Soil Investigation

In-Situ Testing

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Laboratory Tests
Laboratory testing

Some applicable tests

Direct shear test

Simple shear test

Triaxial compression test

One-dimensional compression (consolidation) test

Interface slip

Shear distortion and failure

Compression, distortion and shear failure

Soil Sampling
In Situ Testing

◆ There is a wide variety of different tests that can be used for evaluating the properties of the ground

◆ It is often preferable to do an in situ test in an attempt to measure a particular parameter, rather than obtain a sample and do a laboratory test

   - sampling results in disturbance (reduces strength and stiffness)
   - sometimes only best (strongest) material recovered - not representative of overall in situ material

◆ Typical parameters that may be obtained either directly, or indirectly from in situ tests:

   - strength
   - stiffness
   - permeability
   - relative density
   - horizontal stress

In Situ Testing

◆ Some of the most common types:

   - Penetration tests
     - dynamic (hammered in using drop weight) - e.g. Standard Penetration Test (SPT)
     - static (pushed in smoothly using hydraulics) - e.g. Cone Penetration Test (CPT)
   - Vane shear test (for strength of soft clays)
   - Dilatometer test (DMT)
   - Pressuremeter test (PMT) or self-boring pressuremeter test (SBP)
   - Plate bearing test
   - Screw plate test

◆ Types used depend on geographical location (and on predominant soil types)

   - in USA - mainly Standard Penetration Test (SPT) - very crude test
   - in Australia - mainly cone penetration test (CPT), with some sampling, but SPT still used widely
   - in SE Asia and Japan - mainly SPT
   - offshore engineering - mainly CPT with sampling
   - Europe - CPT (except France - Ménard pressuremeter test)

◆ Geophysics (various non-intrusive tests)
Some In Situ Tests

- **Standard Penetration Test (SPT)**
- **Cone Penetration Test (CPT)**
- **Deep Model Test (DMT)**
- **Pore Pressure Test (PMT)**
- **Vane Shear Test (VST)**
Sampling in Soil

Drilling operations in soil generally do not directly recover samples, although the cuttings and spoil can be inspected to get an idea of the material being penetrated.

Samples will generally be taken at about 1.5 m depth intervals.

In general, thin-walled tube samplers are used in cohesive soils to obtain "undisturbed" samples, and the Standard Penetration Test is used in non-cohesive soils to obtain a disturbed sample (and yield a test result).

There is wide variety of other sampling methods.

Split-Barrel Sampling

When the Sample is Sand and Underwater table

Spring Core Catcher

2" Standard Split Spoon Sampler

Water Port

Ball valve

18" Split Barrel

Driving Shoe

1-3/8"
Standard Penetration Test (SPT)

Split-Barrel Samplers

Data from Robertson, et al. (1983)
Cone Penetration Test

CPT

CPT Setup

Friction ratio: 
\( \frac{f_t}{q_c} \)
Open 6 tonne CPT Truck
(Georgia Tech Geomechanics Group, Atlanta)
reaction from ground anchors

Screw-type ground anchors

Cone Penetration Vehicles
CPT used with Drill Rig

Procedures for CPTu

Porous Element Materials
- Sintered Metals
- Ceramics
- Plastics (disposable)

Saturation of Porous Elements:
- Water
- Glycerine
- Silicone

Procedures:
- Vacuum for 24-hours
- Pre-saturated elements
- Prophylactic to maintain fluids

Grease-Filled Slots - (no element)
Geostratigraphy by Piezocone Tests, Blytheville, AR

Flat Plat Dilatometer Test
Flat Plate Dilatometer Test (DMT)

- Direct push of stainless steel plate at 20-cm intervals; No borings; no cuttings.
- Introduced by Marchetti (1980).
- 18° angled blade
- Pneumatic inflation of flexible steel membrane using nitrogen gas
- Two pressure readings taken (A and B) within about 1 minute
Flat Plate Dilatometer


DMT in Piedmont Residuum, Charlotte, NC
Pressuremeter Test

Pressuremeter Test (PMT)

1. Excavate an ionisation of
   Pressure Cylinder Forms
   into the PMT mode.

2. Measure corresponding
   Pressure at each increment.

Prepared Hole

Drill Rod

Screen Plate

Temporary Covering

Facade number

100 mm

3. Plot Pressure versus
   Volume Change of the
   instrument. Simultaneously,
   calculate the following:

   - Total Volume
   - Total Weight
Pressuremeter Test (PMT)

Prebored PMT data from Utah DOT project

Pre-Bored Pressuremeter

Menard Pressure Panel  Texam Monocell Probe
CPTu in Piedmont Weathered Schist

Fugro Sounding at MARTA site, North Atlanta

Pressuremeter Test
Pressuremeter Test

**Types:**
- Inserted into pre-drilled borehole (Ménard type); for rock or very hard ground
- “Self-boring” pressuremeter (SBP) – drills itself into the ground – for sand or soft to stiff clays

**Principle:**
- membrane inflated – measure inflation pressure and membrane expansion
- plot pressure (p) against “cavity strain” \( \varepsilon = \Delta r / r_o \)
- obtain shear strength \( (s_u) \) from pressure-strain curve
- obtain stiffness (shear modulus \( G_u \)) from unload-reload loop
- for SBP, “liftoff” pressure should be equal to in situ horizontal stress \( \sigma_{ho} \)
  - often affected by disturbance (but still best method of measuring \( \sigma_{ho} \))
- where pore pressure transducer built into membrane, can deduce coefficient of consolidation \( c_v \) from “holding test” (hold pressure constant and measure rate of dissipation of excess pore pressure)

**In WA:**
- UWA has SBP
- some consultants have versions of non-self boring pressuremeters

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**Pressuremeter Test**

Basic principle

“Self-boring” pressuremeter for soil

Gives:
- Stiffness
- Strength
- Coefficient of consolidation
- Horizontal stress?
**SBP Test in sand in Perth**

- **Go = 229 MPa** (seismic CPT)
- **G_m = \frac{1}{2} slope of unload-reload loop**

**Rock Strength from Pressuremeter**

- **Kings Park Formation (siltstone) - Shelley Bridge, Leach Highway**
  - (insertion-type pressuremeter, 20 MPa capacity)

**In situ** strengths may be significantly different from that measured on core samples in the laboratory.

Field strength may be **lower** due to scale effects and influence of discontinuities.

Field strength may be **higher** due to drying, disturbance and stress relief on core samples in weak rock.

Data from Jewell and Fahey (1984)
Dilatometer Test

Marchetti Dilatometer Test (DMT)

Marchetti Dilatometer

Flexible stainless steel membrane:
expand with gas - measure pressure for “liftoff” ($P_a$) and for movement of 1 mm ($P_b$)

Operation of the DMT

Push force provided by penetrometer or drill rig or other equipment

<table>
<thead>
<tr>
<th>1. Dilatometer blade</th>
<th>4. Control box</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Push rods (e.g., CPT)</td>
<td>5. Pneumatic cable</td>
</tr>
<tr>
<td>3. Pneumatic electric cable</td>
<td>6. Gas tank</td>
</tr>
<tr>
<td>7. Expansion of the membrane</td>
<td></td>
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</tbody>
</table>
DMT and CPT Profiles, “Bishop’s See” Site, Perth

Note: $I_d$ is not the relative density index

Plate Load Test
Plate Load Test

Typical foundation

Plate typically 0.3 to 0.5 m diameter

Plate load test only useful for small foundations (where stress “bulb” is similar between plate and foundation)

Steel beams

Concrete blocks

Kemledge supported well back from excavation

Scaffold tube supports (outside influence zone of plate)

Settlement dial gauges

Plates

Hydraulic load cell

Hydraulic jack

Plaster of Paris bedding

Spread beam

Hydraulic load cell pressure gauge

Typical foundation

Plate Load Test

Plate load test only useful for small foundations (where stress “bulb” is similar between plate and foundation)
Vane Shear Test (VST)

- Field Vane (FV) per ASTM D 2573
- Performed at bottom of boring or by direct push placement of device
- Four-sided blade pushed into clays and silts to measure following:
  - $s_{uv}$ (peak) = Peak Undrained Strength
  - $s_{uv}$ (remolded) = Remolded Strength (after 10 revolutions)
  - Sensitivity, $S_t = s_{uv}$ (peak)/$s_{uv}$ (remolded)
**Vane Shear Test (VST)**

1. Insertion of Vane
2. Within 1 minute, rotate vane at 60 rpm; Measure peak torque, $T_p$
3. Perform additional 8 to 10 revolutions
4. Measure residual torque, $T_r$, for remolded case

Vane Shear Test (VST) per ASTM D 2573:

- Undrained shear strength: $S_\varphi = \frac{6 T}{\pi D^2}$  
  For $H/D = 2$
- In-Situ Sensitivity: $S_i = S_{\varphi\varphi} / S_{\varphi\varphi}$ (peak)/$S_{\varphi\varphi}$ (remolded)

**Vane Shear Devices**

- Scandinavian Vanes
- McClelland Offshore Vane
Results from Vane Shear Tests
San Francisco Bay Mud, MUNI Metro Station

Vane Strength, $s_{uv}$ (kPa)

- Peak
- Remolded

Depth (meters)

Sensitivity, $S_t$

Depth (meters)

Pizometers
Piezometers

Standpipe piezometer shown here for monitoring static water levels.

The borehole is sealed to prevent passage of water from the top sand layer to the bottom sand layer.

If drilling fluid is used when the hole is advanced, this may affect performance.

Other types of piezometers are preferred for pore pressure monitoring in fine grained soils.

Piezometer assembled prior to installation
Pumping Test
Permeability Tests

Pump Testing

Pumping from production well
Observation wells

Original water table
Groundwater surface while pumping

$S_1$
$S_2$

$r_1$
$r_2$
Geophysical Test

Geophysical Methods

- Non-intrusive method of “seeing” into the ground
- Seismic: based on fact that compression waves or shear waves travel at different speeds in the ground, and that waves reflect off interfaces between materials of different density or stiffness
- Magnetic
- Gravitational
- Electrical conductivity
- Radar
Geophysical Methods

◆ Mechanical Wave Measurements
  - Crosshole Tests (CHT)
  - Downhole Tests (DHT)
  - Spectral Analysis of Surface Waves
  - Seismic Refraction
  - Suspension Logging

◆ Electromagnetic Wave Techniques
  - Ground Penetrating Radar (GPR)
  - Electromagnetic Conductivity (EM)
  - Surface Resistivity (SR)
  - Magnetometer Surveys (MT)

Crosshole Testing

Shear Wave Velocity:

\[ V_s = \frac{\Delta x}{\Delta t} \]

Note: Verticality of casing must be established by slope inclinometers to correct distances \( \Delta x \) with depth.
Sounding - Shelby County, TN

Seismic Refraction
Seismic Refraction

Seismic Refraction

ASTM D 5777

Note: $V_{p1} < V_{p2}$

Determine depth to rock layer, $z_R$

Vertical Geophones

Soil: $V_{p1}$

Rock: $V_{p2}$
Seismic Reflection

Electrical Methods
ElectroMagnetic Induction

Combined 3-D Plot/Contour Map of EM Induction Data

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