CIVL451 Lecture 2

Site Exploration and Characterization
Definition

The process of determining the layers of natural soil deposits that will underlie a proposed structure and their physical properties is generally referred to as site investigation.
EXPLORATION PROGRAM

• The purpose of the exploration program is to determine, within practical limits,
  – the stratification and
  – engineering properties of the soils

• The principal properties of interest will be the
  – strength,
  – deformation, and
  – hydraulic characteristics.

• The program should be planned so that the maximum amount of information can be obtained at minimum cost.
The purpose of a soil investigation program

1. Selection of the type and the depth of foundation suitable for a given structure.
2. Evaluation of the load-bearing capacity of the foundation.
3. Estimation of the probable settlement of a structure.
4. Determination of potential foundation problems (for example, expansive soil, collapsible soil, sanitary landfill, and so on).
5. Establishment of ground water table.
6. Prediction of lateral earth pressure for structures like retaining walls, sheet pile bulkheads, and braced cuts.
Steps of subsurface exploration program

Preliminary site investigation

• In this phase a few borings are made or a test pit is opened to establish in a general manner
  – the stratification,
  – types of soil to be expected, and possibly
  – the location of the groundwater table.

• One or more borings should be taken to rock, or competent strata, if the initial borings indicate the upper soil is loose or highly compressible.

• This amount of exploration is usually the extent of the site investigation for small structures.
Assembly of all available information about the proposed structure:

- dimensions,
- column spacing,
- type and use of the structure,
- basement requirements, and
- any special architectural considerations of the proposed building.
Preliminary Investigation Stage

• During the conceptual planning of a project, a preliminary geotechnical investigation is to be carried out.

• Attend periodic meetings with the Design Manager and the Consultant team to obtain the instructions regarding project requirements.

• In the preliminary investigation stage, provide the following:
(1) Air Photo Interpretation

- Where air photographs are available, map the site and surrounding area terrain to indicate some or all of the following:
  - general drainage patterns
  - general slopes and ranges or gradient
  - bedrock outcrops, where present
  - general surficial soil types
  - poorly drained or bog areas (peat or muskeg)
  - erosion features
  - old or potential slope failure areas.
(2) Literature Search

- Review the geology of the area from known data, either to supplement the
- air photo interpretation, or to replace it where air photos are not available.
- Search all available physiographical data and previous site investigation
- data, along with any available well water records.
(3) Site Reconnaissance

Following air photo interpretation and/or literature search, carry out a preliminary site reconnaissance to physically examine

- land forms,
- drainage,
- erosion features, etc.

In addition, hand auger holes or rod soundings may be put down, or shallow test pits excavated to confirm the general surficial soil, bedrock and groundwater conditions.
• This may be in the form of a field trip to the site which can reveal information on the type and behavior of adjacent structures such as

  – cracks,
  – noticeable sags, and possibly
  – sticking doors and windows.

• The type of local existing structures may influence, to a considerable extent, the

  • exploration program and
  • The best foundation type for the proposed adjacent structure.
(3) Preliminary Investigation Report

- Present the findings of the work in the preliminary investigation report.
- Present the data in a form that enables the client to assess the economic effect which the soil, bedrock and groundwater may have on the viability of the project.
Detailed Geotechnical Investigation

Upon completion of the preliminary investigation, meet with the Design Manager and the Consultant team to review other relevant planning concept design information. The detailed geotechnical investigation shall include:

1. Field Exploration
2. Field Sampling
3. Field Testing
4. Groundwater Records
5. Laboratory testing of samples
6. Classification tests
7. Strength tests
Where the preliminary site investigation has established the feasibility of the project, a more detailed exploration program is undertaken.

The preliminary borings and data are used as a basis for locating additional borings, which should be confirmatory in nature, and determining the additional samples required.
Field Exploration

• The pattern of borehole drilling and/or test pit excavation should be agreed between the geotechnical consultant and the Consultant's design engineer.

• The nature of the project to be designed and the known subsurface conditions of the area usually dictate the
  – location,
  – spacing and
  – depth of the test holes.

• Carry out the drilling of boreholes by an experienced drill crew using the type of equipment best suited for the terrain and anticipated soil conditions.
Field Sampling

- The frequency and type of sampling may be varied by the requirements of the project, but should be under the control of the geotechnical consultant.

- Normally, standard sampling intervals below the 4.5 m or 6 m depth if conditions warrant such increase.

- Types of samples normally used include
  - soils carried out at 0.75 m intervals initially, with a spacing often increased to 1.5 m spoons and
    – thin wall Shelby tubes.
  - Other types of samplers which may be required in certain types of soil are piston and Oesterberg samplers and foil samplers.

- In test pit excavations, representative bulk samples may be recovered from the different stratigraphy units as necessary.
Field Testing

Types of tests normally done include

• insitu vane,
• standard penetration,
• dynamic cone penetration,
• pressure meter

• Other tests depending on soil conditions may include
  – static cone penetrometer,
  – flat dilatometer,
  – plate load tests, etc.
Groundwater Records

• Fluctuations in the elevation of the groundwater occur over a period of time.
• The existing groundwater level should be monitored by piezometers or other methods as a routine part of any investigation.
• The installation of such equipment should be in accordance with recognized standards.
• Such installations usually require additional visits to the site to make field observations until conditions have reached equilibrium.
• Record all observations of the encountering of seepage water or initial water percolation into test pits.
• Record the rate of inflow and rise of water levels at the time of the initial observations in order to assess correctly the apparent influence which the water condition may have on the design project as well as on construction procedures.
Laboratory Testing of Samples

• Test representative samples from the detailed site investigation in the laboratory for the determination of soil properties essential to the preparation of the geotechnical report.

• Determine natural moisture content of samples at the time of the investigation.

• Base the report and recommendations on the laboratory results obtained.
Classification Tests

• Classification testing of samples is frequently carried out to identify soil type.

• Such classification tests include
  – grain size analysis,
  – Atterberg limits,
  – moisture content determinations

• and is to be carried out in accordance with recognized practice such as recommended by ASTM.
Strength Tests) Engineering Behaviour

- Strength and consolidation tests should be carried out on undisturbed samples if conditions warrant such testing.

- Such tests may be carried out in a variety of ways, depending upon the parameters required and the soil type being examined, but all such tests are to be carried out in accordance with recognized practice, e.g. ASTM.
Depth of Boring

• The approximate required minimum depth of the borings should be predetermined.

• The estimated depths can be changed during the drilling operation, depending on the subsoil encountered.

• To determine the approximate minimum depth of boring, engineers may use the following rule:
Depth of Boring

1. Determine the net increase of stress, $\Delta \sigma$ under a foundation with depth as shown in the Figure on the next slide.

2. Estimate the variation of the vertical effective stress, $\sigma'_v$, with depth.

3. Determine the depth, $D = D_1$, at which the stress increase $\Delta \sigma$ is equal to $(1/10) \ q$ ($q =$ estimated net stress on the foundation).

4. Determine the depth, $D = D_2$, at which $\Delta \sigma / \sigma'_v = 0.05$.

5. Unless bedrock is encountered, the smaller of the two depths, $D_1$ and $D_2$, just determined is the approximate minimum depth of boring required.

Table shows the minimum depths of borings for buildings based on the preceding rule.
Depth of Boring

Determination of the minimum depth of boring
# Depth of Boring

<table>
<thead>
<tr>
<th>Building width (m)</th>
<th>Number of Stories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Boring Depth (m)</td>
<td></td>
</tr>
<tr>
<td>30.5</td>
<td>3.4</td>
</tr>
<tr>
<td>61.0</td>
<td>3.7</td>
</tr>
<tr>
<td>122.0</td>
<td>3.7</td>
</tr>
</tbody>
</table>
Depth of Boring

For hospitals and office buildings, the following rule could be used to determine boring depth

\[ D_b = 3S^{0.7} \] (for light steel or narrow concrete buildings)

\[ D_b = 6S^{0.7} \] (for heavy steel or wide concrete buildings)

where:

\[ D_b = \text{depth of boring, in meters} \]

\[ S = \text{number of stories} \]
Depth of Boring

• When deep excavations are anticipated, the depth of boring should be at least 1.5 times the depth of excavation.

• Sometimes subsoil conditions are such that the foundation load may have to be transmitted to the bedrock. The minimum depth of core boring into the bedrock is about 3m.

• If the bedrock is irregular or weathered, the core borings may have to be extended to greater depths.
Spacing of Boring

• There are no hard and fast rules for the spacing of the boreholes.
• The following table gives some general guidelines for borehole spacing.
• These spacing can be increased or decreased, depending on the subsoil condition.
• If various soil strata are more or less uniform and predictable, the number of boreholes can be reduced.
## Spacing of Boring

### Approximate Spacing of Boreholes

<table>
<thead>
<tr>
<th>Type of project</th>
<th>Spacing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multistory building</td>
<td>10-30</td>
</tr>
<tr>
<td>One story industrial plants</td>
<td>20-60</td>
</tr>
<tr>
<td>Highways</td>
<td>250-500</td>
</tr>
<tr>
<td>Residential subdivision</td>
<td>250-500</td>
</tr>
<tr>
<td>Dams and dikes</td>
<td>40-80</td>
</tr>
</tbody>
</table>
SOIL BORING

• The earliest method of obtaining a test hole was to excavate a test pit using a pick and shovel.

• Because of economics, the current procedure is to use power-excavation equipment such as a backhoe to excavate the pit and then to use hand tools to remove a block sample or shape the site for in situ testing.

• This is the best method at present for obtaining quality undisturbed samples or samples for testing at other than vertical orientation.
SOIL BORING

Trial Pit
1-2 m width
2-4 m depth

Bore hole
75 mm dia
10-30 m depth
Boring tools

Hand tools

Auger boring

Power drills

posthole auger

helical auger
Boring tools

- Rope
- Derrick
- Pressure water
- Drill rod
- Casing
- Chopping bit
- Driving shoe
- Water jet at high velocity
- Wash boring
Boring tools

Sampling devices: (a) scraper bucket
(Continued) (b) thin-walled tube; (c) and (d) piston sampler
Preparation of Boring Logs

1. Name and address of the drilling company
2. Driller’s name
3. Job description and number
4. Number, type, and location of boring
5. Date of boring
6. Subsurface stratification, which can be obtained by visual observation of the soil brought out by auger, split-spoon sampler, and thin-walled Shelby tube sampler
7. Elevation of water table and date observed, use of casing and mud losses, and so on
8. Standard penetration resistance and the depth of SPT
9. Number, type, and depth of soil sample collected
10. In case of rock coring, type of core barrel used and, for each run, the actual length of coring, length of core recovery, and RQD
## Boring Log

### Name of the Project
Two-story apartment building

### Location
Johnson & Olive St.

### Date of Boring
March 2, 1982

### Boring No.
3

### Type of Boring
Hollow stem auger

### Ground Elevation
60.8 m

<table>
<thead>
<tr>
<th>Soil description</th>
<th>Depth (m)</th>
<th>Soil sample type and number</th>
<th>N</th>
<th>( w_n ) (%)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light brown clay (fill)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silty sand (SM)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>SS-1</td>
<td>9</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>SS-2</td>
<td>12</td>
<td>17.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*G.W.T. 3.5 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light gray silty clay (ML)</td>
<td>5</td>
<td>ST-1</td>
<td>20.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>SS-3</td>
<td>11</td>
<td>20.6</td>
<td></td>
</tr>
<tr>
<td>Sand with some gravel (SP)</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End of boring @ 8 m</td>
<td>8</td>
<td>SS-4</td>
<td>27</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

\( N \) = standard penetration number (below/304.8 mm)

\( w_n \) = natural moisture content

\( LL \) = liquid limit; \( PI \) = plasticity index

\( q_u \) = unconfined compression strength

SS = split-spoon sample; ST = Shelby tube sample

Ground water table observed after one week of drilling
SOIL SAMPLING

• Two types of soil samples can be obtained during sampling disturbed and undisturbed.
• The most important engineering properties required for foundation design are strength, compressibility, and permeability.
• Reasonably good estimates of these properties for cohesive soils can be made by laboratory tests on undisturbed samples which can be obtained with moderate difficulty.
• It is nearly impossible to obtain a truly undisturbed sample of soil; so in general usage the term "undisturbed" means a sample where some precautions have been taken to minimize disturbance or remolding effects.
• In this context, the quality of an "undisturbed" sample varies widely between soil laboratories.
Disturbed vs Undisturbed

- **Good quality** samples necessary.

\[ A_R < 10\% \]

Thicker the wall, greater the disturbance.

\[ A_R = \frac{O.D.^2 - I.D.^2}{I.D.^2} \times 100 (\%) \]
Disturbed vs Undisturbed

- samples (disturbed) collected in split-spoon sampler

$A_R = 112\%$; use for classification

I.D. = 35 mm
O.D. = 51 mm
Rock coring

Rock coring: (a) single-tube core barrel; (b) double-tube core barrel
GROUND WATER TABLE LEVEL

Groundwater conditions and the potential for groundwater seepage are fundamental factors in virtually all geotechnical analyses and design studies. Accordingly, the evaluation of groundwater conditions is a basic element of almost all geotechnical investigation programs. Groundwater investigations are of two types as follows:

• Determination of groundwater levels and pressures.
• Measurement of the permeability of the subsurface materials.
FIELD STRENGTH TESTS

The following are the major field tests for determining the soil strength:

1. Vane shear test (VST).
2. Standard Penetration Test (SPT).
3. Cone Penetration Test (CPT).
4. The Borehole Shear Test (BST).
5. The Flat Dilatometer Test (DMT).
6. The Pressure-meter Test (PMT).
7. The Plate Load Test (PLT).
FIELD STRENGTH TESTS

In bore holes

SPT
VST
PMT
CPT
DMT
Standard Penetration Test (SPT)

SPT Resistance (N-value) is the total number of blows to drive the sampler the 2nd and 3rd 6” increments.

140 lb Hammer dropping Anvil 30”

Anvil

Drill Rod

Split-Barrel Drive sampler

Seating Spoon = 6”

Second Increment = 6”

Third Increment = 6”
Standard Penetration Test (SPT)
Standard Penetration Test (SPT)

Corrections are normally applied to the SPT blow count to account for differences in:

- energy imparted during the test (60% hammer efficiency)
- the stress level at the test depth

The following equation is used to compensate for the testing factors (Skempton, 1986):
Standard Penetration Test (SPT)

\[ N_{60} = 1.67 E_m C_b C_r N \]

where \( N_{60} = \) SPT \( N \)-value corrected for field testing procedures

\( E_m = \) hammer efficiency (for U.S. equipment, \( E_m \) equals 0.6 for a safety hammer and equals 0.45 for a doughnut hammer)

\( C_b = \) borehole diameter correction (\( C_b = 1.0 \) for boreholes of 65- to 115-mm diameter, 1.05 for 150-mm diameter, and 1.15 for 200-mm diameter hole)

\( C_r = \) rod length correction (\( C_r = 0.75 \) for up to 4 m of drill rods, 0.85 for 4 to 6 m of drill rods, 0.95 for 6 to 10 m of drill rods, and 1.00 for drill rods in excess of 10 m)

\( N = \) measured SPT \( N \)-value
Standard Penetration Test (SPT)

Empirical correlation between SPT \( N_{60} \) value, vertical effective stress, and friction angle for clean quartz sand deposits. (Adapted from DeMello, 1971; reproduced from Coduto, 1994.)
Cone Penetration Test (CPT)

- **Sleeve Friction** ($f_s$)
- **Cone Resistance** ($q_c$) or **Tip Resistance** ($q_T$)

**Friction Ratio**, $f_R = \frac{f_s}{q_c} \times 100\%$

- Typically 0 - 10%.
  - Granular
  - Cohesive
Cone Penetration Test (CPT)
Cone Penetration Test (CPT)
Cone Penetration Test (CPT)

SCPT Correlations

In Clays,

\[ c_u = \frac{q_c - \sigma_{vo}}{N_k} \]

cone factor (15-20); varies with cone

In Sands,

\[ E = 2.5 - 3.5 \ q_c \]

(for young normally consolidated sands)
Cone Penetration Test (CPT)

$\phi'$ from SPT/CPT in Granular Soils

After Peck et al. (1974)  
After Meyerhof (1976)
The Plate Load Test (PLT)
The Plate Load Test (PLT)

Several dial gauges attached to an independent suspension system to record plate settlements with each increment of the jack load.
The Plate Load Test (PLT)
The Plate Load Test (PLT)
Scale Effect in Foundation Design
Geotechnical Design Reports

• At the end of all subsoil exploration programs, the soil and/or rock specimens collected from the field are subjected to visual observation and appropriate laboratory testing. After the compilation of all of the required information, a soil exploration report is prepared for the use of the design office and for reference during future construction work. Although the details and sequence of information in the report may vary to some degree is depending on the structure under consideration and the person compiling the report.
Subsoil Exploration Report

1. A description of the scope of the investigation
2. A description of the proposed structure for which the subsoil exploration has been conducted
3. A description of the location of the site, including any structures nearby, drainage conditions, the nature of vegetation on the site and surrounding it, and any other features unique to the site
4. A description of the geological setting of the site
5. Details of the field exploration—that is, number of borings, depths of borings, types of borings involved, and so on
6. A general description of the subsoil conditions, as determined from soil specimens and from related laboratory tests, standard penetration resistance and cone penetration resistance, and soon
7. A description of the water-table conditions
8. Recommendations regarding the foundation, including the type of foundation recommended, the allowable hearing pressure, and any special construction procedure that may be needed; alternative foundation design procedures should also be discussed in this portion of the report
9. Conclusions and limitations of the investigations
Geotechnical Report

• The Geotechnical Report should outline the terms of reference of the investigation, should summarize the findings of the field investigation and the supplementary laboratory testing and should then present the conclusions and recommendations based on these findings.
The factual data comprises
  • the terms of reference,
  • the details of the field investigation procedures,
  • the results of the field investigation,
  • the results of the field testing,
  • records of groundwater observations,
  • laboratory test results,
  • site plan and inferred soil stratigraphy, etc.
Report Recommendations

Recommendations may cover a variety of activities, such as

- alternative founding depths with recommended design bearing values,
- pile design considerations,
- estimates of potential settlements,
- recommended safe slopes of banks or excavation walls,
- earth pressures for shoring design,
- dewatering requirements, soil stabilization, etc.
Subsoil Exploration Report

The following graphical presentations should be attached to the report:

1. A site location map
2. A plan view of the location of the borings with respect to the proposed structures and those nearby
3. Boring logs
4. Laboratory test results
5. Other special graphical presentations
Example Table of Contents for a Geotechnical Investigation (Data) Report