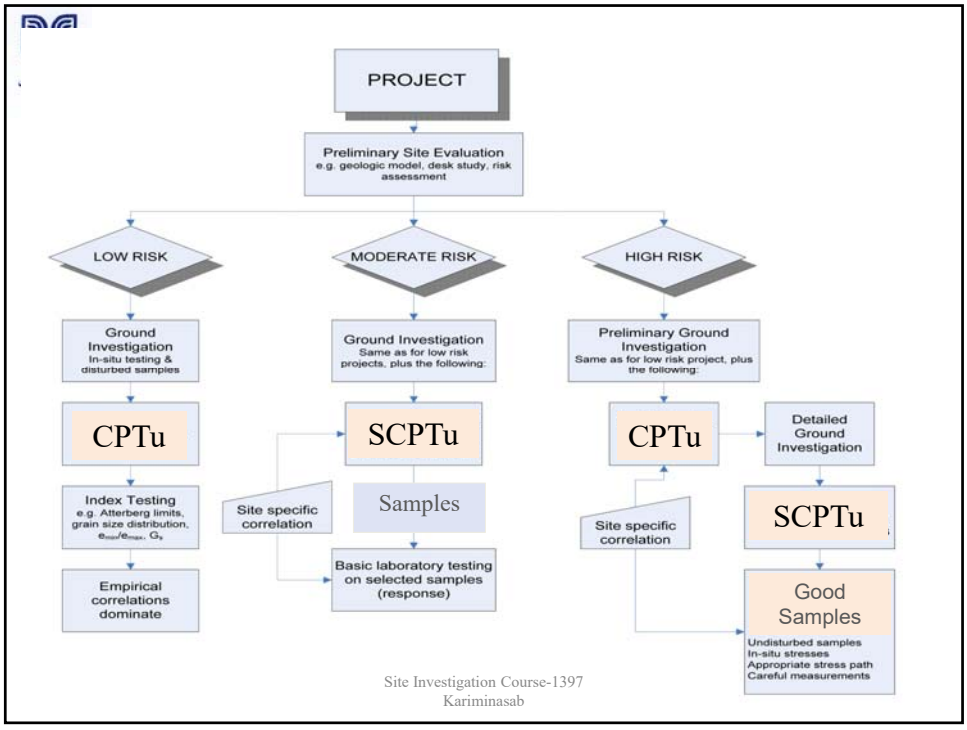
What level of sophistication is appropriate for site investigation & analyses?

GOOD	**Precedent & local experience**	*POOR*
SIMPLE	**Design objectives**	*COMPLEX*
LOW	**Level of geotechnical risk**	*HIGH*
LOW	**Potential for cost savings**	*HIGH*

Traditional Methods ***Advanced Methods***

Simplified ***Complex***


PROJECT
Preliminary Site Evaluation
e.g. geologic model, desk study, risk assessment
LOW RISK
MODERATE RISK
HIGH RISK
Ground Investigation
In-situ testing & disturbed samples
In-situ Testing
e.g. SPT, CPT, DMT
Index Testing
e.g. Atterberg limits, grain size distribution, e_{min}/e_{max}, G_s
Empirical correlations dominate
Ground Investigation
Same as for low risk projects, plus the following:
Additional specific in-situ tests
e.g. FVT, SCPTu, PMT
Site specific correlation
Samples
Basic laboratory testing on selected samples (response)
Preliminary Ground Investigation
Same as for low risk project, plus the following:
In-situ Testing
Identify critical zones
Detailed Ground Investigation
Site specific correlation
Additional in-situ tests & high quality undisturbed samples
High quality laboratory testing (response)
Undisturbed samples
In-situ stresses
Appropriate stress path
Careful measurements


PROJECT
Preliminary Site Evaluation
e.g. geologic model, desk study, risk assessment
LOW RISK
MODERATE RISK
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CPTu
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Same as for low risk projects, plus the following:
SCPTu
Site specific correlation
Samples
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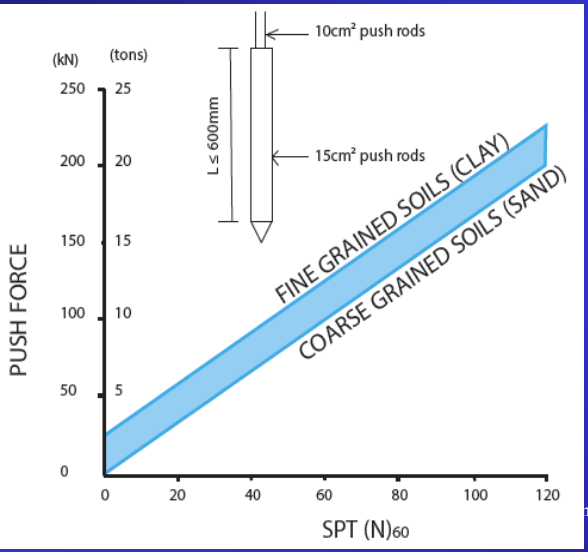
Preliminary Ground Investigation
Same as for low risk project, plus the following:
CPTu
Detailed Ground Investigation
Site specific correlation
SCPTu
Good Samples
Undisturbed samples
In-situ stresses
Appropriate stress path
Careful measurements

How deep can you push the CPT?



Depends on:

- Reaction/push force
- Rod friction
- Density of ground

With 15 cm² cone (& 10cm² push rods) and *20 tons* reaction – can penetrate soil with SPT $(N)_{60} > 100$ (i.e. soft rock)

How accurate is the CPT?

- Most commercial cones are designed to measure max. full-scale output (FSO) tip stress, q_c = 1,000tsf (100 MPa)
- Most strain gauge load cells have accuracy of ± 0.1% FSO, i.e. accuracy ~ ± 1tsf (0.1 MPa)
  - Sands (q_c > 100tsf) - accuracy better than 1% of measured value
  - Soft clays (q_c < 10tsf) - accuracy maybe less than 10% of measured value

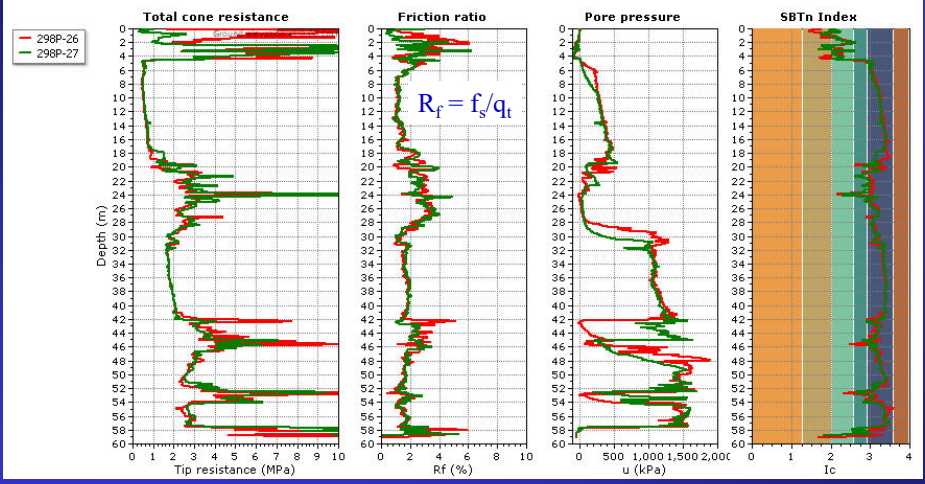
Need low capacity cones for soft clays

Accuracy - Repeatability

- In general:
  - Tip (q_t) is more accurate & repeatable than sleeve (f_s)
    - Prefer separate load cells to improve accuracy of f_s
    - Equal end area sleeves to minimize water effects on f_s
    - Check dimensional tolerance on sleeve
  - Tip (q_t) is more accurate & repeatable than u_2
    - *Except in very soft fine-grained soils (where q_c can be very small and u_2 can be very large)*
    - Potential loss of saturation in stiff dilative soils (negative values for u_2)

Robertson, 2015

Repeatability - example



High level of repeatability

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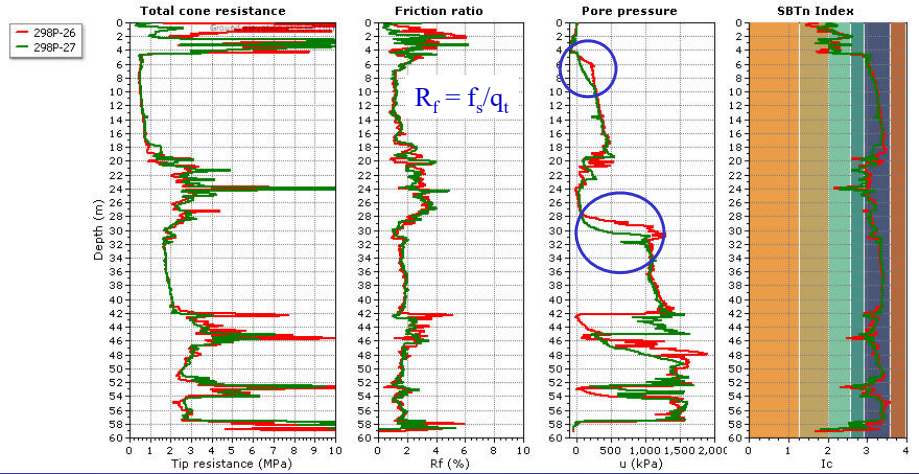
Repeatability - example



Loss of saturation can produce "sluggish" pore pressure response

Robertson, 2015

Repeatability of pore pressures data?

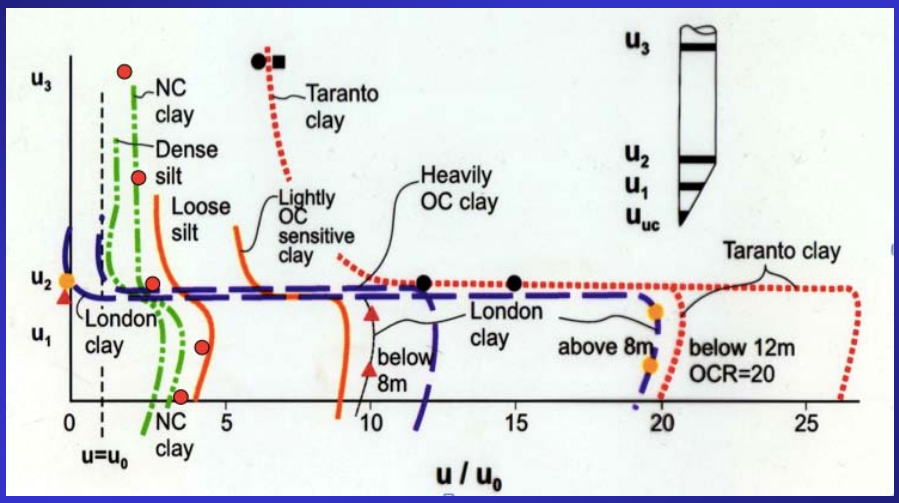
Why is pore pressure data so complex and often lacks repeatability?

- complex stress and strain field around cone
- strongly dilative soils can produce negative pore pressures at u_2 location

Pore pressure data can be very good in soft fine-grained soils with high GWL

- high positive pore pressures throughout
- short depth to saturated soils

Complex distribution of pore pressures



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Modified from Campanella et al. 1985

Robertson, 2015

Dissipation test

- Provides information on:
  - Equilibrium pore pressure, u_0 (at that location and time)
    - piezometric profile (is it hydrostatic?)
    - piezometric surface (i.e. GWL)
  - Rate of dissipation
    - Controlled primarily by coefficient of consolidation (c_h) and permeability (hydraulic conductivity, k_h)
    - Varies by orders of magnitude (very fast to very slow)

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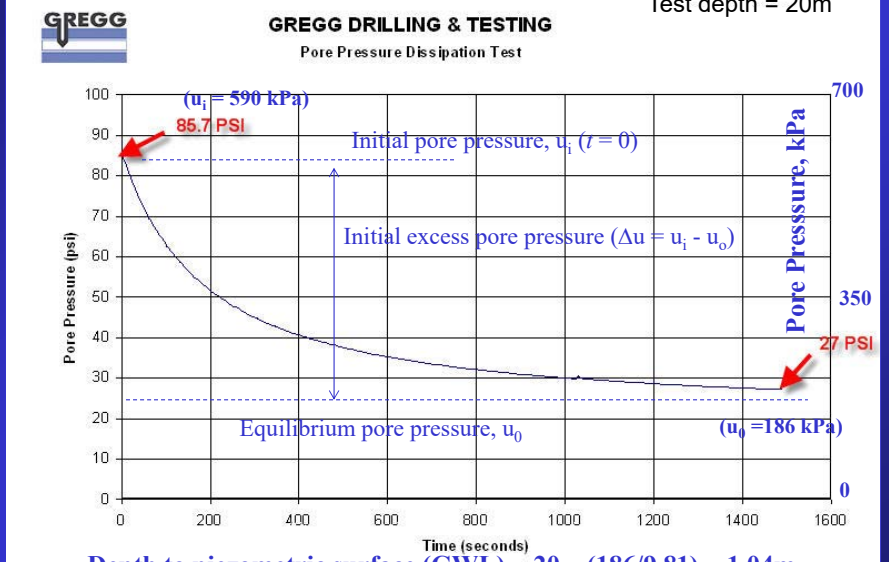
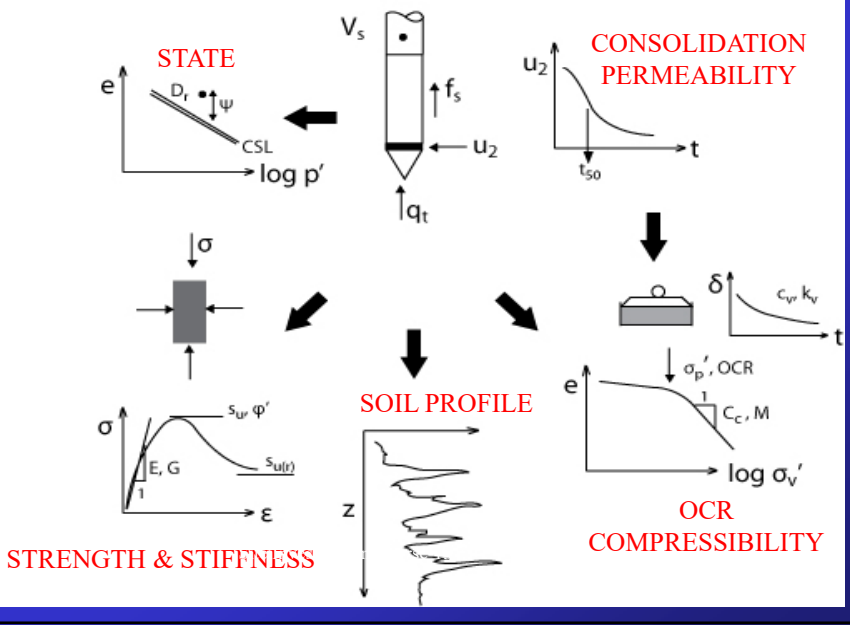
Dissipation Test

Test depth = 20m

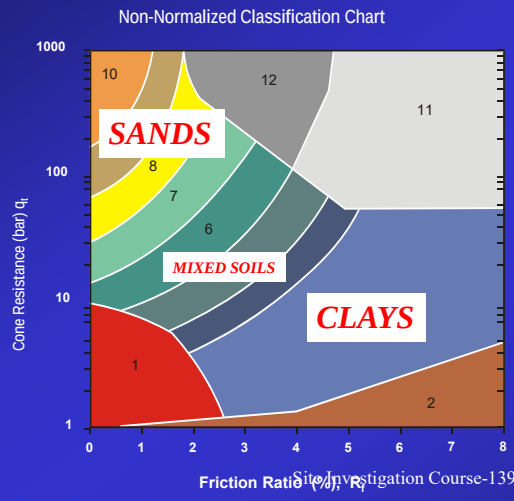


Depth to piezometric surface (GWL) = 20 – (186/9.81) = 1.04m

CPTu Interpretation



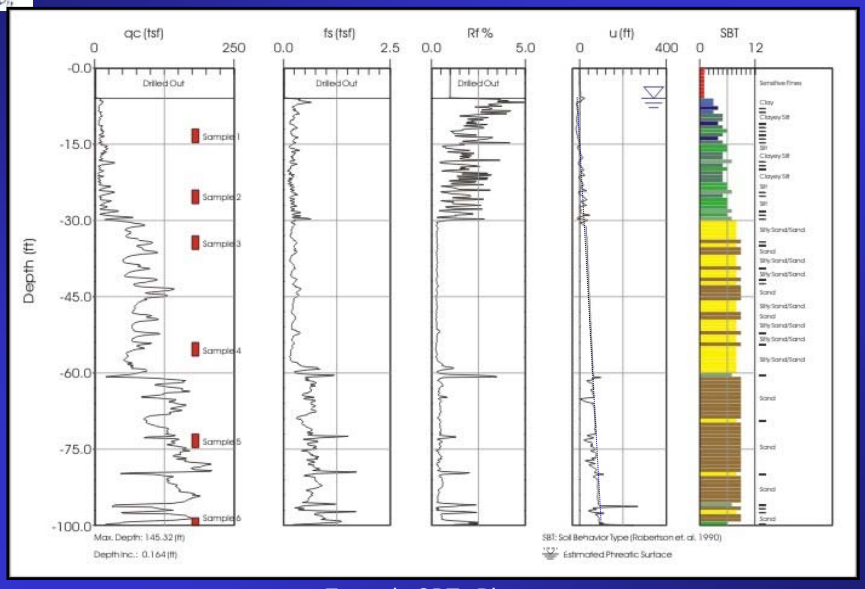
CPT - Soil Behavior Type (SBT)



CPT *SBT* based on *in-situ mechanical behavior characteristics (i.e. strength, stiffness & compressibility)* - not the same as traditional *classification* based on *physical characteristics (i.e. Atterberg Limits and grain size distribution)* carried out on disturbed samples

After Robertson & Campanella, 1986

Example CPT Data Presentation



Example CPTu Plot

CPT – Normalization

CPT:

$$Q_t = (q_t - \sigma_v) / \sigma'_{vo}$$

$$F = f_s / \sigma'_{vo}$$

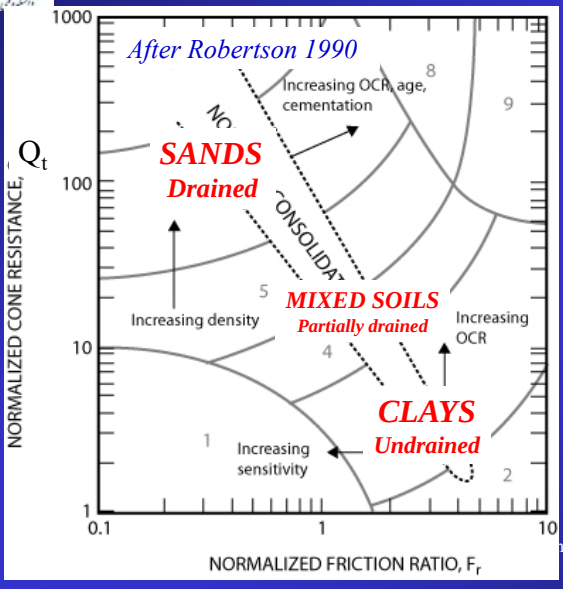
$$F_r = [f_s / (q_t - \sigma_v)]100\ (\%)$$

CPTu:

$$B_q = (u_2 - u_0) / (q_t - \sigma_v)$$

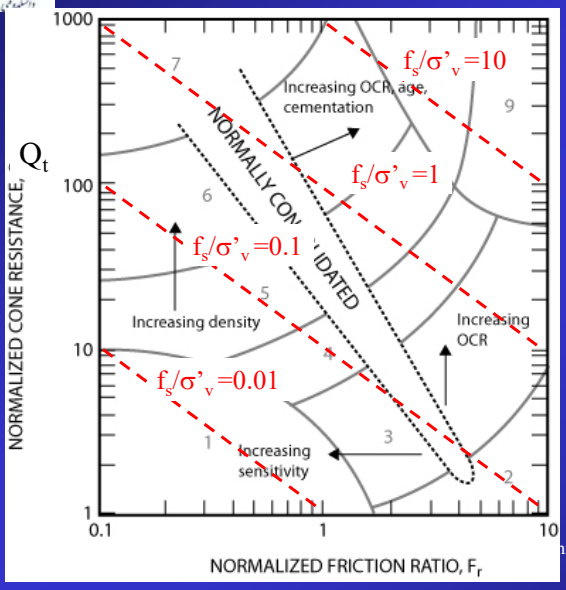
$$U = (u_2 - u_0) / \sigma'_{vo}$$

CPT Normalized SBT



CPT *SBT* based on *in-situ mechanical behavior* (*strength, stiffness, compressibility*) Not same as traditional '*classification*' based *physical characteristics* (*Atterberg limits, grain size*) on *disturbed samples*

CPT Soil Behavior Type SBT



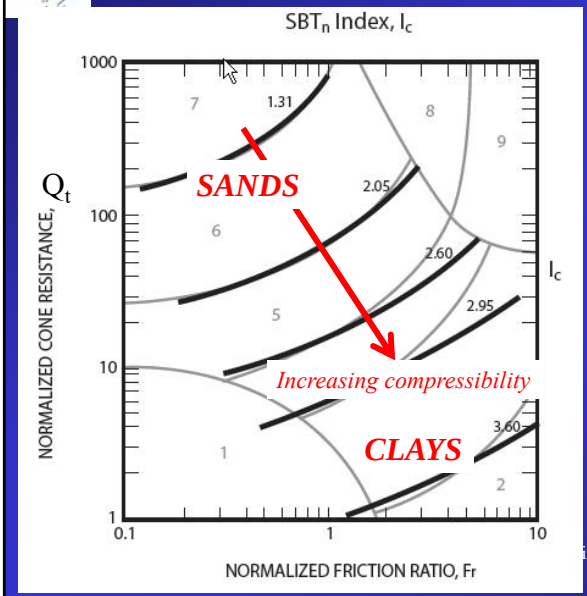
Normalized CPT sleeve resistance

$F = f_s / \sigma'_{vo}$

also a measure of stress history (similar to K_D)

Varies by 3 orders of magnitude!

CPT SBT Index, I_c



Soil Behavior Type Index, I_c

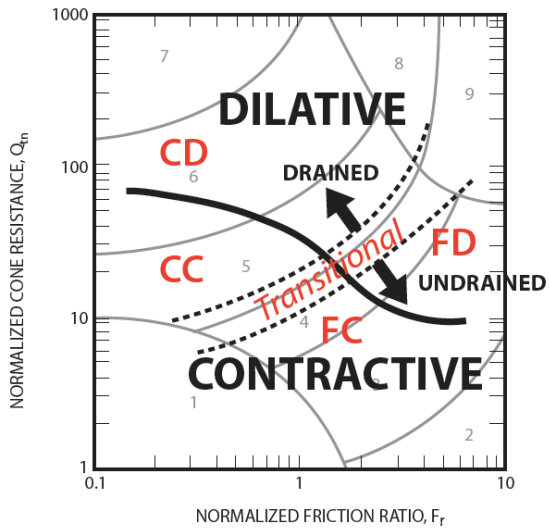
(first proposed by Jefferies & Davies, 1993)

$I_c = [(3.47 - \log Q)^2 + (\log F + 1.22)^2]^{0.5}$

Function primarily of Soil Compressibility

Note:
Q_t plays larger role than F_r

Generalized CPT Soil Behaviour Type

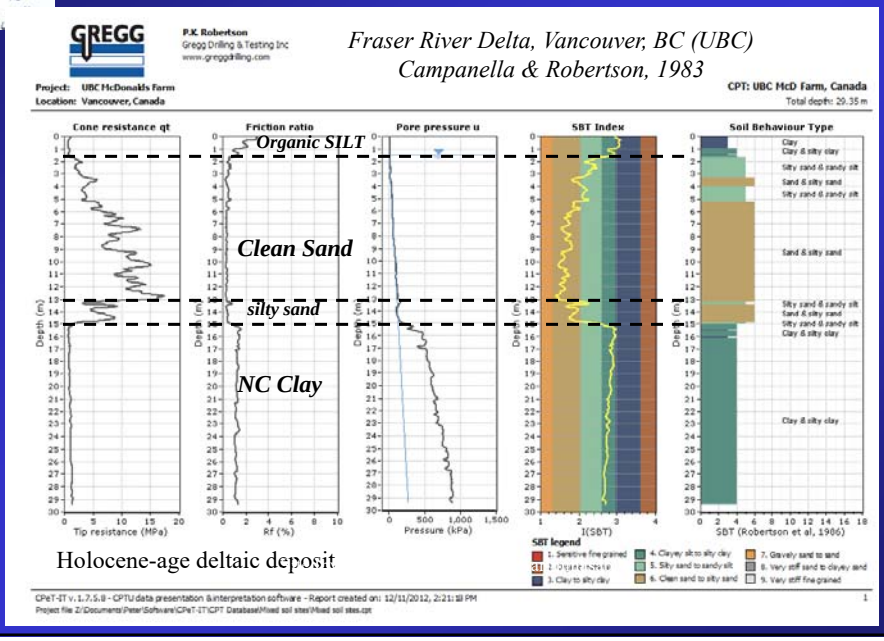


CPT Soil Behaviour

CD: Coarse-grain-Dilative
(mostly drained)
CC: Coarse-grain-Contractive
(mostly drained)
FD: Fine-grain-Dilative
(mostly undrained)
FC: Fine-grain-Contractive
(mostly undrained)

Modified from Robertson, 2012

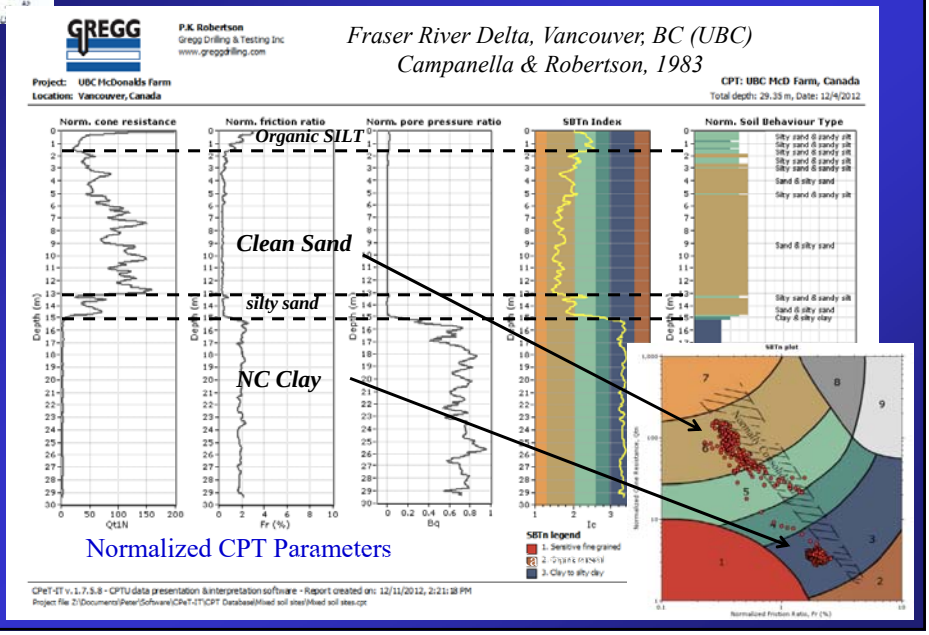
Example CPT - UBC Fraser River



Fraser River Delta, Vancouver, BC (UBC)
Campanella & Robertson, 1983

Holocene-age deltaic deposit

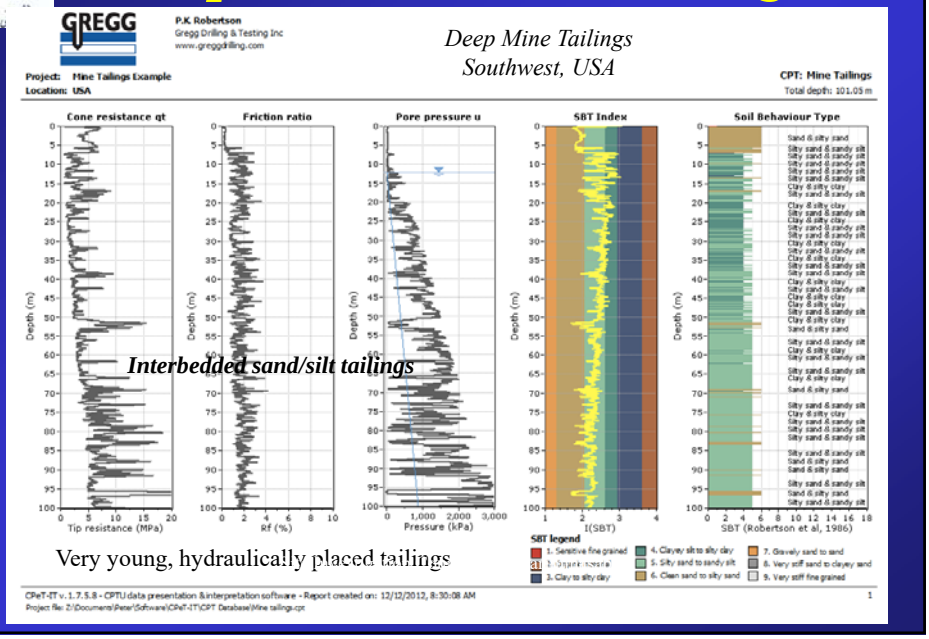
Example CPT - UBC Fraser River



Fraser River Delta, Vancouver, BC (UBC)
Campanella & Robertson, 1983

Normalized CPT Parameters

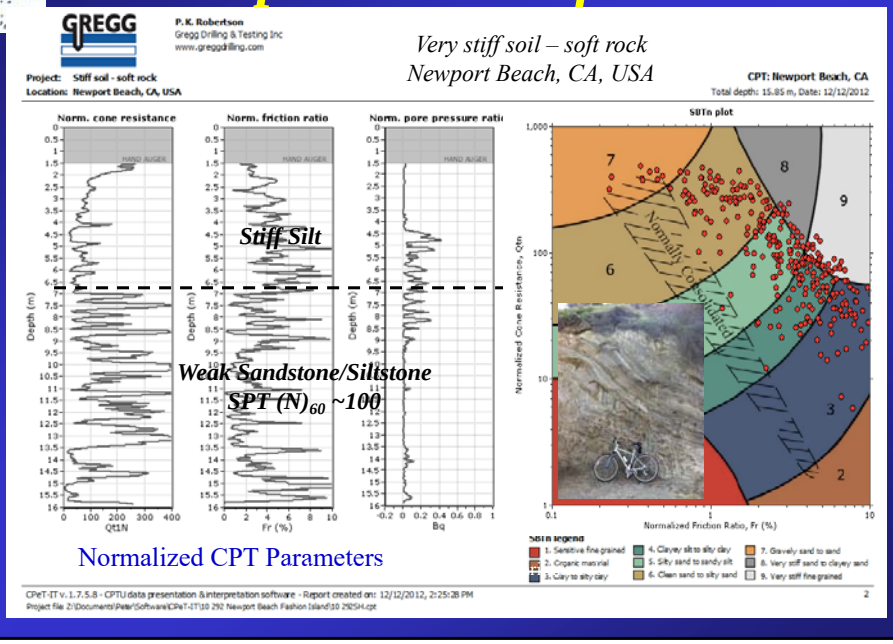
Example 100m CPT – Tailings



Deep Mine Tailings
Southwest, USA

Very young, hydraulically placed tailings

Example CPT – Soft Rock



Requirements for a Good Insitu Test

- Reliable, operator independent measurements
  - Examples: CPT, CPTu, SCPTu, DMT
- Repeatable disturbance of surrounding soil
  - Examples: CPT, CPTu, SCPTu, DMT
- Measurement of more than one independent variable
  - Example: CPTu, SCPTu, SDMT

Real soil behavior complex – need to measure more than one in-situ response

Factors affecting CPT interpretation

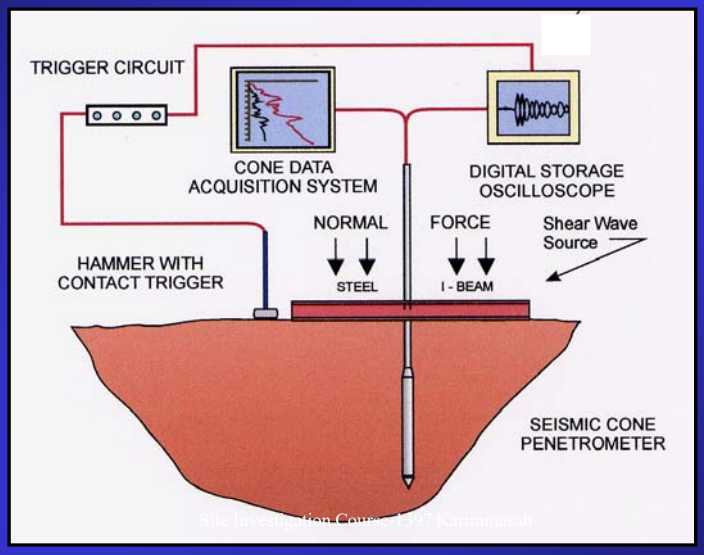
- Geology & geologic history
  - In-situ stresses (*importance of horizontal stresses*)
  - Soil compressibility (*mineralogy*)
  - Cementation
  - Particle size (*e.g. gravel size*)
  - Stratigraphy/layering

CPT should be interpreted within a geologic context

Seismic CPT (SCPT)

- >30 years experience (1983)
- Simple, reliable, and inexpensive
- Direct measure of soil stiffness
  - Small strain value, $G_o = \rho \cdot V_s^2$
- Typically 1m (~3ft) intervals
- Combines q_c and V_s profile in same soil

Basic SCPT Configuration



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Seismic CPT



CPT truck/drill-rig with (build-in) seismic beam

Seismic beam





Figure 1. AutoSeis shear wave seismic source.

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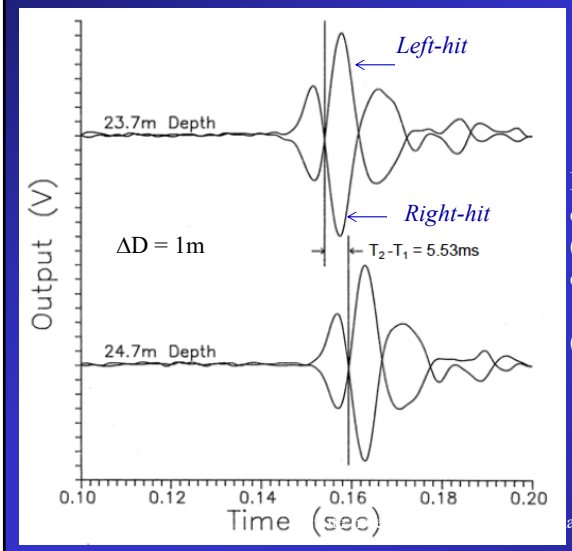
Polarized shear wave traces



$$V_s = \frac{(L_2 - L_1)}{(T_2 - T_1)}$$

L = calculated straight path distance from source to receiver (use horizontal offset X & vertical depth D)

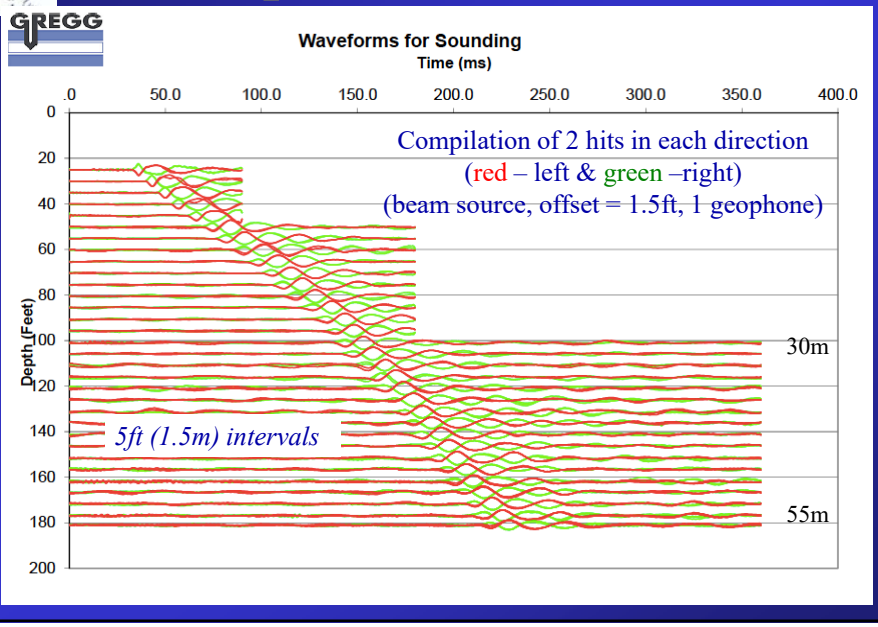
$(T_2 - T_1)$ = time difference



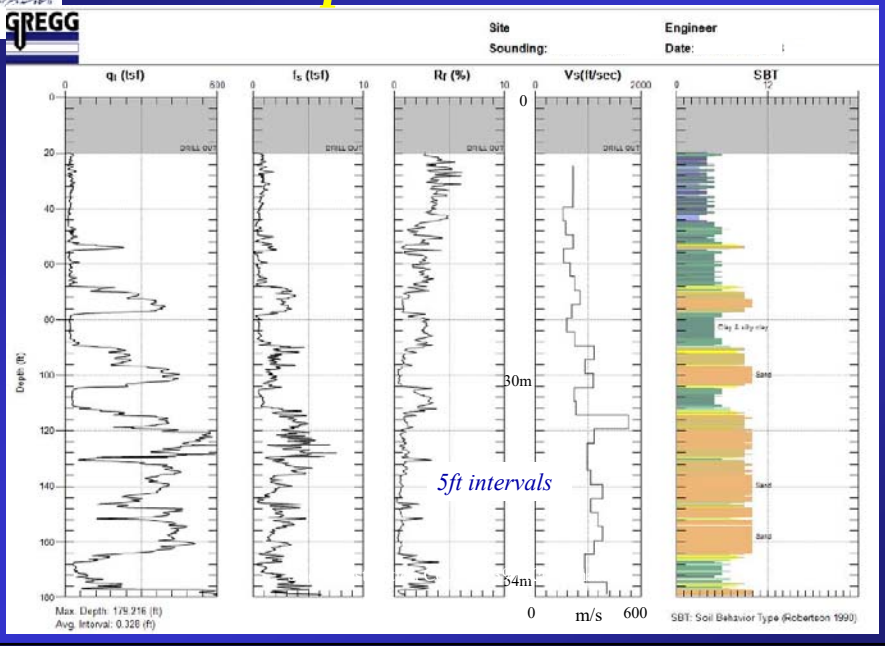
ariminasab

After Butcher et al 2005 (ISSMGE TC 10)

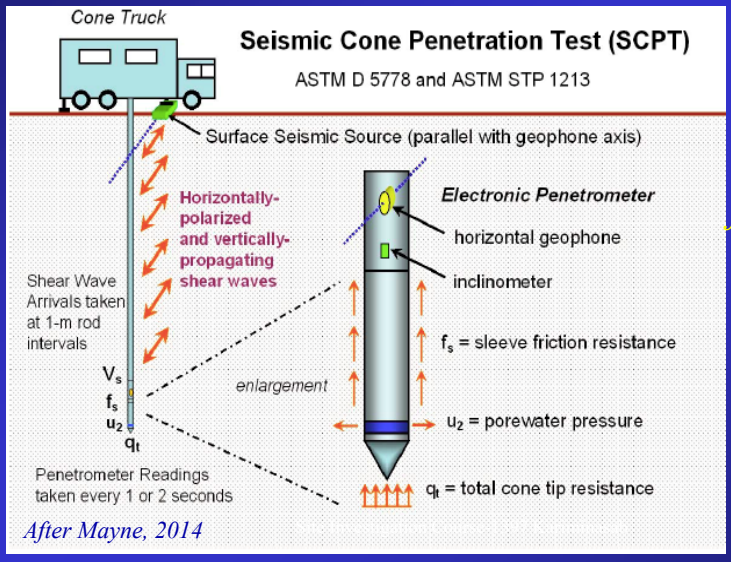
SCPT polarized wave traces



Example Seismic CPT



SCPTu - Advantages



After Mayne, 2014

SCPTu

7 measurements!

- q_t
- f_s
- u_2
- V_s (V_p)
- t_{50}
- u_o
- i

diss

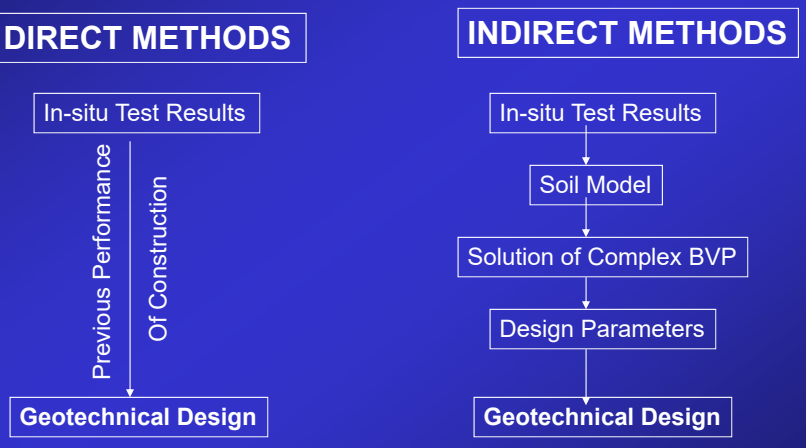
Perceived applicability of CPTu for Deriving Soil Parameters

	Initial state parameter				Strength Parameters			Deformation Characteristics*			Flow Charact.	
Soil Type	γ/D_r	ψ	K_o	OCR	S_t	s_u	Φ'	E	M	G_o	k	c_h
Clay	3-4		2	1-2	2-3	1-2	4	2-3	2-3	2-3	2-3	2-3
Sand	2-3	2-3	5	4-5			2-3	2-3	2-3	2-3	3	3-4

Applicability rating: 1 high reliability, 2 high to moderate, 3 moderate, 4 moderate to low, 5 low reliability.

** Improved when using SCPTu*

In-situ Testing and Geotechnical Design



Perceived Applicability

	Pile Design	Bearing Capacity	Settlement*	Compaction Control	Lique-faction
Sand	1-2	1-2	2-3	1-2	1-2
Clay	1-2	1-2	3-4	3-4	2-3
Intermediate Soils	1-2	2-3	3-4	2-3	2-3

Reliability rating: 1 = High, 2 = High to Moderate, 3 = Moderate, 4 = Moderate to Low, 5 = Low

** Higher when using SCPT*

Software Development

- PC based data acquisition systems
- Digital data
- Real-time interpretation
- Color presentation
  - Soil profile
  - Interpretation parameters
- Interpretation software *(e.g. CPeT-IT)*

Summary

- CPT is a fast, reliable, cost effective means to evaluate soil profile, geotechnical parameters, groundwater conditions and preliminary geotechnical design.
- Suitable for a wide range of soils, except for dense gravels and hard rock.
- SCPTu should be used for higher risk projects

CONE PENETRATION TESTING USE IN GROUND MODIFICATION

During ground modification works, the soil is changed in its condition, consistency, and/or properties from its initial state.

In situ testing by CPT allows quantification of the level and degree of quality control and effectiveness of the site improvement program.

CONE PENETRATION TESTING USE IN GROUND MODIFICATION

An important aspect of quality control testing is to realize that time effects may occur after implementation of the site improvement program.

CONE PENETRATION TESTING USE IN GROUND MODIFICATION

Therefore, it may be necessary to conduct a series of CPTu soundings at various times after the ground modification has been applied to properly quantify the degree of effectiveness and to fully appreciate the benefits of the improvement program.

Ground Modification Method	Reference Source	Use of CPT
Blast Densification	Mitchell (1986)	Quantify time increases with q_t
Compaction of Trench Backfill	Islam and Hashmi (1995)	Determine relative compaction
Compact Natural Sands by Rollers	Alperstein (2001)	CPTs to quantify improvement
Compaction Grouting	Chun et al. (2003)	CPTUs for check on remediation of foundation settlements
Controlled Modulus Columns	Plomteux et al. (2004)	CPTs for initial investigation; columns too hard for CPTs after cement grouting
Deep Soil Mixing	Puppala and Porhaba (2004); Puppala et al. (2004)	Quality assurance and verification
Dynamic Compaction	Ghosh (1995)	Quality control by CPT
	Huang et al. (1998)	CPT for quality assurance
GeoPiers (rammed aggregate piers)	Lillis et al. (2004)	Piers in clay at NGES–Amherst
Jet Grouting	Collotta et al. (2004)	CPTs initially; too hard for CPTs after cement grouting
Stone Columns	Durgunoglu et al. (1995)	Quality control
	Chen and Bailey (2004)	Lessons in sands and silts
	Shenthan et al. (2006)	CPT before and after installation
Surcharging	Schneider and Mayne (2000)	Measure degree of improvement
Vibro-Compaction	Mitchell and Solymar (1984)	Measure CPT increases with time
	Alperstein (2001)	Verify sand condition by CPT
Vibro-Replacement	Howie et al. (2000)	SCPTU for degree of change
Wick Drains	Lutenegger (1988)	Evaluate c_{vh} from dissipations

NGES = National Geotechnical Experimentation Site.

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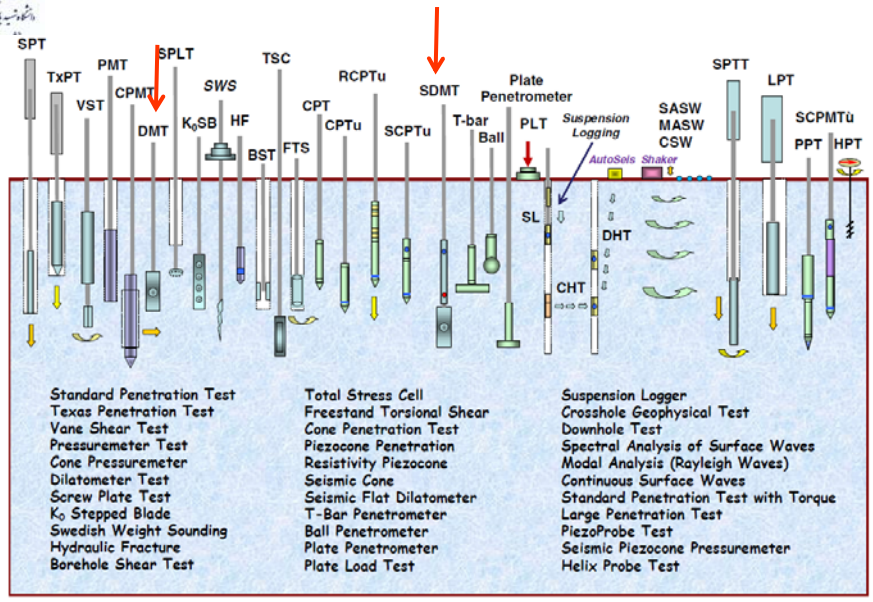
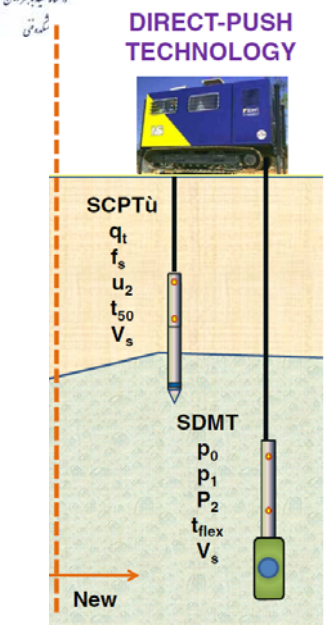
In situ Testing Method



(Mayne et al., 17th Int. Conf. on Soil Mech. and Geotech. Eng., 2009)

SDMT and SCPTU



"... In this fast-paced world, a more efficient approach … In particular, the Seismic Piezocone (SCPT) and the Seismic Dilatometer (SDMT) ... offer clear opportunities in the economical and optimal collection of data"

"... SCPT and SDMT direct-push tests should serve as the basis … in routine daily site investigation practices …"

Mayne P.W., Georgia Institute of Technology, Atlanta, USA

(17th Int. Conf. on Soil Mech. and Geotech. Eng., Alessandria d'Egitto 2009)

The Flat Dilatometer Test
DMT