Foundation Engineering Course

(2 hrs. theoretical + 1 hr. tutorials)/week

Fourth year

Roads and Bridges Section

Building and Construction Engineering Department

University of Technology

Contents

1. Soil Investigation
2. Shallow Foundations
   A. Bearing capacity
   B. Settlement
   C. Structural design
3. Deep Foundation
   A. Static pile capacity
   B. Dynamic pile capacity
   C. Pile groups
   D. Pile test
4. Retaining Structures
   A. Lateral earth pressure
   B. Retaining walls
   C. Flexible retaining structures (Sheet pile walls)
5. Slope Stability Analysis
6. Soil Improvement
University of Technology

Building and Construction Engineering Department

Roads and Bridges Section

FOUNDATION ENGINEERING COURSE

Subject:- Soil Investigation

Prepared by :- Prof. Dr. Kais Taha Shlash

Course designation : geo. 01
Soil Investigation (or Site Investigation or Ground Exploration): is the technical investigation committed before the preparation of any preliminary design or final plans by which the necessary information is obtained about:

1. Hydrological, geological and soil conditions.
2. Geotechnical properties of soil at the proposed building site.
3. The performance of the various soil types encountered when acted upon by the structural and applied loads, water and temperature.

This information is necessary as a background for the design of footings and the construction methods to be applied.

I - Purpose of Soil Investigation

-A suitable foundation must satisfy:

1. Applied pressure on foundations ($q_{act}$) $\leq$ Allowable bearing capacity ($q_{all}$).
2. Settlement must be within acceptable limits.
3. No harmful effects on nearby structures.

-Taking these into consideration, the purpose of soil investigation becomes:
A - Deciding the suitability of the chosen site for a particular project. (Owner economical study)
B - Determining the soil properties required for the design of footings. (Engineer)
   i - Bearing Capacity (shear strength parameters).
   ii - Settlement (Compressibility parameters).
   iii - Water Table Location (permeability parameters).
C - Controlling construction: (Contractor)
   i - Selection of equipment.
   ii - Avoiding obstruction.

II - Planning of Soil Investigation (see Bowles pp 81-84)

-An engineer planning a soil exploration program for a specified job must:

1- Have a clear idea of what he is trying to accomplish by the exploration.
2- Be well acquainted with the current methods and procedures for soil boring, sampling and testing.
3- Keep in mind the relative costs of soil exploration versus the cost of the foundation construction.

-The actual planning includes some or all the following steps:

1- Assembly of all available information on the dimensions, column spacing, type and use of the structure, basement requirements and any special architectural considerations of the proposed building.

2- Reconnaissance of the area

   i) Field trips $\rightarrow$ adjacent buildings $\rightarrow$ open cut $\rightarrow$ nearby excavation construction
   ii) Study the available information $\rightarrow$ geological maps, aerial photographs $\rightarrow$
   previous soil reports.
III- Methods of Investigations (see also Table 3-1, pp82 Bowles)

A- Direct Methods

1- Trial Pits (صحر الفحص أو المقاطع)
   - Simple excavation using ordinary tools (Shovels)
   - Simple and reliable for stratification and types
   - Maximum depth 4-5 meters

2- Shafts and Headings
   - Deep pits using lateral supports such as sheet piles.
   - Very costly (used for expensive, large and important structures like dams)

3- Percussion Boring (أسلوب الطرد)
   - A method of forming a hole using a “bailer”, which is lifted, rotated slightly and dropped onto the bottom of the hole. Water is circulated to bring the soil cutting to the ground surface. Casing is required as well as a pump to circulate the water.
   - Widely used in England and Iraq.

4- Mechanical Auger (إب구ه أو مقاطب ميكانيكي) (Fig. 2 pp4)
   - Method of forming a hole by rotating an auger.
   - If undisturbed samples are required then casing is used
   - Types: a) short flight auger b) continuous flight auger c) continuous flight auger with hollow stem d) bucket auger

5- Hand and Portable Augers (إبغيه بيدوية) (Fig. 2 pp4)
   - Used to depths around 5m and very cheap.
   - Not recommended for gravelly soils, very stiff soils and soils which the borehole collapses when boring without casing (such as sandy soils under water table).
   - Types a) Iwan auger (diameter up to 200 mm) b) small helical auger (diameter 50 mm)

6- Wash Boring (طريقة النسل) (Fig. 3 pp4)
   - Water is pumped through a string of hollow boring rods and is released under pressure through narrow holes in a chisel attached to the lower end of the rods
   - The soil is loosened and broken up by the water jets and the up and down movement of the chisel
Used for most types of soils (slow for gravel)
Common method for advancing test holes.

7- Rotary Drill
Continuous rock core by means of rotary diamond drill bit attached to a core barrel and drill rod.
Common type for bed rock.

B- Indirect Methods
1- Aerial Photography
For inaccessible and unfamiliar areas.
May be adopted as an aid in planning for detailed investigations.
2- Geophysical Methods
a) Seismic methods (see Bowles pp123-127)
Shock or seismic waves are created by detonating small charges or by striking a rod or plate near the surface.
The radiating waves are picked up and time of travel from the source recorded by detectors known as geophones or seismometers.
(i) Refraction methods: time of arrival of waves refracted at interfaces between different strata is recorded.
(ii) Reflection method: record the travel time of waves reflected from interface between adjoining strata.
See Example 3-6 pp 127 Bowles.
b) Electrical Resistivity Method
Four metallic spikes (electrodes) are driven into the ground at equal intervals along a line. A known potential is then applied between the outermost electrodes and the potential drop between the innermost electrodes is measured. This enables to estimate the resistivity of stratum from which the nature of the stratum is predicted.
Used to determine vertical and horizontal extent of soil strata.
Depth < 30 m.
3- Geological Information
Fig. 2. (a) Short-flight auger, (b) continuous-flight auger, (c) bucket auger, (d) hand (hand) auger.

Fig. 1. (a) Percussion boring rig, (b) boring rods and chisel, (c) shell, (d) cutter.

Fig. 3. Wash boring.

Fig. 4. Rotary drilling.
IV- Sampling and Samples

A- Types
1- Disturbed Samples
   - Taken during boring in plastic bags.
   - Used mainly for classification purposes.
2- Undisturbed Samples
   - Special types of tubes are used such that the structure of the grains is approximately the same as that in the site.
   - Very difficult to obtain for various reasons which will be discussed in article (C).
   - Used to determine the mechanical properties of soil
   (i) Shear strength (c, \(\phi\)) (ii) Consolidation Characteristics (Cv, cs) (iii) Permeability
   (k) (iv) Stress Strain relationship (Young’s modulus and Poisson’s ratio)

3- Remolded Samples
   - Disturbed Samples compacted in special molds
   - For research purposes

B- Requirements for obtaining Undisturbed Samples
1- Diameter : \(D > 75 \text{ mm}\)
2- Length : \(L \geq \text{intended length} + 100\text{mm}\)
3- Area Ratio : \(A_r = \frac{(D_o^2 - D_i^2)}{D_i^2} \times 100\)
   where \(D_o = \text{outside diameter of the tube}\)
   \(D_i = \text{inside diameter of the tube}\)
   \(A_r < 12\%\) for 50 mm sample
   \(A_r < 15\%\) for 75 mm sample
   \(A_r < 20\%\) for 100 mm sample
4- Recovery Ratio :
   \(L_r = \frac{\text{(actual length of recovered sample)}}{\text{(theoretical length of sample i.e. length of tube)}}\)
   \(L_r = 1\) → very good sample
5- Inside Clearance Ratio
   \(C_r = \frac{(D_i - D_t)}{D_i} \times 100\)
   \(C_r > 0.5\) (for sand)
   \(C_r < 3\) (For Clay)

C- Causes of Disturbation
1- Due to advancing the borehole (during boring)
   a- Sample friction on the sides due to auger rotation.
   b- Samples below water table may drain during covering process.
   c- Volume displacement of the tube.
2- Due to changes in prevailing condition
   a- Loss of hydrostatic pressure may cause gas bubble voids to form in the sample.
   b- Changes in water and effective stresses during drilling.
c- Samples are always unloaded of the in-situ confining pressure with some unknown resulting expansion.

d- Working environment (temperature).

e- Handling and transporting a sample from the site to the lab and transferring the sample from sampler to the testing machine.

D- **Degree of Disturbance**: Depends upon:

1- The way by which the sampler is driven into the soil (pushing or driving), [Pushing is better].

2- Rate of penetration: high rate causes developing excess pore water pressure.

3- Dimensions of the sampler.

E- **Soil Samplers**

1- Open Drive Sampler (Fig. 5a pp 8)
   - Consists of a length of steel tube with a cutting shoe attached to one end of the tube while the other end is connected to sampler head and boring rod.
   - Usual internal diameter = 100mm, length = 450 mm, $A_t = 30\%$
   - Suitable for clayey soils
   - If used for sandy soils, then a core-catcher is used.

2- Thin Walled Samplers (Fig. 5b pp8) [Shelby or U100]
   - The tube itself has a cutting edge (without shoe)
   - Used for soft to firm clay
   - Diameter = 35mm to 100 mm, Length = 0.4 to 0.5 m, $A_t = 10\%$

3- Split Barrel Samplers (Fig. 5c pp8)
   - Consists of a tube, which is split longitudinally into two halves, a shoe and a sampler head.
   - Internal diameter = 35 mm, External diameter = 50 mm, $A_t = 100\%$
   - Used with standard Penetration Test (SPT) in sand

4- Stationary Piston Sampler (Fig. 5d pp 8)
   - Consists of a thin walled tube fitted with a piston which prevent water or loose soil from entering the tube
   - Diameter = 35 to 100mm
   - Used for soft clay and can be used for silts and silty sand

5- Continuous Sampler (Fig. 6 pp8)
- Highly specialized sampler capable of obtaining undisturbed samples up to 25 mm in length (used for soft clay)
- Use of foil to minimize friction between sample and tube
6- Compressed Air Sampler (Fig. 7 pp8)
- Used to obtain undisturbed samples of sand below water table
7- Liners
- Small tubes (Dia=37mm) to be used to get samples from the Shelby tube
8- Sand Bailer
- Normally used for cleaning the borehole or excavating

V- Number, Spacing and Depth of Boring

- The spacing of borings can not be determined with absolute exactness. They depend upon:
1- Nature and condition of soil
   a- If the soil conditions are of well-known stratification (simple and thick layers) → widely spaced borings are sufficient.
   b- If the soil conditions vary appreciably over site (thin layer) then closely spaced borings are required.
   c- If soil conditions are uniform → moderate investigation is justified.
2- The shape and extent of building (10 – 20m apart)
3- Importance of the project (cost of boring)

Rules
1. For individual buildings of less than 300 m² plan area, 3 boreholes are the minimum (not to be on a straight line).
2. For large sites or group of buildings, 5 boreholes are the minimum (4 at corners and 1 at the middle).
3. As a guideline you may use Table (1).
4. For large sites: probes are needed (penetration test, seismic method, electrical resistivity method) to obtain information in areas between boreholes.
5. In case of limestone rock (from geological information) use seismic method between boreholes to check any cavities.
6. For some special structures
   a- Retaining Walls:
      Minimum spacing 120 m at centerline with some
      Of these B.H. located at both sides of the centerline
   b- Slope Stability Problems
      3 to 4 B.H. at critical zones and at least one B.H. outside the zone
### Table (1) Recommended guide for number of borings

<table>
<thead>
<tr>
<th>Phase of Investigation</th>
<th>Geological Structure</th>
<th>No. and Spacing of Boring</th>
<th>Location of Boring in the Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preliminary Investigation (to assess the suitability of site)</td>
<td>Uniform</td>
<td>5 to 10 boring per km²</td>
<td>Depends on topography of the site</td>
</tr>
<tr>
<td></td>
<td>Irregular or Unknown</td>
<td>10 to 30 borings per km²</td>
<td></td>
</tr>
<tr>
<td>General Investigation (selection of area of most favorable ground)</td>
<td>Uniform</td>
<td>300 x 300 m</td>
<td>Regular square network of borings parallel to contour</td>
</tr>
<tr>
<td></td>
<td>Irregular or Unknown</td>
<td>100 x 100 m</td>
<td></td>
</tr>
<tr>
<td>Detailed Investigation (for individual building where location has been fixed)</td>
<td>Uniform</td>
<td>At least 3 borings 10 to 30 m apart</td>
<td>As regular as possible network to suit individual buildings taking into consideration preliminary investigation</td>
</tr>
<tr>
<td></td>
<td>Irregular or Unknown</td>
<td>3 to 5 borings for each building (10-30 m diagonal)</td>
<td></td>
</tr>
</tbody>
</table>

### Depth of Borings

1. Highway and airfields: minimum depth of borings is 3m but should extend below organic soil, muck, artificial fill or compressible layers such as soft clays and sites.

2. Retaining Walls and Slope Stability Problems:
   a. Below organic soil, muck, artificial fill or compressible layers.
   b. Deeper than possible surface of sliding.
   c. Deeper than the width of the base of wall (increase of retaining wall).
   d. Equal to the width at bottom of cuts.

3. Structural Foundation: depends upon soil profile and the type of feasible foundation
   a. Below organic soil, muck, artificial fill or compressible layers.
   b. Single separate narrow strip footings:
      - Depth = 3 x width of footing >6m
   c. Group of overlapping footings or raft
      - Depth = 1.5 x least width of the group or raft
   d. For heavy structures the depths of one of the boreholes should extend to 2* width of footing (Heavy loads > 20 T/m² = 200 kPa)
   e. The depth of the boreholes should extend to the point where the net increase in stress due to the action of the load of the building is less than 10% of the total surface load
   f. The depth of the borehole should extend to the point where the net increase in stress due to building (∆q_s) is less than 3% of the overburden stress in soil.
   g. For pile foundation, depth of boring should extend to bearing strata + 3 pile diameter

![Diagram of Building and Construction Stresses](image)
Example-1
A four storey building (20 mx30 m) with a basement (depth = 4m below ground surface) is proposed. The net pressure ($\Delta q_s$) of the building at the basement level is 75 kPa. The soil is silty clay with a dry and submerged unit weight equal to 16 kN/m$^3$ and 9 kN/m$^3$ respectively. The water table was found at elevation 1 m below ground surface. Determine for a detailed soil investigation the number, layout and depth of the boreholes.

Solution
1- No. of B.H.: Area = $30*20 = 600 \text{ m}^2 > 300 \text{ m}^2 \Rightarrow$ use 5 boreholes
2- Layout: 4 at corners and one at the center.
3- Depth: Using the criteria in page
   a- No information.
   b- Not valid
   c- Depth ($z$) = 1.5*B = 1.5*20 = 30 m
   d- One of the boreholes should extend to 40 m ($-2*B$) [Not necessary]
   e- Assuming a 2:1 distribution
      \[ Q = \Delta q_s * B * L = q_i (L+z) (B+z) \]
      For $q_i = 0.1 \Delta q_s$
      \[ \Delta q_s * 20 * 30 = 0.1 \Delta q_s (30+z) (20-z) \]
      Solving to get $z= 52.6$ m
   f- Effective stress at depth $z$ ($p_o$) = $1*16 + 9*(z+3) = 43 + 9z$
      $0.05 * p_o = q_i$ [where $q_i$ is defined in item (e)]
      $0.05*(43 + 9 z) = 75 * 20 * 30 / ((30 + z)*(20+z))$
      solving to get $z= 29.4$ m which is the same as (c)
   g- Not valid (No piles)

Therefore, the final depth of boring = 30 m + 4 m = 34 m [choose minimum of (e) and (f)] [4 m is the depth of basement]

VI- Soil Testing

1- Laboratory Tests
   a- Classification Tests: Unit Weight, Water Content, Specific Gravity, Void Ratio, Grain Size Distribution (Sieve and Hydrometer), Atterberg Limits (Liquid Limit, Plastic Limit and Shrinkage Limits), Chemical Tests.
   b- Shear Strength Tests: Unconfined Compression Test, Direct Shear Test, Triaxial Compression Test [Unconsolidated Undrained test (UU), Consolidated Drained Tests (CU), Consolidated Drained Tests (CD)], Laboratory Vane Test, Plane Strain Test.
   c- Compressibility Tests: Consolidation Test
   d- Permeability Tests: Constant Head and Falling Head.
   e- Compaction Tests: Standard Proctor, Modified Proctor, Field Density and CBR.
2- In-situ Test (Field Tests)
   a- Standard Penetration Test (S.P.T) [Bowles pp97-102]
      - It is the most widely test used in Iraq and worldwide
      - The test consists of driving a standard split spoon (50.8 mm O.D. and 35 mm I.D.) into soil under the blows of a drop weight (hammer) of 65 kg falling freely through .75 m. The number of blows required for 300mm of penetration of sampler in the soil is designated as N values [ASTM D-1586]
      - The blows for the first 150 mm is not used.
      - Used as an estimate of the shear strength of soils
      - Good for cohesionless soils and give a rough results for cohesive soils.
      - For cohesionless soil, you may use Table (2) [Table 3-2 Bowles] as an empirical relationship between N' and [D_r, q and y_f].
      - For cohesive soil, you may use Table (3) [Table 3-3 Bowles] as an empirical relationship between N' and [q_u and y_f]. This table is unreliable because penetration depends not on the strength only but also on other parameter such as compressibility. A strong cohesive soil with a high air content may have a lower N-value than if the same soil was saturated since in this case (saturated), the voids cannot collapse as the sampler advances.
      - The in-situ N values must be corrected before used in tables.
   - Correction for N-values
     (i) Correction for uplift pressure (water table): For soils consisting very fine or silty sand below water table, a correction is made when N>15 because excess pore water pressure set up during drilling the sampler can not dissipate. You may use one of the following
        \[ N' = 15 + 0.5 \times (N-15) \]  
        Terzaghi and Peck (1943)
        \[ N' = 0.6 \times N \]  
        Bazaraa (1967)
     (ii) Depth for overburden: N-values for a depth corresponding to an effective overburden pressure of 110 kPa (1 T/ft²) is considered to be a standard. For \( p_o' > 25 \text{ kPa} \) (0.25 T/ft²) a correction factor (C_N) should be used
        \[ C_N = 0.77 \log (2000/p_o') \]  
        [SI units]
        \[ C_N = 0.77 \log (20/p_o') \]  
        [FPS units]
        \[ N_{corr} = N_{act} \times C_N \]
        where \( p_o' \) = effective overburden pressure at the depth of sampling in kPa (Tsf)

      OR the following equation can be used as proposed by Bazaraa [see Bowles]
      \[ N' = \left(4\times N\right)/\left(1+X_1\times p_o'\right) \]  
      for \( p_o' < 75 \text{ kPa} \) (1.5 ksf)
      \[ N' = \left(4\times N\right)/\left(3.25+X_2\times p_o'\right) \]  
      for \( p_o' > 75 \text{ kPa} \) (1.5 ksf)
      where \( X_1 = 0.04 \) for SI units \( = 2 \) for FPS units
      \( X_2 = 0.01 \) for SI units \( = 0.5 \) for FPS units
Notes:
1- N'>N for $p_0$<75 kPa, N'<N for $p_0'$>75 kPa
2- N' should not be more than 2*N or much less than N
3- Do not used these equations when the blow count indicate a relative
density (D_s<0.5) [see Table 3-2 Bowles]
4- Use these equations cautiously.

(iii) For dilation effect: In saturated fine or silty dense or very dense sands
which tends to dilate during shear, N-values may be great.
Approximately reduce 5 blows for each 40 blows.[not commonly used
unless stated clearly]

(iv) Correction for water table: when drilling below ground water level in
sand or silt, water level may drop below water table or the drill rods
are removed rapidly, hence an upward hydraulic gradient is created.
The sand may become quick and its relative density ($D_s$) may be
reduced and N-values may be much lower than the corresponding
values of undisturbed soil. Hence care is required to maintain water
level at or slightly above water table in the borehole. [not commonly
used unless stated clearly]

-Factors affecting N-values
1- Variation of hammer height of fall
2- Friction along the guides (rope, pulley)
3- Disturbed shoe of the spoon.
4- Inadequate cleaning of borehole.
5- Poor setting of spoon
6- Failure to maintain the hydrostatic pressure in the hole (i.e. quick
sand)
7- Careless of the crew
8- Avoiding stones and obstruction.

Example 2: The N values for a test performed at a depth of 8 m below the ground
surface is 35, if the water table is at a depth of 2 m and the dry unit weight is 14
kN/m^3 and the saturated unit weight is 18 kN/m^3. Calculate the corrected N?

Solution: 1) Correction for water table:
$$N_1 = 15 + 0.5 \times (35-15) = 25$$

2) Correction for overburden
$$p_0' = 14 \times 2 + 6 \times (18-10) = 76 \text{ kPa}$$
$$C_N = 0.77 \log \left( \frac{2000}{76} \right) = 1.093$$
$$N_{corr.} = 1.093 \times 25 = 27.3 \text{ say 27}$$
Table 2. Empirical values for \( D \), and unit weight of granular soils based on the standard penetration number with corrections for depth and for fine saturated sands

<table>
<thead>
<tr>
<th>Description</th>
<th>Very loose</th>
<th>Loose</th>
<th>Medium</th>
<th>Dense</th>
<th>Very dense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative density ( D ), *</td>
<td>0</td>
<td>0.15</td>
<td>0.35</td>
<td>0.65</td>
<td>0.85</td>
</tr>
<tr>
<td>Standard penetration no. ( N )</td>
<td>6</td>
<td>10</td>
<td>30</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Approx. angle of internal friction ( \phi ) †</td>
<td>25°-30°</td>
<td>20°-32°</td>
<td>30°-35°</td>
<td>35°-40°</td>
<td>36°-43°</td>
</tr>
<tr>
<td>Approx. range of moist unit weight, (psi)</td>
<td>70-100</td>
<td>90-115</td>
<td>110-150</td>
<td>130-140</td>
<td>150-160</td>
</tr>
<tr>
<td>(kN/m³)</td>
<td>(11-16)</td>
<td>(14-18)</td>
<td>(17-20)</td>
<td>(17-22)</td>
<td>(20-27)</td>
</tr>
</tbody>
</table>

* USRB [Gibbs and Holtz (1957)].
† After Meyerhof (1956). \( \phi = 25 + 250 \), with more than 5 percent fines and \( \phi = 30 + 250 \), with less than 5 percent fines. Use larger values for granular material with 5 percent or less fine sand and silt.

It should be noted that excavated material or material dumped from a truck will weigh 70 to 90 pcf.

Material must be quite dense and hard to weigh much over 130 pcf. Values of 105 to 115 pcf for non-saturated layers are common.

Table 3-4. Empirical values for \( q_v \) and consistency of cohesive soils based on the standard penetration number

<table>
<thead>
<tr>
<th>Consistency</th>
<th>Very soft</th>
<th>Soft</th>
<th>Medium</th>
<th>Stiff</th>
<th>Very stiff</th>
<th>Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td>( q_v ), ksf</td>
<td>0</td>
<td>0.5</td>
<td>1.0</td>
<td>2.0</td>
<td>4.0</td>
<td>8.0</td>
</tr>
<tr>
<td>( N ), standard penetration resistance</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>16</td>
<td>32</td>
</tr>
<tr>
<td>( S_s ), pcf</td>
<td>100-120</td>
<td>110-150</td>
<td>120-140</td>
<td>130-160</td>
<td>150-170</td>
<td></td>
</tr>
<tr>
<td>(kN/m³)</td>
<td>(16-19)</td>
<td>(17-20)</td>
<td>(19-22)</td>
<td>(21-24)</td>
<td>(24-27)</td>
<td></td>
</tr>
</tbody>
</table>

* These values should be used as a guide only. Local cohesive samples should be tested and the relationship between \( N \) and the unconfined compressive strength \( q_s \), established as \( q_s = A N \).

Figure 5.10. Devices for direct measurement of consistency of soil under field conditions. (a) Dutch cone penetrometer. (b) Refined Dutch cone penetrometer. (c) Conical drive point for sand and gravel. (d) Vanodecator apparatus.
**b- Dynamic Cone Penetration Test**

- Used for hard deposits.
- The cone (usually 65 mm in diameter and with an apex angle of 60°) is driven into the soil by a drop of a standard hammer falling a standard distance.
- Record number of blows / 0.3 meter (N<sub>c</sub>)
- Friction on sides increases with depth, hence the diameter of the cone must be greater than the outside diameter of the pipe.
- If depth of investigation is more than 6m, use bentonite
- Fast and economical (no borehole is required)
- Gives continuous penetration of strata penetrated. It often reveals the presence of strata, which are not recovered or observed in sampling.
- Limitations:
  1. No samples are taken
  2. Misleading results in gravel or boulder strata
- N<sub>c</sub> values must be corrected for overburden pressure.
  \[ N'_c = C_1 \times N_c \]
  where \( C_1 = 0.8 \text{ to } 1.2 \) when bentonite is used
  \[ = 1.5 \text{ up to depth 3m and bentonite is not used} \]
  \[ = 1.75 \text{ for depth 3 to 6m and bentonite is not used.} \]

**c- Static (Dutch) Cone Penetration Test (CPT)**

- Preferable for soft cohesive deposits (fine sands, silty fine sands and clay).
- Pushing hydraulically a steel cone (diameter = 35.7 mm and apex angle 60°) at a rate of 10 to 20 mm/sec and recording the required force and hence the stress (qc) can be calculated using the following equation:
  \[ qc = \frac{\text{force required}}{\text{base area}=1000 \text{ mm}^2}. \]
- The outer rod is pushed and the force required for pushing the cone and sleeve is recorded and the stress (qt) can be calculated
  \[ qf = qt - qc \]
- The data obtained are used for bearing capacity and settlement analysis and static pile capacity.
- For sand and coarse silt, you may use the following table

<table>
<thead>
<tr>
<th>q&lt;sub&gt;c&lt;/sub&gt; (kPa)</th>
<th>1000</th>
<th>2000-4000</th>
<th>4000-12000</th>
<th>12000-20000</th>
<th>&gt;200000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rel. Den. (D&lt;sub&gt;r&lt;/sub&gt;)</td>
<td>&lt;20</td>
<td>20-40</td>
<td>40-60</td>
<td>60-80</td>
<td>&gt;80</td>
</tr>
<tr>
<td>φ (deg)</td>
<td>25-30</td>
<td>30-35</td>
<td>35-40</td>
<td>40-45</td>
<td>&gt;45</td>
</tr>
</tbody>
</table>

- Relationship between N [SPT] and qc is shown in the following table

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>q&lt;sub&gt;c&lt;/sub&gt; / N (q&lt;sub&gt;c&lt;/sub&gt; in kPa)</th>
<th>E&lt;sub&gt;c&lt;/sub&gt; (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silts, fine sand, slightly cohesive soils</td>
<td>150-300</td>
<td>1.5-2 qc</td>
</tr>
<tr>
<td>Fine to medium sand</td>
<td>300-450</td>
<td>2-4 qc</td>
</tr>
<tr>
<td>Coarse sands</td>
<td>450-700</td>
<td>1.5-3qc</td>
</tr>
<tr>
<td>Sandy gravel, gravelly sand</td>
<td>700-2000</td>
<td></td>
</tr>
<tr>
<td>Stiff clay, sandy clay</td>
<td></td>
<td>5-7 qc</td>
</tr>
</tbody>
</table>
- Advantages
  1- Fast and economical
  2- Gives a continuous resistance of the strata
  3- Gives skin friction of soil [used for piles]
  4- More reliable for sand below water table
  5- No boring is required
- Limitations:
  1- Unsuitable for gravelly soils
  2- Does not reveal the types of soils encountered.
  3- No samples are taken
  4- Test depth 15 to 20 m

d- Field Vane Test [Bowles pg. 114]
- Used for determination of undrained cohesion of soft to medium stiff clay
- Valuable in sensitive clays where it is difficult to obtain truly undisturbed samples
- Sensitivity = (strength in undisturbed state)/(strength in remolded state)
- Inserting a four bladed vane in the undisturbed or remolded soil at required depth and rotating it from the surface through link rods to determine the torsional force required (T) to cause a cylindrical surface to be sheared by the vane
  \[ T = c \cdot \pi \cdot \left( d^2 \cdot h/2 - d^3/6 \right) \]
  where
  \[ T = \text{Torque} \]
  \[ c = \text{Undrained shear strength} = \text{cohesion for clayey soils} \]
  \[ h = \text{Height of blade} \]
  \[ d = \text{Diameter of blade}. \]

e- Plate Load Test [Bowles pg. 110]
- Used to measure the load necessary to induce a given amount of settlement of a model footing.
- A square (.3 m x .3 m or .45m x .45 m) or circular (diameter = .3 m or .45 m) plate is seated on the stratum to be tested, usually at the bottom of a trial pit and loaded. The load is maintained until full consolidation settlement has taken place. The test is continued with further increments of load. Settlement is plotted against load.
- Suitable for sandy soils.
- Usually of short duration, hence consolidation settlement do not fully occur during this test.
- Zone of stressed soil beneath the plate is much smaller than that beneath the larger foundation so will be unaffected by deeper strata whose load bearing and settlement characteristic may affect the behavior of the foundation.
- Bearing capacity prediction
q (footing) = q (plate) For clay
q = q_p x B_p
For sand

OR you may use Housel equation
V = A*q + P*s

where V = total load on a bearing area
A = contact area of footing (or plate)
P = perimeter of footing
q = bearing pressure
s = perimeter pressure

- By conducting two plate load tests, we can solve the equation for q and s and then re-use the equation for fully scale footing.
- Settlement prediction
- Sp = (Bp/Bf)^a
- where a = ½ to 1/3 for sand and gravel = ½ for saturated silt=1/2 to 2/3 for clay and dry silt = 1 for compacted fill
- If ground water is at the level of the test plate, reduce the values by ½

Example 3: Two plat load tests were performed using plates .3x.3 m and .45x.45 m.
For 12 mm settlement, the loads were 37.5 and 75 kN, respectively. What size square footing is required to carry 80 kN column load.
Solution: V = A * q + P * s
[.3x.3m plate] 37.5 = .09 * q + 1.2 * s
[.45x.45m plate] 75 = .2025 * q + 1.8 * s

solving the two equations to get q = 277.77 and s = 10.41

[full scale footing] 80 = 277.77 * B^2 + 10.41 * 4 * B

solving to get B =~ .47 m say .5 m for 12 mm settlement

f- Water Table Location (Bowles pg 105)
- Ground water affects many important phases of foundation design (Bearing capacity and settlement)
- Methods
  1- For permeable sand or gravel, W.T. will reach its final levels in few minutes
  2- For soils of low permeability (silt, fine sand and clay) it may take several days or weeks. There are two methods
    a- Fill the hole with water and then bail it out. After bailing a quantity, observe if the water level in the hole is rising or falling. The true level is one that lies between a rising and a falling level.
    b- Apply a computational method proposed by Hvorslev. Measure the rise (or fall) for two or more equal time interval ΔT:

\[ ΔT = T_1 - T_0 = T_2 - T_1 = T_3 - T_2 \]

\[ H_0 = h_1^2 / (h_1 - h_2) \]
\[ H_1 = h_2^2 / (h_1 - h_2) \]
\[ H_2 = h_3^2 / (h_2 - h_3) \]

Solving to get 3 values of Dw and take the average
f- Permeability Test

There are two types of tests:
1- Pumping out Test
\[ k = q \left( \frac{\log (r_2/r_1)}{\pi (z_2^2 - z_1^2)} \right) \]
2- Pumping In Test
\[ k = \frac{q}{(5.5 \times r \times \Delta h)} \]
where \( q \) = constant rate of flow
\( r \) = radius of casing
\( \Delta h \) = differential head of water
\( k \) = permeability

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**Example 3-3**

It is desired to establish the location of the groundwater table in a clayey material. The borehole was drilled to a depth of 35 ft below the ground surface, and the water rise was recorded on three successive days as follows:

- First day:
  - \( h_1 = 2.1 \) ft at 24 h
  - \( h_2 = 1.9 \) ft at 24 h
  - \( h_3 = 1.7 \) ft at 24 h

**SOLUTION**

- \( h_0 = \frac{(2.1)^2}{2.1 - 1.9} = 22.1 \) ft
- \( h_1 = \frac{(1.9)^2}{2.1} = 18.1 \) ft
- \( h_2 = \frac{(1.7)^2}{1.9} = 14.4 \) ft

Referring to the figure, on which the \( H \) values just computed have been placed, the depth to the water table is as follows:

- First day:
  - \( D_1 + h_0 = 22.1 + 35 = 57.1 \) ft
  - \( D_1 = 12.9 \) ft

- Second day:
  - \( D_2 + 18.1 + 2.1 + 1.9 = 35 \) ft
  - \( D_2 = 12.9 \) ft

- Third day:
  - \( D_3 + 14.4 + 1.7 + 1.9 + 2.1 = 35 \) ft
  - \( D_3 = 14.9 \) ft

Averaging results, we obtain a depth to the water table of

\[ D_w = 13.6 \] ft

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Figure E3-3
VII- Report Writing

1- Introduction
   a- General description of the project
   b- The work carried out briefly

2- General description of the site
   a- The presence of any trees, old buildings, filled area, roads and other features.
   b- Information from historical records on previous usage of the site.
   c- Other observations such as flooding, erosion, earthquakes, slope instability and cracks of nearby buildings.

3- General Geology of the Area
   a- Compare geological information on maps of the site with conditions founds in the boreholes.
   b- Features which will affect foundation work such as faults.

4- Description of Soil Conditions Found in Boreholes (and trial pits)
   a- Short description on stratification.
   b- Borehole layout with one or more sections through the boreholes.
   c- A single drawing is is better than pages of written matter.

5- Laboratory Tests Results
   a- Short description of test results.
   b- Table of results.
   c- Test procedure for non standard tests only.

6- Discussion of Results
   a- The heart of the report. The writer should discuss the problem without (if’s) and (but).
   b- Should be broken into sub-headings
      (i) General: description of main structures and the related loading which are to be considered with a general assessment of the ground conditions and the types of foundation which could be adopted.
      (ii) Shallow Foundation: Type of foundation, foundation depth, allowable bearing pressure and settlement. Should state the advantage gained by going deeper or changing the type on bearing capacity and settlement.
      (iii) Deep Foundation: Depth of bearing stratum to which piles should be driven, working load, settlement, difficulties in driving and any effect on adjacent structures.
   c- The writer should come straight to the point.
   d- The reason why results are high or low.
   e- The recommendation for the foundation must be based on the facts stated in the report.

7- Conclusions:
   - This part includes a summary (to help busy engineers) of the points stated in the discussion and the main points or conclusions obtained from the report.
   - Note: Inadequate writing and careless typing or drawing may lead the client to think that the whole investigation has been carried out in similar manner.