IN-SITU TESTS

Assist. Prof. Berrak TEYMUR

IN-SITU TESTING

- Provide:
  - alternative design data
  - in-situ properties where undisturbed sampling is not possible
  - Large volume of material
- Methods:
  - Standard Penetration Test (SPT)
  - Cone Penetration Test (CPT)
  - Pressuremeter test
  - Dilatometer test
  - Other methods (vane shear, permeability etc.)

In-situ Tests

1- Standart Penetration Test (SPT):

- 63.5kg hammer weight (Donut, safety,automatic trip hammer),
- 0.76m height,
- Totaly 45cm penetration through soil.
- First 15cm ignores,
- Blow # versus last30cm.
- Used primarily in granular soils

▪Test procedure may be found in ASTM D-1586, BS1377.

Standart Penetration Test (SPT):

Advantages

- Varying diameters,
- Low cost,
- Widely used,
- Experience.

Limitation

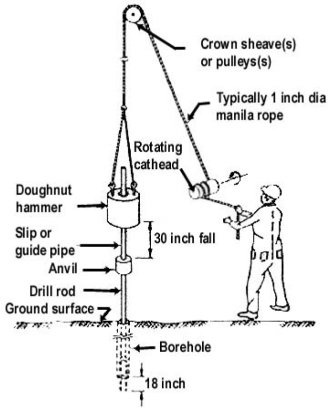
- International standards of variability of procedures
  - Methods of drilling and supporting the hole
  - Hammer mechanisms and rod sizes used
  - The split-spoon geometry (minor effect)
  - Method of testing

•Corrections - overburden pressure and PWP build-up

•Correction factor of blow number for fine sand, silty sand, silty soils under GWT

$$N' = 15 + \frac{(N-15)}{2}$$

SPT



- Besides obtaining soil samples, SPTs provide correlations;
  - relative density and friction angle
  - undrained shear strength
  - direct estimate of settlement

Empirical values for Dr and q_u of granular and fine soils based on SPT blow numbers

Clay

N	*Consistency*	*q_u (kPa)*
2	Very soft	<25
2-4	Soft	25-50
4-8	Medium	50-100
8-15	Stiff	100-200
15-30	Very stiff	200-400
>30	Hard	>400

Sand & Silts

State	N * (blows/ 300mm)	Friction angle, deg	Relative Density (%)
Very Loose	<4	<30	<15
Loose	4 - 10	30 – 32	15 - 35
Medium Dense	10 - 30	32 – 35	35 - 65
Dense	30 - 50	35 – 38	65 - 85
Very dense	>50	>38	85 - 100

CONE PENETRATION TEST

The end resistance of the cone at any depth called the '***cone penetration resistance'*** is (q_c) measured. q_c is the force required to advance the cone divided by the end area. Unlike the SPT, soil samples cannot be recovered during the CPT.

- Instrumented probe jacked into ground at constant rate of penetration (2cm/sec)
- Cone resistance (q_c) and sleeve friction (q_s) measured
- cone resistance (q_c) correlates with strength, and friction ratio (q_s/q_c) with material type
- Should always be correlated with borehole information

▪ASTM D-3441, BS 1377 (Part 9)

CONE PENETRATION TEST

Applicable	Not Applicable
Soft clays	Very stiff clays
Fine to medium course sands	Hard clays
	Gravels

CONE PENETRATION TEST

- 60° cone,
- $10cm^2$ base area,
- $150cm^2$ friction sleeve,
- 10-50mm long sample collection.

Advantages

- Repeatable and reliable data,
- Faster and cheaper,
- Continuous data profile.

Limitations

- No samples,
- Correlations with CPT are less,
- Less experiences,
- Drainage condition is unknown.

CONE PENETRATION TEST

Types of cones:

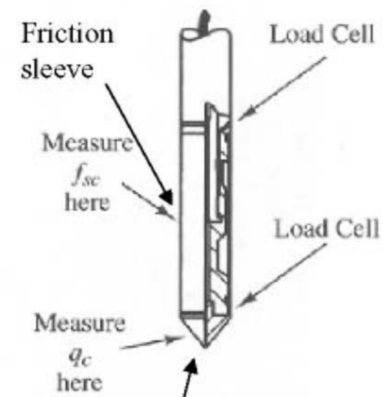
- Mechanical cone (Dutch cone - reading every 200 mm)-The tip is connected to an inner set of rods and it is first advanced about 40mm giving the cone resistance. With further thrusting, the tip engages the friction sleeve.
- Electrical cone (constant readings)-The tip is attached to a string of steel rods. It is pushed into the ground at the rate of 20mm/s. Wires from the transducers are threaded through the centre of the rods and continuously give the cone and side resistances.
- Electrical piezocone
- Seismic cone

CONE PENETRATION TEST

Friction Ratio :

F_R< 1% :sands,
F_R> 5% :clays

$$F_R = \frac{q_s}{q_c}.100$$



Used for design of piles and to estimate the bearing capacity and settlement of foundations.

Parameter Determination(Sands)

- Based on Meyerhof (1965)

q_c, MPa	State	Dr (%)	Friction angle, deg
<2	Very Loose	<20	<30
2 – 4	Loose	20 – 40	30 – 35
4 – 12	Med dense	40 – 60	35 - 40
12 – 20	Dense	60 – 80	40 - 45
>20	Very dense	80 - 100	45

Parameter Determination(Clays)

- Approximate relationship

$$c_u = (q_c - p)/N_k$$

q_c = cone resistance

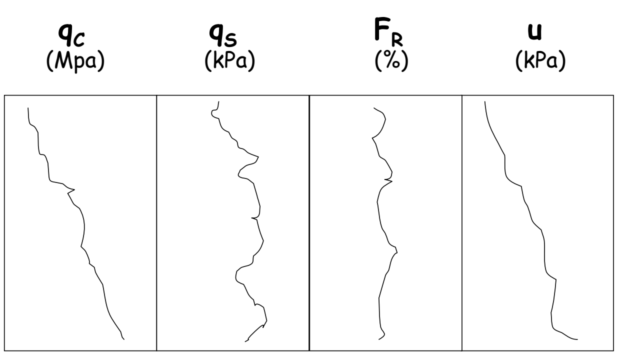
p = total over-burden pressure

N_k = 10 – 15 for NC clays

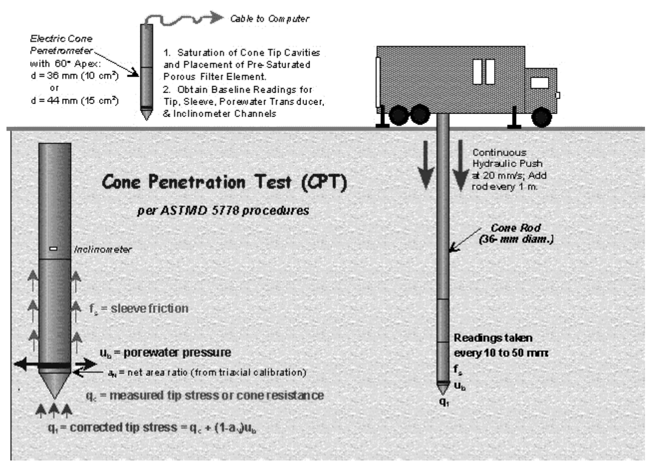
= 15 – 20 for OC Clays

CONE PENETRATION TEST

Data collected during electrical CPT



PC: q_C can be correlated to : ϕ, D_r, c_U, N



http://www.ce.gatech.edu/~geosys/Faculty/Mayne/Research/devices/cpt.htm

CPT-Related Websites

- The Liquefaction Site (and CPT site): www.liquefaction.com
- Link page to manufacturers, suppliers, and CPT services: http://www.usucger.org/insitulinks.html
- Listing of available videos on CPT and other in-situ tests: http://www.geoinstitute.org/in-situ.html
- The book *Cone Penetration Testing in Geotechnical Practice* (Lunne, Robertson, & Powell, 1997)

THE PRESSUREMETER TEST

The Pressuremeter test is an in-situ test developed by Menard in 1956. Applicable for : soft clay , fine to medium sands.

The pressuremeter is a cylindrical device designed to apply a uniform radial pressure to the sides of a borehole in which it is placed. There are two different basic types:

- The Menard pressuremeter which is lowered into a pre-formed borehole
- The Self-boring pressuremeter which forms its own borehole and thus causes much less disturbance to the soil prior to testing

THE PRESSUREMETER TEST

In both cases, the pressuremeter test involves the application of known stresses to the soil and the measurement of the resulting soil deformation.

The sides of the borehole are loaded by pressurising a fluid contained within a flexible rubber membrane.

The expansion of the cavity is determined either by measuring the volume of fluid needed to pressurise the membrane and/or by measuring the movement of the soil at the cavity wall using lvdts (displacement transducers).

Generally, pressuremeters are designed for maximum inflation pressures in the ranges 2.5-10MPa in soils and 10-20 MPa in very stiff soils and weak rocks. E and K_0 can be determined.

THE PRESSUREMETER TEST (MPT)

The device consists of three parts (top, cell and bottom) as shown below:

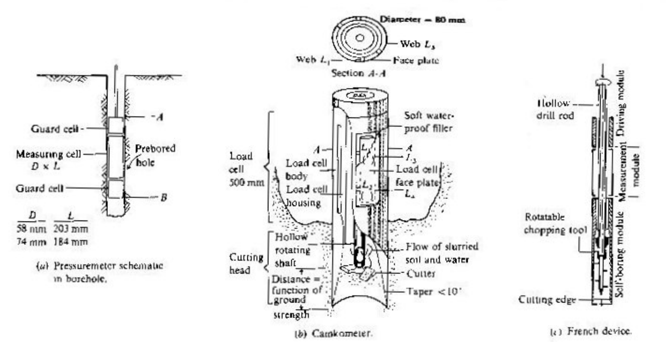
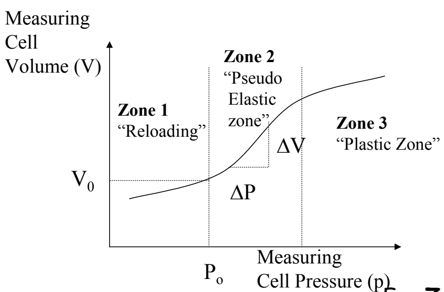


Figure 3-31 Pressuremeter testing; (*b*) and (*c*) above are *self-boring*, or capable of advancing the distance *AB* of (*a*) so that in situ lateral stress is not lost.

Bowles, 1997

THE PRESSUREMETER TEST



Zone 1: Soil pushed back to initial state
Zone 2: Pseudo elastic, V vs P is linear
Zone3: Plastic Zone

For **Zone 2** :

$$E = \frac{2(1+\mu)V_o\Delta p}{\Delta V}$$

where E : Young's
μ : Poissons
V_o: Volume corresponding to beginning of zone 2 at p_o
$\Delta p / \Delta V$ = 1 / (slope of line in zone 2)

THE PRESSUREMETER TEST

Also, the relationship between E and G is given by

$$E = 2(1+\mu).G$$

$$G = \frac{V_o \Delta p}{\Delta V}$$

Pressuremeter test results can also be used to determine the 'at rest earth pressure coefficient';

$$Ko = \frac{P_o}{\sigma'}$$

Note:In France, shallow and deep foundation design is all based on pressuremeter tests.

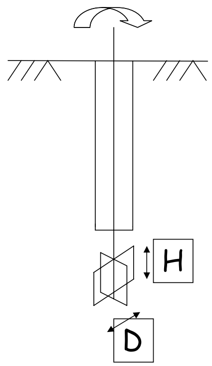
FIELD VANE TEST

- The vane shear test may be used during the drilling operation to determine the in-situ undrained shear strength (c_u) of clay soils, particularly soft clays.
- The vane shear apparatus consists of four blades on the end of a rod. The height, H of the vane is twice the diameter, D. The dimensions of vanes are; D=38.1mm, H=76.2mm, 1.6mm thick blades and 12.7mm diameter of rod.
- This test is performed every 0.75 to 1 m of depth.

FIELD VANE TEST

- The vanes of the apparatus are pushed into the soil at the bottom of a borehole without disturbing the soil appreciably.
- Torque is applied at the top of the rod to rotate the vanes at a standard rate of 0.1º/sec. This rotation will induce failure in a soil of cylindrical shape surrounding the vanes.
- The maximum torque, T applied to cause failure is measured.

FIELD VANE TEST



$$T = c_u \pi \left(\frac{D^2 H}{2} + \frac{a D^3}{4} \right)$$

$$\frac{H}{D} = 2$$

where

a = { 2/3 : uniform end shear; 3/5 : parabolic end shear; 1/2 : triangular end shear

T : Nm $f(c_u, H, D)$

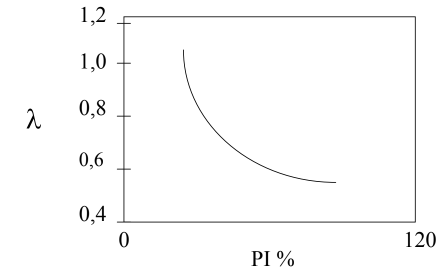
- ❑are rapid, economical and extensively used
- ❑gives good results in soft and medium-stiff clays
- ❑errors can occur due to poor calibration of torque measurement and damaged vanes
- ❑correlations with preconsolidation pressure and OCR exist

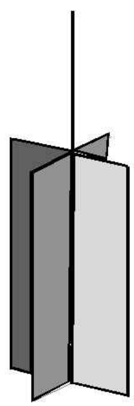
FIELD VANE TEST

When ; H/D= 2 & a=2/3

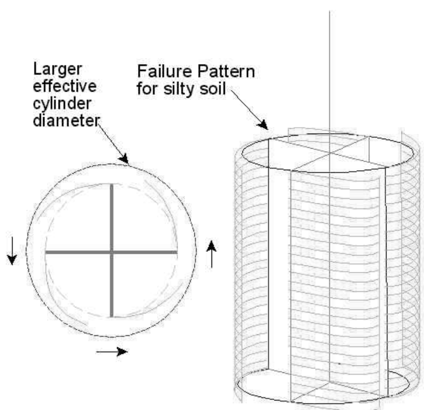
$$c_u = 0.2728 \frac{T}{D^3}$$

$$(c_u)_{design} = \lambda (c_u)_{field}$$





Field Vane Shear



Field Vane Shear testing in silty clays

FIELD TESTS-Plate Loading Test

- Is carried out to estimate the bearing capacity and settlement beneath the single footings.
- A loading plate is circular or square in shape and is manufactured from machined steel plate with a min. thickness of 25mm. The diamater of circular plates ranges from 150-760mm.
- The load is either of gravity type applied through a platform or reaction type applied by a hydraulic jack.
- The plate loading test procedure may be found in ASTM D-1194, ASTM D-1195 and ASTM D-1196.

PLATE LOAD TEST

Most reliable way to obtain the ultimate bearing capacity at a site is to perform a load test.

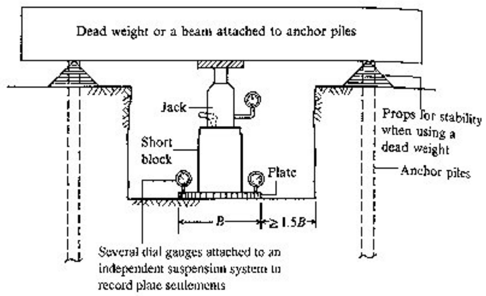


Figure 4-8 Plate-load testing. The method of performing this test is outlined in some detail in ASTM D 1194.

Bowles, 1997

PLATE LOAD TEST

Procedure

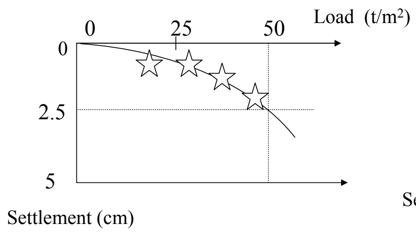
1) Piles should be driven first, to avoid excess vibration & loosening of soil in excavation area.

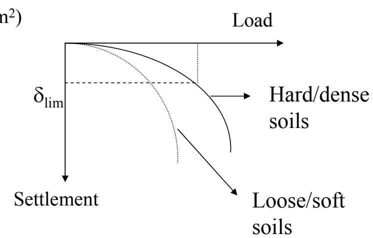
2) Excavate a hole a certain depth that the test is to be performed. Test hole depth > 4B

3) A load is placed on the plate (usually steel) and settlements are recorded from a gauge. Load increments ≈1/5 bearing capacity of soil or 1/10 estimated failure load. Time of loading ≥1 hr & should be same duration for all increments.

4) Test should continue until settlement = 25 mm or, until capacity of testing apparatus is reached.

PLATE LOAD TEST





If ΔH = 2.5cm failure } q_{ult}= 50 t/m²

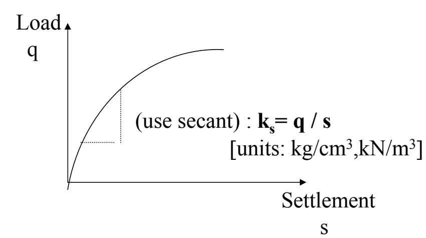
δ_{lim} ⇒ 1/2 load corresponding to 10 mm settlement

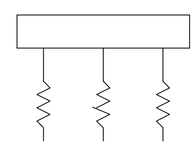
Note: Plate load test results do not include effects of **CONSOLIDATION**

PLATE LOAD TEST

Coefficient of Subgrade Reaction , k_s :

Used to obtain E: when modelling soil as elastic springs (Winkler)





$$EI\,\frac{d^4y}{dx^4} = -kBy$$

Coring of Rocks

- When a rock layer is encountered during a drilling operation, rock coring may be necessary. For coring of rocks, a core barrel is attached to a drilling rod. A coring bit is attached to the bottom of the core barrel. The coring is advanced by rotary drilling. Water is circulated through the drilling rod during coring and the cutting is washed out. To evaluate the rock quality encountered, Rock Quality Designation (RQD) is used.
- RQD=

$$\frac{\Sigma \text{Length of recovered pieces equal to or larger than } 101.6\text{mm}}{\text{Theoretical length of rock cored}}$$

0-0.25 very poor and 0.9-1 is excellent rock quality.

Geophysical Testing

Advantages

- relatively cheap compared to borehole and in-situ testing option
- non-destructive (no holes/excavations are required)

Disadvantages

- results are often inconclusive or unreliable
- not yet fully accepted by the industry.

GEOPHYSICAL METHODS

- Useful in ground investigation in reconnaissance stage
- Supplementary method (not suitable for all soils)
- Capable of
  - estimating depth to bedrock
  - estimating depth to water table
  - filling in detail between borehole
- Less cost than other in-situ tests
- **Definitive interpretation of the results is difficult, so should be used for preliminary work**

GEOPHYSICAL METHODS

1) Seismic Refraction Method:

Seismic waves have different velocities in different types of soil.

Two types of stress waves:

P Waves : plane waves
200 m/s in sands to 2500 m/s in clays

S Waves : shear waves

GEOPHYSICAL METHODS

Seismic refraction surveys are useful in obtaining preliminary information about the thickness of the layering of various soils and the depth to rock or hard soil at a site.

They are conducted by impacting the surface at a point and observing the first arrival of the disturbance (stress waves) at other points.

The impact can be created by a hammer blow or by a small explosives charge. The first arrival of disturbance waves at various points can be recorded by geophones.

GEOPHYSICAL METHODS

P-S waves velocities:

$$V_{soil} = \frac{L_o}{T_o}$$

$$V_{rock} = \frac{(L_3 - L_1)}{(T_3 - T_1)}$$

$$\upsilon_P = \sqrt{\frac{E}{\gamma/g}\frac{(1-\mu)}{(1-2\mu)(1+\mu)}}$$

First arrival time to detectors are determined :

$$\upsilon_s = \sqrt{\frac{G}{\gamma/g}}$$

$$\frac{\upsilon_p}{\upsilon_s} = \sqrt{\frac{2-2\mu}{1-2\mu}}$$

For a typical Poisson's ratio 0.3, the ratio; $\frac{\upsilon_p}{\upsilon_s} = 1.87$

GEOPHYSICAL METHODS

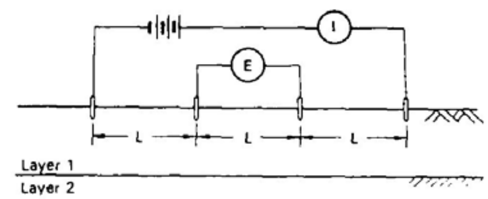
2) Electrical Resistivity Method:

Differences in electrical resistance of different soil types.

Method

* Place 4 electrodes with equal spacing 'A'.
* Apply a direct current to outer electrodes 'I'.
* Measure potential drop in inner electrode.

GEOPHYSICAL METHODS



Craig, 1992

The resistivity of soil is determined by:

$$\rho = \frac{2\pi LV}{I}$$

V:Voltage drop

The resistivity survey is particularly useful in locating gravel deposits within a fine-grained soil.

GEOPHYSICAL METHODS

3) Cross Hole Seismic Survey:

Two holes are drilled a distance, L, apart. A vertical impulse is created at the bottom of one of the boreholes by an impulse. The shear waves generated are recorded by a transducer at the other borehole.

Method

Shear wave velocity: $V_s = \frac{L}{t}$

Shear modulus : $G = V_s^2 \frac{\gamma}{g}$

SOIL EXPLORATION REPORT

- **Scope**
- **Description of structure**
- **Description of location of site**
- **Geological setting**
- **Detailed field exploration**
- **Subgrade conditions**
- **Water table conditions**
- **Foundation recommendations**
- **Conclusions and limitations**

Summary

- Goal: estimate geometry of soil strata and ground water and estimate pertinent engineering properties
- Field Investigation – identify materials and layering, retrieve samples and engineering properties through in-situ testing
- Laboratory Testing – determine engineering properties from samples