Geotechnical data processing and interpretation

Samuel Lloyd - Fugro GeoConsulting Limited - February 2015
Overview

Project lifecycle and an overview of a site investigation
Classification of soil
Offshore laboratory work
CPT data and interpretation
Onshore laboratory work
Failure mechanisms in soil
Soil stiffness
Different foundation types
Project Lifecycle

- Geotechnical Investigation
- Laboratory testing
- Geophysical Survey
- Foundation Design
- Ground Model – Desk study
In Situ Testing

- Strength characteristics
- Pore water pressure
Borehole Drilling and Sampling
Borehole Drilling and Sampling

- Soil sampling
- In situ testing
Borehole Drilling and Sampling

- Classification
- Strength characteristics
- Dynamic response
Interpretation and Integration

- Data integration
- Maximising value of datasets
Engineering Ground Model

- Spatial engineering ground model
Engineering Ground Model
The End Product
Classification of Soil

A. Grain size

- Pebbles: 4–64 mm
- Granules: 2–4 mm
- Coarse sand: 0.5–2 mm
- Medium sand: 0.25–0.5 mm
- Fine sand: 0.06–0.25 mm
- Silt: 0.004–0.06 mm
- Clay: < 0.004 mm

GRANULAR

- DRAINED BEHAVIOUR
- NON-COHESIVE

FINE GRAINED

- UNDRAINED BEHAVIOUR
- COHESIVE
Basic soil description

Soil classification tests: moisture content and unit weight

Shear strength tests: TV, PP, LV, FC, UU

In situ data processing

Fieldwork generates huge datasets for large offshore wind farms
Cone resistance

**Definition:**
The force necessary to move the cone tip during sounding, divided by the base area of the cone.

\[
q_c = \frac{Q}{A} \text{ in kN/m}^2 \text{ or kPa}
\]

![Cone resistance diagram](image)
Friction

Definition:
The force necessary to move the friction sleeve down during sounding, divided by the outer cylindrical area of the friction sleeve.

Friction is calculated as follows:

\[ f_s = \frac{F}{A} \text{ in kN/m}^2 \text{ or kPa} \]

For the subtraction cone, the formula becomes:

\[ f_s = \frac{(Q+F)-Q}{A} \]
**Definition:** The measured water pressure in the ground, which occurs during sounding.
CPT Results – Interpreted Values

Shear strength – important strength measurement in clay – can be related to cone resistance and pore-pressure by a ‘cone factor’ which is correlated with nearby laboratory results.

Relative density – important to determine how densely packed grains are in the sand. Related to cone resistance.

Many other parameters can be derived using empirical relationships.
Laboratory Testing Programme

- **Soil Unitisation**
  - Expected geotechnical soil units
  - Borehole Logs

- **Sample Availability / Suitability**
  - Undisturbed wax samples for tests requiring undisturbed soil, large enough bag samples for test that does not require undisturbed samples (e.g. PSD, PD etc.)

- **Cost**
  - Client guidance may be to perform one soil plasticity every metre in clay – is this required?
  - Rationalise the cost for more expensive tests (£1000 each)

- **Time**
  - Several weeks may be spent revising proposed laboratory testing programmes before approval is granted
  - Client would like to have the results of long running tests (e.g. thixotropy test c. 60 days, creep test) by next week
Overview Tests by Soil Type

CLAY
- Classification – Plasticity Index
- PSD Sedimentation (pipette)
- Triaxial Tests – UU, CIU, CAUc, CAUe
- Direct Simple Shear (DSS) Test
- 1-D Compression Test (IL & CRS)
- Ring Shear Test
- Permeability

SAND
- Classification – Min and Max Density
- PSD – Sieve and Sedimentation
- Triaxial Tests – CID, CIU, CAD
- Shear Box Test

ADVANCED
- Cyclic Triaxial
- Cyclic Direct Simple Shear
- Resonant Column
- Bender Element
- Stress Path Triaxial – $K_0$
Clay States

FLUID SOIL-WATER MIXTURE

- Liquid State
- Plastic State
- Semisolid State
- Solid State

Increasing Water Content

DRY SOIL

Liquid Limit, $w_l$

Plastic Limit, $w_p$

Shrinkage Limit, $w_s$

$I_p$ (PI)
Index Tests – Atterberg Limits

Liquid limit

Dial to record cone penetration
Release button
80g cone and rod
Cone
Brass container for soil

Mass of Assembly 80±0.1g
Hollow Stem
Lead Shot

The BS1377 fall cone

Plastic limit

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Particle Size Distribution

**Diagram:**
- Pipette Assembly
- Sliding Panel
- Constant-Temperature Bath

**Graph:**
- British Standard Sieve Size (microns)
- Percentage passing (%)
- CLAY  Fine  Medium  Coarse
- SILT  Fine  Medium  Coarse
- SAND  Fine  Medium  Coarse
- GRAVEL  Fine  Medium  Coarse
- COBBLES
Integrated interpretation of in situ and laboratory tests

- CPTU (Vane) (SCPT)
- Estimate in situ stresses & stress history
- Laboratory index test
- Carry out advanced laboratory tests
- Evaluate soil design parameters:
  - strength
  - deformation etc.
- Experience "bank" of similar soils
Incremental Loading Consolidation Test

- Load steps usually applied for 24 hours (could be longer for low permeability soil)
Constant Rate of Strain Consolidation Test
1-D Consolidation Tests

- Comparison of IL and CRS test data
- CRS may provide more reliable definition of preconsolidation
- However CRS data should be corrected for rate effects
Ring Shear Test

- Ring shaped sample sheared through application of torque – no travel limit
- Allows determination of residual shear stress across rupture surface

- Used for design in soils where strength may be governed by pre-existing slip surfaces
- Also used to measure soil to steel interface friction or other available interface
- Use in Imperial College Pile Design (ICP) method calculation
The Triaxial Test

drainage line
porous discs
load cell
cell body

to cell pressure system
to drainage or back pressure system
load frame platen
drainage line
to pore pressure apparatus
The Triaxial Test

\[ \sigma_1 = \Delta \sigma + \sigma_3 \]

\[ \Delta \sigma \]

\[ u \]

Plane-strain compression (PSC)

\[ \sigma_3 \]

\[ \delta \varepsilon_2 = 0 \]

Plane-strain extension (PSE)

\[ \sigma_1 \]

\[ \delta \varepsilon_2 = 0 \]
The Direct Simple Shear Test

FIG. 1 Schematic Diagram of Essential Direct Simple Shear Components.
Typical DSS Results – Clay
Failure Mechanisms

- Direct simple shear test
- Compression test
- Direct simple shear test
- Extension test

- Plane-strain compression (PSC)
- Plane-strain extension (PSE)
- Direct simple shear (DSS)
Wind Turbine Foundations

- Potentially large horizontal loads (wind, wave, current)
- Combined soil-foundation-turbine is a dynamic system
- Generated loads depend on system response and are controlled by the overall system stiffness
- Stiffness degradation is important
Soil Stiffness

- Soil stiffness varies with strain level (non-linear)
- Shear modulus approximately constant in elastic shear strain region

![Graph showing soil stiffness varying with shear strain](image)
Bender Element Test

Piezoelectric Bender Elements
Kramer (1996)

(Dyvik & Madshus, 1985)

\[ G_0 = \rho v_s^2 \]
Resonant Column Test

- Torsional excitation applied to cylindrical specimen
- Resonance frequency determined from measuring the motion of the free end
- Shear wave velocity and shear strain determined using elasticity solutions

\[ G = \rho v_s^2 \]
Cyclic Triaxial Test

Accumulation of shear strain and reduction in shear modulus
Measured Stiffness Range

![Graph showing shear modulus vs. shear strain]

- **BE**: Resonant Column
- **Local Strain**: Triaxial/DSS
Different Foundation Types
Different Foundation Types

- Eiffel Tower
- Tower Bridge
- Maersk Inspirer
- London Eye
- Great Belt East Bridge Pylon
Different Foundation Types

Hard soil: partial penetration (surface)  Soft soil: deep penetration (up to 30 m)
Different Foundation Types

Suction Caissons for a tension leg platform
Testing is performed both offshore and onshore

More advanced testing performed onshore

Results are correlated with in situ testing (CPT) data which can provide derived parameters

An exact and targeted laboratory testing programme is important to save time and money and deliver required data

Engineering ground models are built up from all available data

Different foundation types require different input parameters e.g. compressive or extensional loading?
Thank You