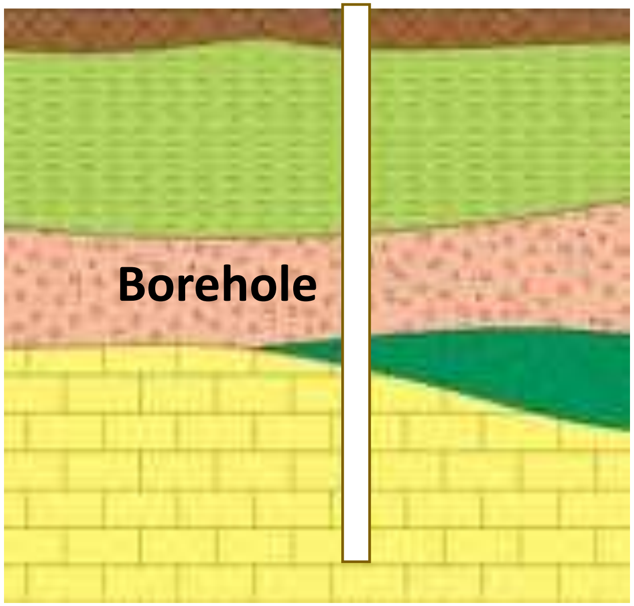
Boreholes

- Boreholes may be excavated by one of these methods:
  1. **Auger Boring**
  2. **Wash Boring**
  3. **Rotary Drilling**
  4. **Percussion Drilling**
- The right choice of method depends on:
  - Ground condition: presence of hard clay, gravel, rock.
  - Ground-water condition: presence of high ground-water table (GWT).
  - Depth of investigation
  - Site access



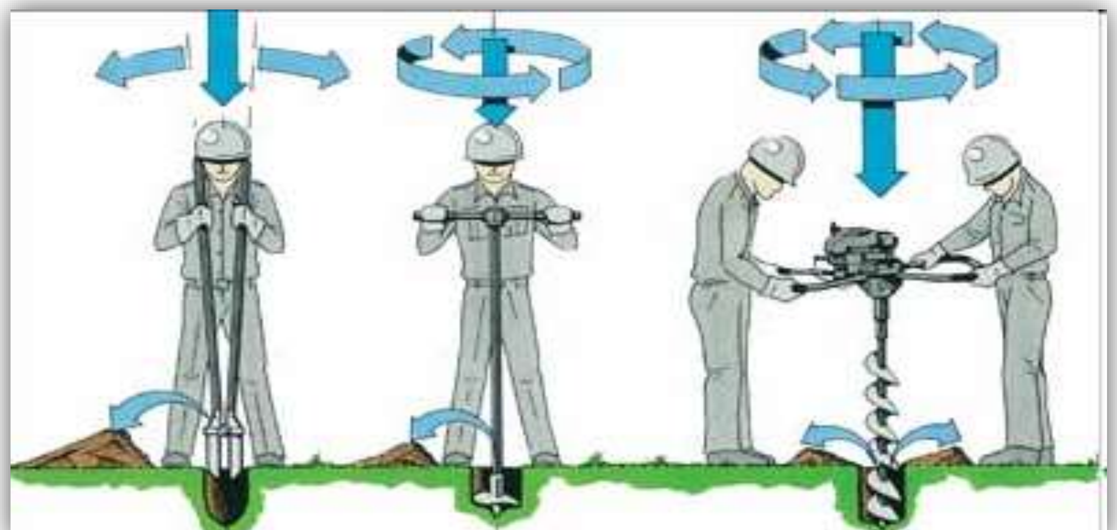
Boreholes

1. Auger Boring

- This is the simplest of the methods. Hand operated or power driven augers may be used.
- Suitable in all soils above GWT but only in cohesive soil below GWT.

Power driven augers

Hand operated augers



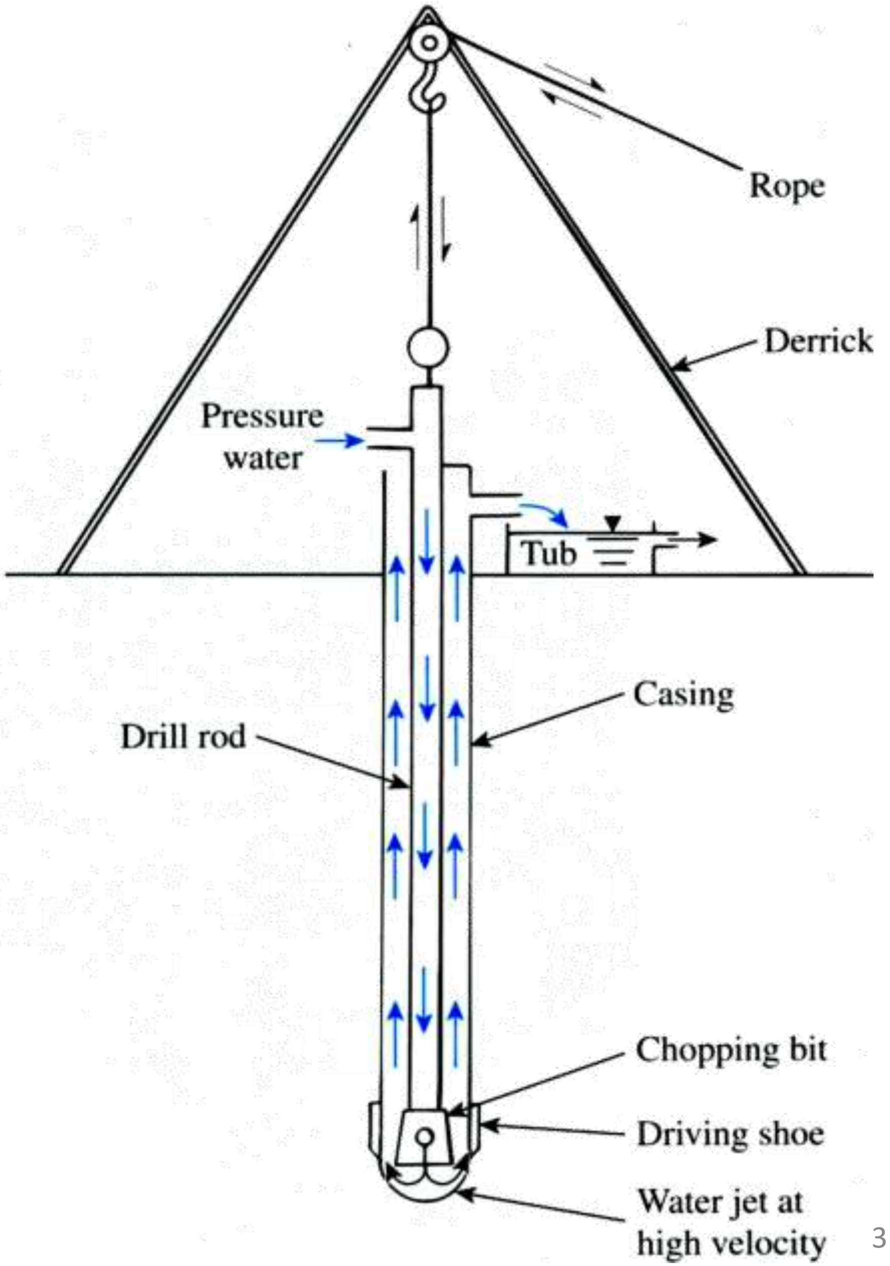
Post hole auger

Helical auger

Boreholes

2. Wash Boring

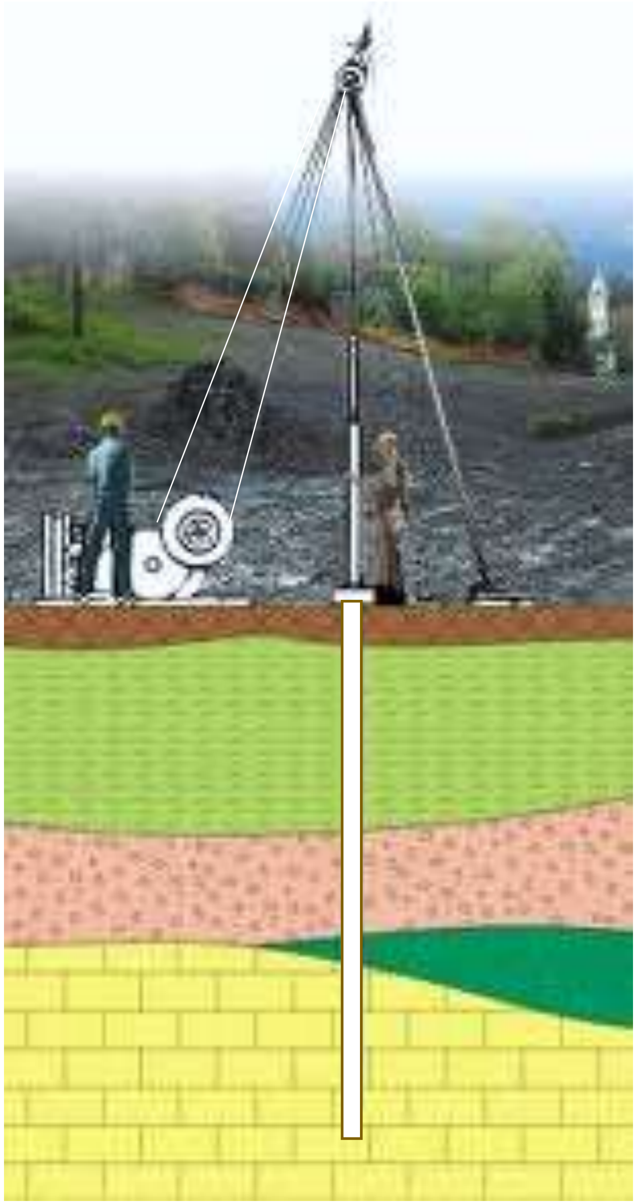
- A casing is driven with a drop hammer. A hollow drill rod with chopping bit is inserted inside the casing.
- Soil is loosened and removed from the borehole using water or a drilling mud jetted under pressure.
- Wash boring is a very convenient method for soil exploration **below** the ground water table provided the soil is either sand, silt or clay. The method is not suitable if the soil is mixed with gravel or boulders.



Boreholes

3. Percussion Drilling

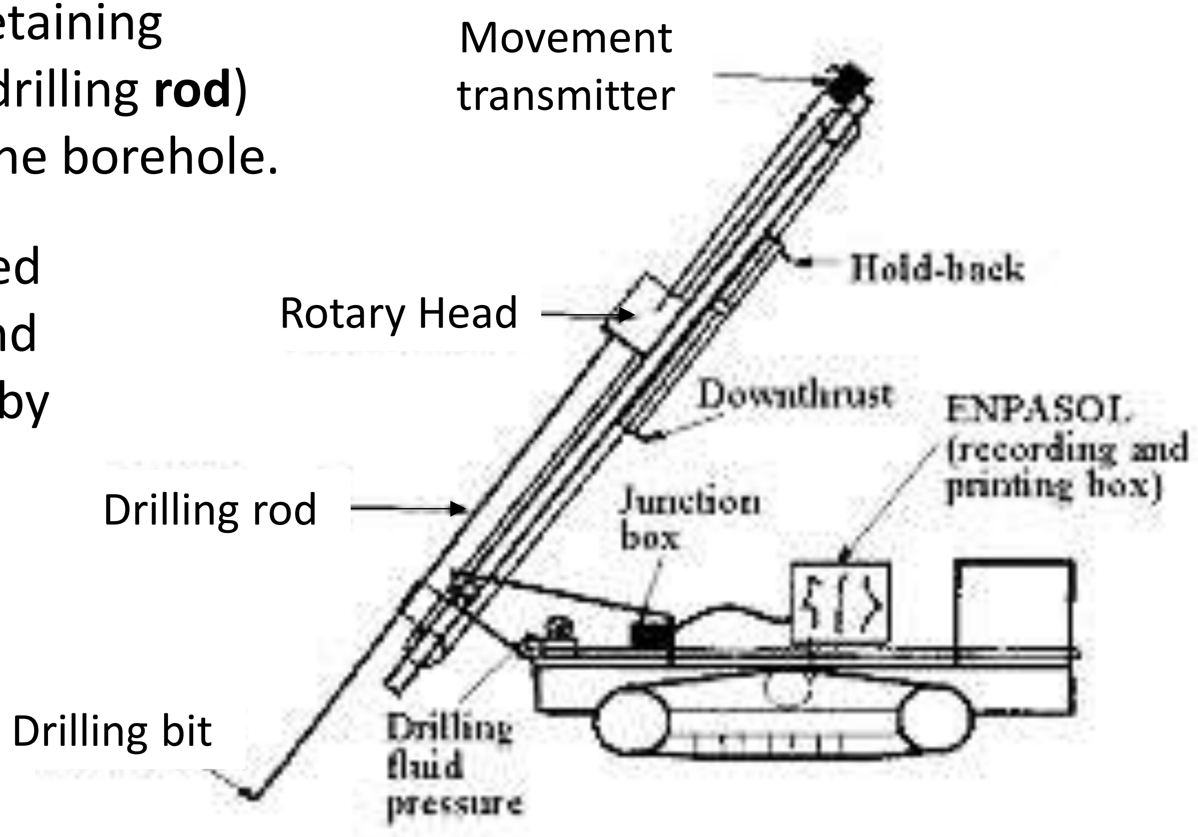
- In this method a heavy drilling bit is alternatively raised and dropped in such a manner that it powders the underlying materials which form a slurry with water and are removed as the boring advances.
- Possibly this is the only method for drilling in river deposits mixed with hard boulders of the quartzitic type.



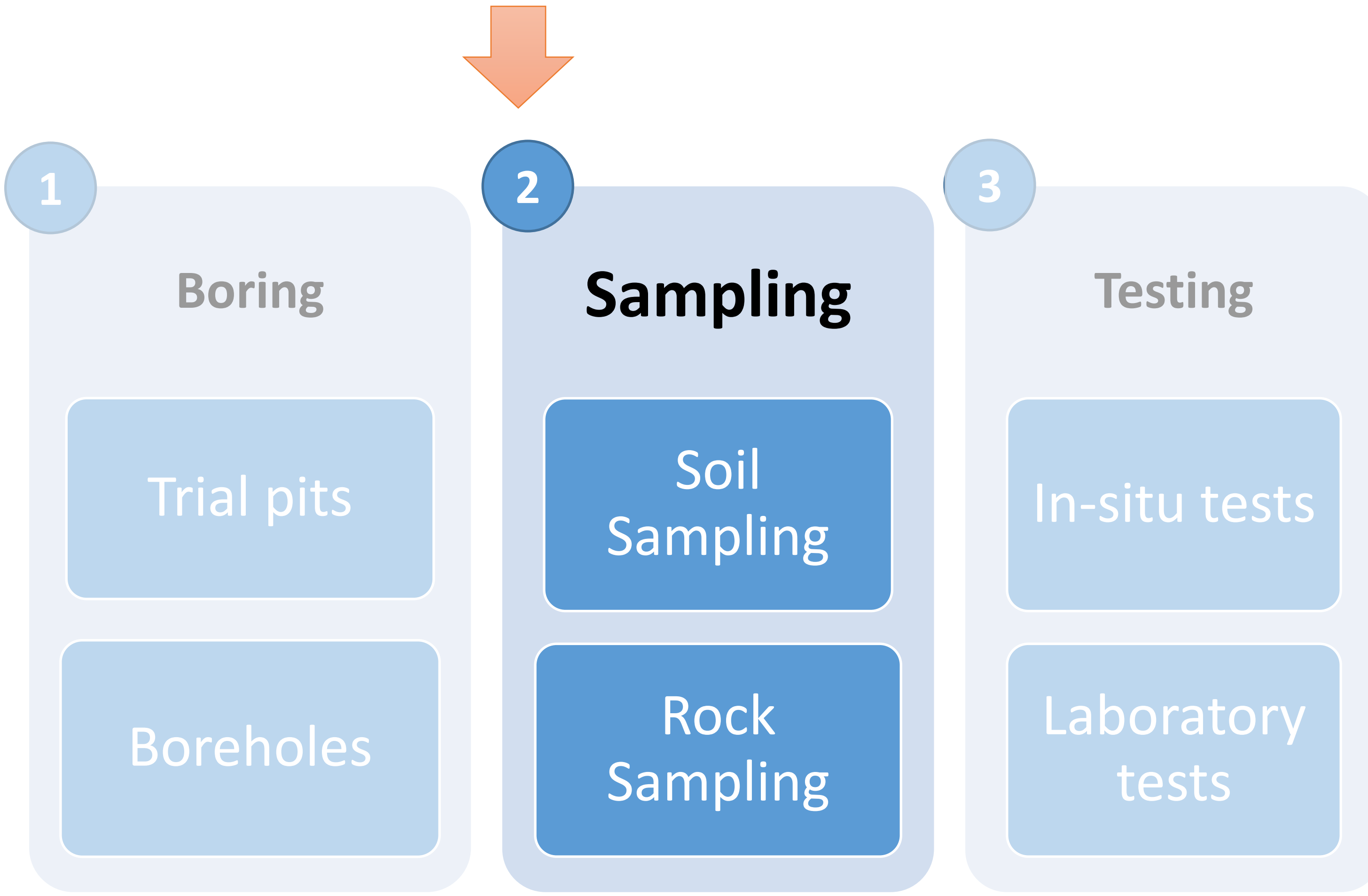
Boreholes

4. Rotary Drilling

- In this method a rapidly retaining drilling **bit** (attached to a drilling **rod**) cut the soil and advance the borehole.
- When soil sample is needed the drilling rod is raised and the drilling bit is replaced by a **sampler**.
- This method is suitable for soil and **rock**.



Sampling


1
Boring
Trial pits
Boreholes
2
Sampling
Soil Sampling
Rock Sampling
3
Testing
In-situ tests
Laboratory tests

Soil sampling

Samples from each type of soils are required for laboratory testing to determine the engineering properties of these soils.

Soil samples are recovered carefully, stored properly to prevent any change in physical properties, and transferred to laboratory for testing.

- **Soil Sampling equipment?**
- **Disturbed vs Undisturbed?**

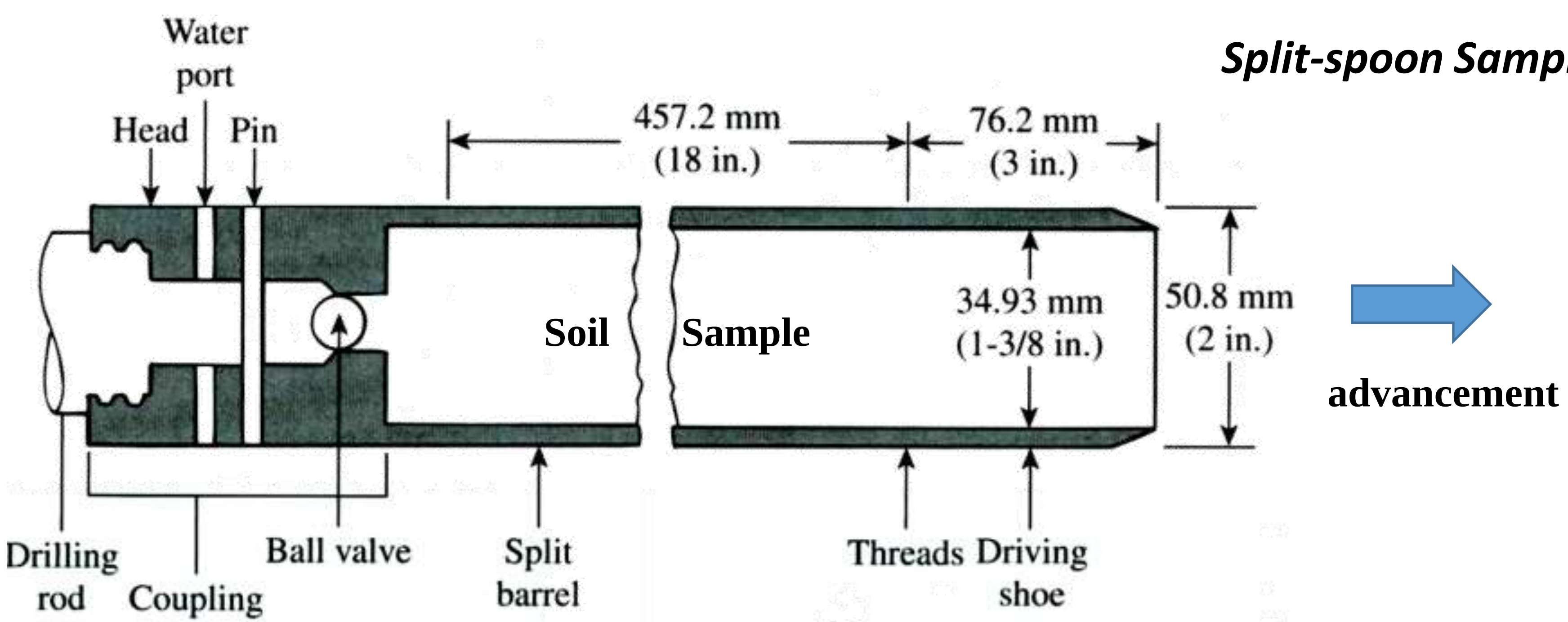
Soil sampling

Soil Sampling equipment

There is a wide range of sampling methods such as Split-spoon, Thin-walled Tube. The choice of method depends on:

- the requirement of disturbed or undisturbed samples
- Type of soil discovered at site (Gravel, Sand, Silt, Clay)

Split-spoon Sampler



Soil sampling

Soil Sampling equipment

Sampler	*Disturbed / Undisturbed*	*Appropriate Soil Types*	*Method of Penetration*	*% Use in Practice*
Split-Barrel (Split Spoon)	Disturbed	Sands, silts, clays	Hammer driven	85
Thin-Walled Shelby Tube	Undisturbed	Clays, silts, fine-grained soils, clayey sands	Mechanically Pushed	6
Continuous Push	Partially Undisturbed	Sands, silts, & clays	Hydraulic push with plastic lining	4
Piston	Undisturbed	Silts and clays	Hydraulic Push	1
Pitcher	Undisturbed	Stiff to hard clay, silt, sand, partially weather rock, and frozen or resin impregnated granular soil	Rotation and hydraulic pressure	<1
Denison	Undisturbed	Stiff to hard clay, silt, sand and partially weather rock	Rotation and hydraulic pressure	<1
Modified California	Disturbed	Sands, silts, clays, and gravels	Hammer driven (large split spoon)	<1
Continuous Auger	Disturbed	Cohesive soils	Drilling w/ Hollow Stem Augers	<1
Bulk	Disturbed	Gravels, Sands, Silts, Clays	Hand tools, bucket augering	<1
Block	Undisturbed	Cohesive soils and frozen or resin impregnated granular soil	Hand tools	<1

Soil sampling

Disturbed vs Undisturbed

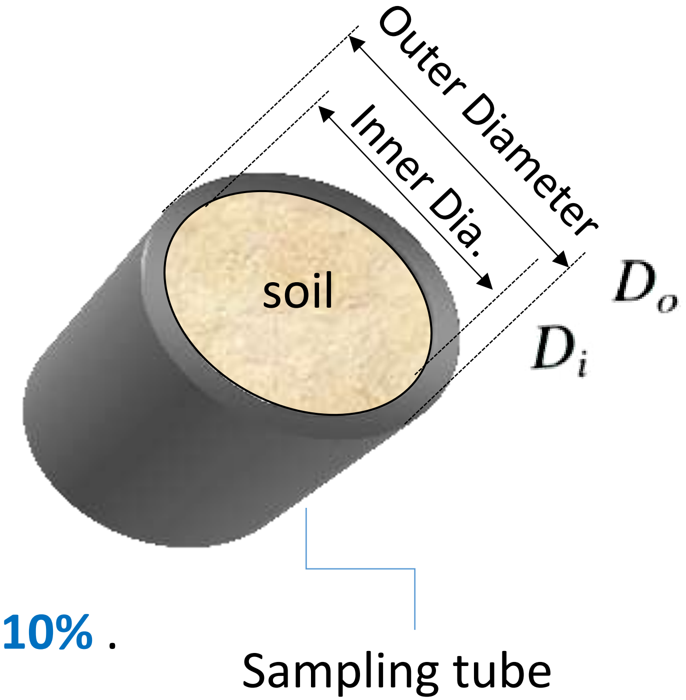
- Two types of soil samples can be obtained during sampling: disturbed and undisturbed.
- The most important engineering properties required for foundation design are strength, compressibility, and permeability. These tests require **undisturbed** samples.
- **Disturbed** samples can be used for determining other properties such as Moisture content, Classification & Grain size analysis, Specific Gravity, and Plasticity Limits.

Soil sampling

Disturbed vs Undisturbed

- It is nearly impossible to obtain a truly undisturbed sample of soil.
- The quality of an "undisturbed" sample varies widely between soil laboratories. So how is disturbance evaluated?
- Quality of samples is evaluated by calculating **Area Ratio** A_R:

$$A_R(\%) = \frac{D_o^2 - D_i^2}{D_i^2}(100)$$



The thicker the wall of the sampling tube, the greater the disturbance. **Good quality samples A_R<10%** .

Soil sampling

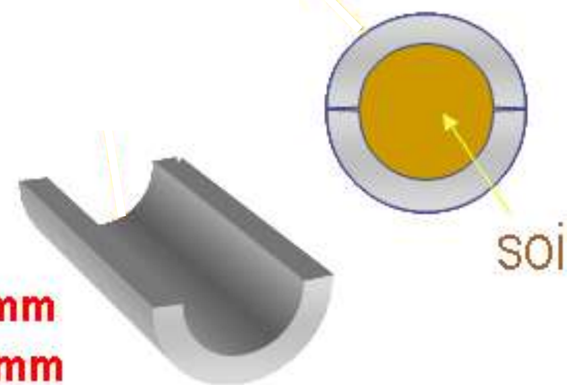
Disturbed vs Undisturbed

- Samples collected in Split-spoon Sampler is usually classified as “disturbed”.

What is the Area Ratio?

Area Ratio A_R = ---------------- =

D_i = 35 mm
D_o = 51 mm



Rock Sampling (Coring)

Rock samples are called “rock cores”, and they are necessary if the soundness of the rock is to be established.

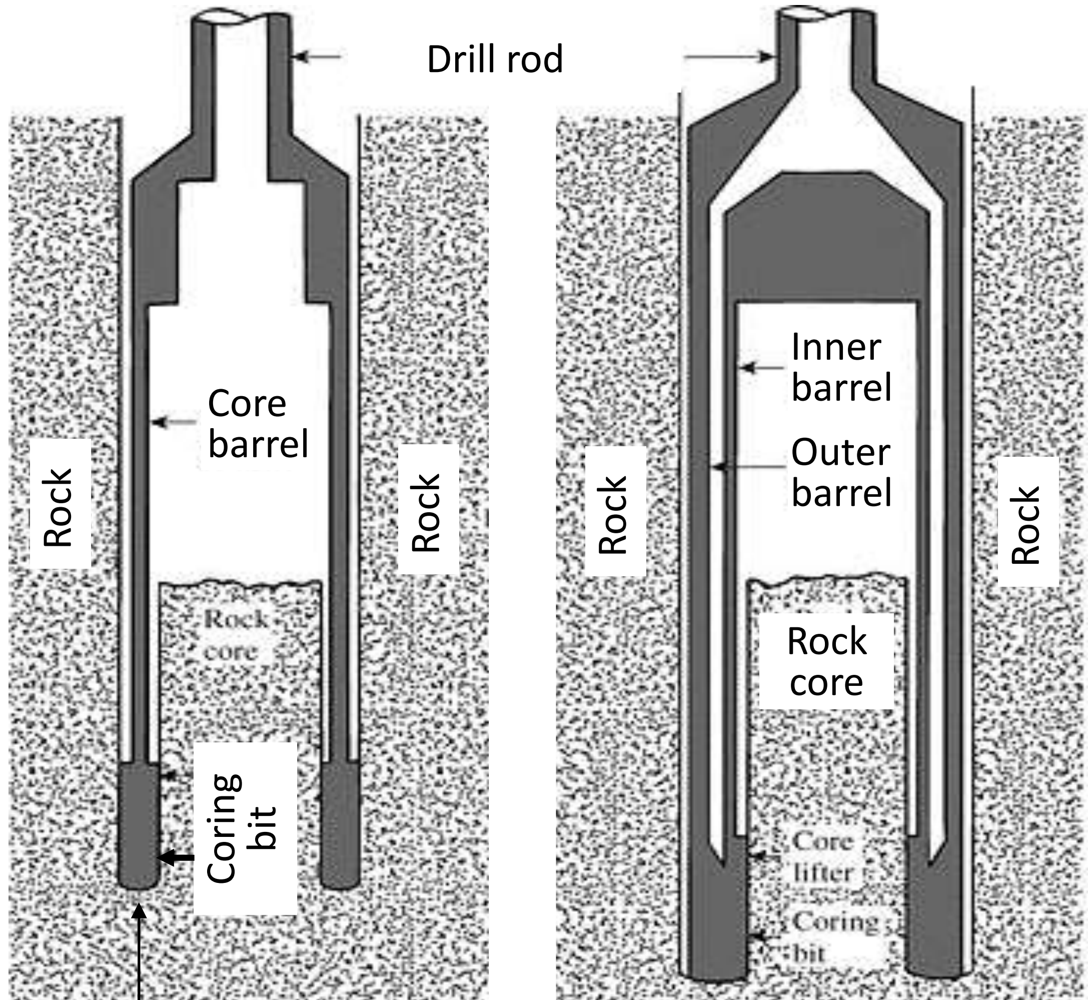
- **Core drilling equipment?**
- **Core recovery parameters?**

Rock Sampling (Coring)

Core drilling equipment

- Coring is done with either tungsten carbide or diamond core bits.
- Rock sampler is called "**core barrel**" which usually has a single tube.
- Double or triple tube core barrel is used when sampling of weathered or fractured rock.

Diamond Drill Bit



(a) (b)

Core barrel: (a) Single-tube; (b) double-tube

Rock Sampling (Coring)

Core drilling equipment

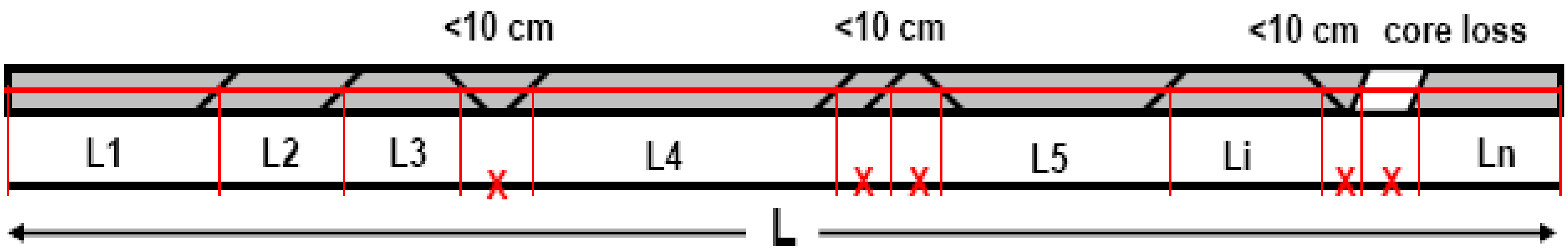
- Cores tend to break up inside the drill barrel, especially if the rock is soft or fissured.
- Core recovery parameters are used to describe the quality of core.
- Length of pieces of core are used to determine:
  - Core Recovery Ratio (R_r)
  - Rock Quality Designation (RQD)

Rock cores

Rock Sampling (Coring)

Core drilling equipment

- Assuming the following pieces for a given **core run**:



$$R_r = \frac{\sum \text{ Core recovery (lengths of intact pieces of core)}}{\text{Length of core advance (Core run)}}$$

Recovery Ratio, R_r

Rock Quality Designation, RQD

$$RQD = \frac{\sum \text{Lengths of intact pieces of core} \geq 10 \text{ cm}}{\text{Length of core advance (Core run)}} = \frac{\Sigma L_i}{L} 100\% \quad (L_i \geq 10 \text{ cm})$$

Rock Sampling (Coring)

Core recovery parameters

- So Rock Quality Designation (RQD) is the percentage of rock cores that have length ≥ 10 cm over the total drill length (core run).
- RQD may indicate the degree of jointing or fracture in a rock mass. e.g. High-quality rock has an RQD of more than 75%.
- RQD is used in rock mass classification systems and usually used in estimating support of rock tunnels.

RQD	Rock Mass Quality
< 25	Very poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
99 – 100	Excellent

Rock Sampling (Coring)

Core recovery parameters

Class Example

Work out R_r and RQD for the following core recovery (intact pieces), assuming the core run (advance) is 150 cm.

What is the rock mass quality based on RQD?

Core Recovery cm
25
5
5
7.5
10
12.5
7.5
10
15
10
5
12.5

Rock Sampling (Coring)

Core recovery parameters

Solution:

- Total core recovery L = 125 cm
- Core recovery ratio:

  R_r = 125/150 = 83%

- On modified basis (for pieces ≥ 10cm), 95 cm are counted, thus:

$$\text{RQD} = \frac{\Sigma L_i}{L} 100\% = 95/150 = 63\ \%$$

- RQD = 50% - 75% → Rock mass quality is "Fair"

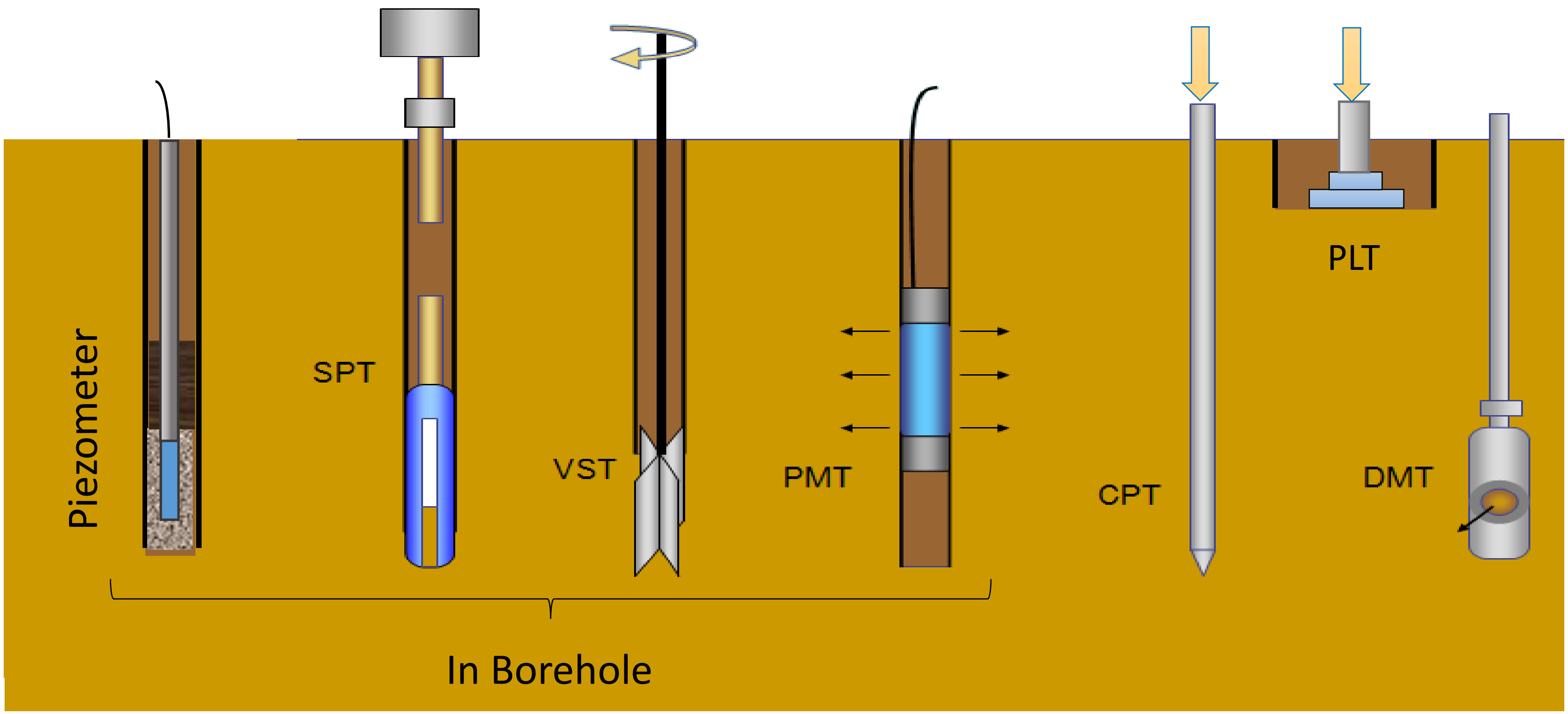
Core Recovery cm	Modified Core Recovery, cm
25	25
5	0
5	?
7.5	
10	10
12.5	
7.5	
10	
15	
10	
5	
12.5	
L = ?	ΣL_i ?

➢Testing

1. **Boring**
   - Trial pits
   - Boreholes
2. **Sampling**
   - Soil Sampling
   - Rock Sampling
3. **Testing**
   - In-situ tests
   - Laboratory tests

In-situ tests

- Introduction
- Groundwater measurements
- Standard Penetration Test (SPT)
- Cone Penetration Test (CPT)
- Plate Load Test (PLT)
- Pressure-meter Test (PMT)
- Flat Dilatometer Test (DMT)
- Vane shear test (VST)
- Elastometer Test (Rock)



Introduction

Definition:

- In-situ tests are carried out in the field with intrusive testing equipment.
- If non-intrusive method is required, then it is better to use **geophysical** methods which use geophysical waves – i.e. without excavating the ground.

Advantage of in-situ testing (against lab testing)

- It avoids the problems of sample recovery and disturbance
- some in-situ tests are easier to conduct than lab tests
- In-situ tests can offer more detailed site coverage than lab testing.

Testing standards

- American Society for Testing and Materials (ASTM)
- British Standard (BS)

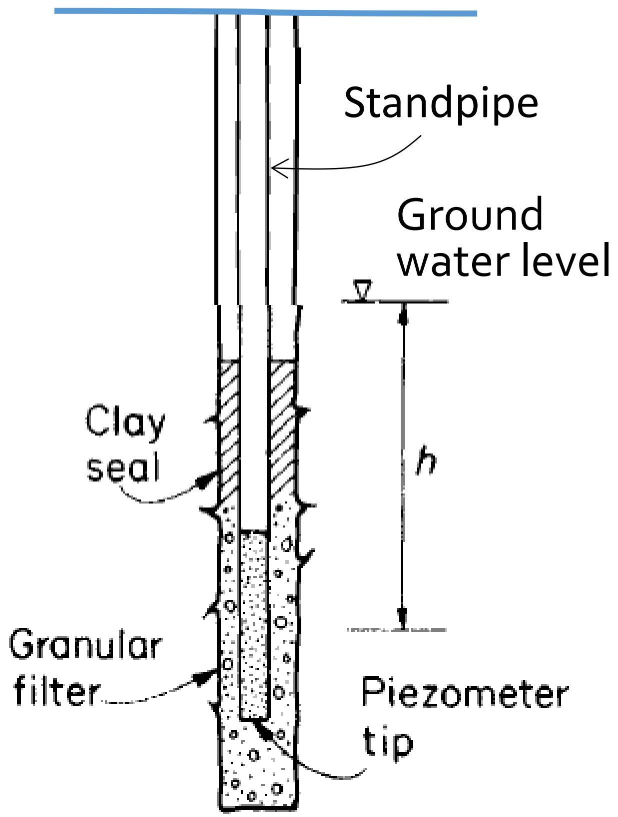
Groundwater measurements

Why Groundwater:

- Groundwater conditions are fundamental factors in almost all geotechnical analyses and design studies.

Types of Groundwater measurements:

- Determination of groundwater levels (GWT) and pressures. Borehole instrumented with **Piezometer** is used for this purpose.
- Measurement of the permeability of the subsurface materials, particularly if seepage analysis is required. The test called Pumping test.

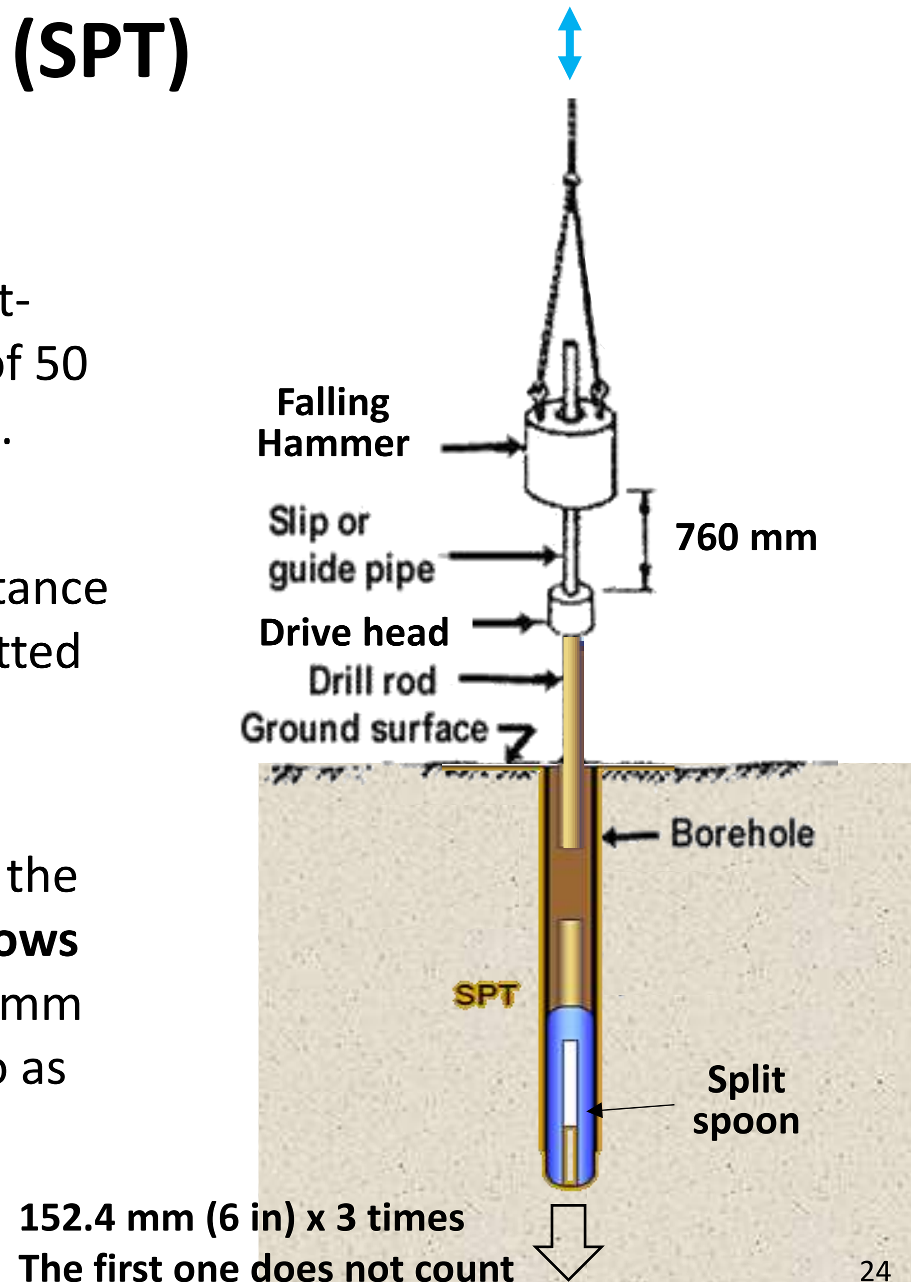


Piezometer

Standard Penetration Test (SPT)

Definition

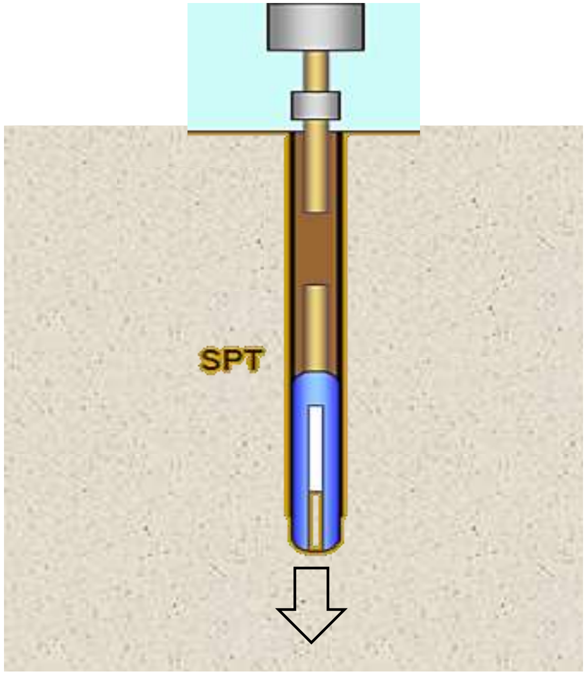
- This empirical test consists of driving a split-spoon sampler, with an outside diameter of 50 mm, into the soil at the base of a borehole.
- Drivage is accomplished by a trip hammer, weighing 65 kg, falling freely through a distance of 760 mm onto the drive head, which is fitted at the top of the rods.
- The split-spoon is driven three times for a distance of 152.4 mm (6 in) into the soil at the bottom of the borehole. The number of **blows** required to drive **(only)** the last two 152.4 mm are recorded. The blow count is referred to as the SPT Number, **SPT-N "N"**.



Standard Penetration Test (SPT)

Advantage

- Relatively quick, simple, reasonably cheap, and suitable for most soils.
- good correlation between **SPT-N** and **soil properties**.
- provides a representative soil sample for further testing.



Disadvantage

- SPT does not typically provide continuous data
- Limited applicability to soil containing cobbles and boulders.
- Samples obtained from the SPT are disturbed.
- SPT N blow require **correction**

Standard Penetration Test (SPT)

Corrections for energy and equipment

- Corrections are normally applied to the SPT blow count (N) to account for:
  - ***Energy loss***: during the test (about only **60%** of energy remains)
  - ***Equipment differences***: hammer, sampler, borehole diameter, rod

- The following equation is used to compensate for these factors:

$$N_{60} = \frac{N \eta_H \eta_B \eta_S \eta_R}{60\%}$$

N_{60} = SPT N value corrected for field procedures
η_H = hammer efficiency (usually 0.50-0.80)
η_B = borehole diameter correction (1.0-1.15)
η_S = sampler correction (0.8-1.0)
η_R = rod length correction (0.75-1.0)
N = measured SPT N value

Usually this correction is made by the Site Investigation operator.

Standard Penetration Test (SPT)

Corrections for overburden pressure

- In granular soil (sand, gravel) the SPT blows are influenced by the ***effective overburden pressure*** at the test depth:

$$(N_1)_{60} = C_N N_{60}$$

C_N = overburden pressure correction factor

Many equations have been suggested for C_N – see Page 86, (Das's text book). For example:

Seed et al.'s relationship (1975):

$$C_N = 1 - 1.25 \log\left(\frac{\sigma'_o}{p_a}\right)$$

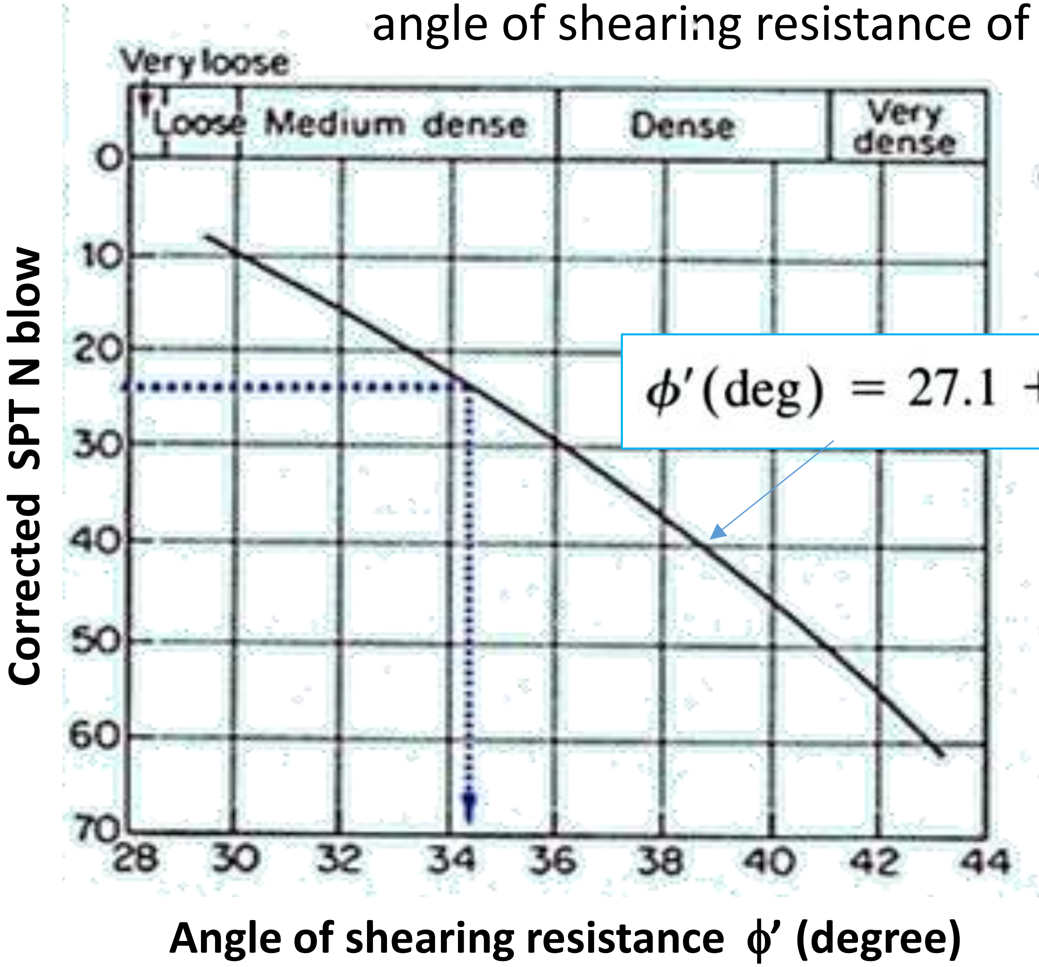
σ'_o = effective overburden pressure

p_a = atmospheric pressure ($\approx$ 100 kN/m^2, or $\approx$ 2000 lb/ft^2)

Standard Penetration Test (SPT)

Correlation between N and friction angle

- There are many equations suggested. The figure shows the correlation with the angle of shearing resistance of **sand** (according to Pecks, 1974).



$$\phi'(\text{deg}) = 27.1 + 0.3N_{60} - 0.00054[N_{60}]^2$$

After Peck et al. (1974)

Standard Penetration Test (SPT)

Class example

The following are the recorded numbers of SPT blows required for spoon penetration of three 152.4cm (6 in) in a sand deposit:

Depth from ground surface (m)	1.5	3	4.5	6	7.5
SPT blows (blow/ 6 in)	3, 4, 5	7, 9, 10	7, 12, 11	8, 13, 14	10, 14, 15

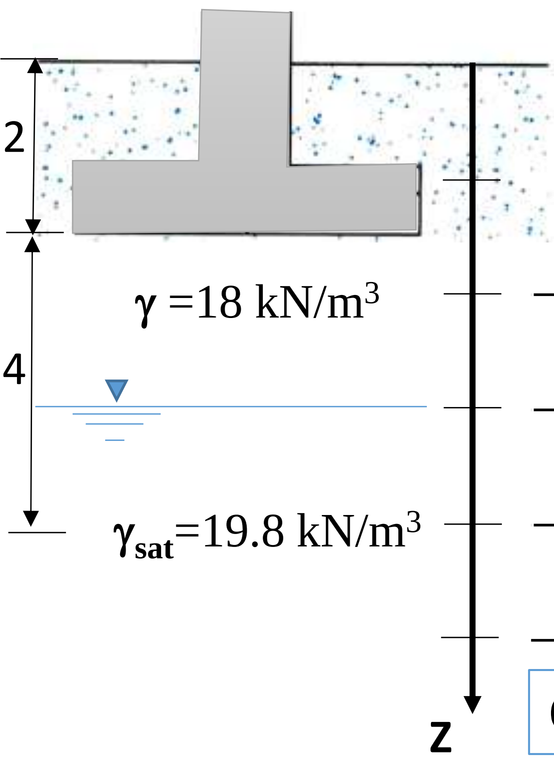
Note. Assume the above SPT blows are corrected for energy and equipment.

The ground water table (GWT) is located at a depth of 4.5m. The wet unit weight of sand above GWT is 18 kN/m^3, and the saturated unit weight of sand below GWT is 19.81 kN/m^3.

- Draw a **sketch** of the foundation showing the given details of the soil.
- Determine the standard penetration number (**SPT-N**) at each depth.
- What is the **corrected** (SPT-N) value? (use Seed's equation).
- Determine the **friction angle** at depth 4m below the footing. (Use Peck's Equation or Chart).

Standard Penetration Test (SPT)

Solution



Z, m	SPT blow	N_{60}	σ_0' (kPa)	$\frac{\sigma'_o}{p_a}$	C_N	$(N_1)_{60}$	ϕ'
1.5	**3, 4, 5**	4+5=9	1.5x18 =27	0.27	1.7	15.3	35°
3	**7, 9, 10**	9+10=19	54	0.54			
4.5	**7, 12, 11**	23					
6	**8, 13, 14**						?
7.5	**10, 14, 15**						

Only the last 2 sets of blows count

$$C_N = 1 - 1.25 \log\left(\frac{\sigma'_o}{p_a}\right)$$

$$(N_1)_{60} = C_N N_{60}$$

Corrected

Standard Penetration Test (SPT)

Correlation between N and untrained shear strength

- The corrected SPT N blow can be **approximately** correlated to many important engineering properties of soil such as shear strength & compressibility.
- This equation shows the correlation with undrained shear strength Su (or Cu) of **clay**. (also with OCR = Over Consolidation Ratio).

In Clay

$$\frac{c_u}{p_a} = 0.29 N_{60}^{0.72}$$

Hara, et al. (1971)

where p_a = atmospheric pressure ($\approx$ 100 kN/m^2

$$\text{OCR} = 0.193 \left(\frac{N_{60}}{\sigma'_o} \right)^{0.689}$$

Mayne and Kemper (1988)

where σ'_o = effective vertical stress in MN/m^2

Standard Penetration Test (SPT)

Correlation between N and untrained shear strength

- The table shows the correlation corrected SPT-N with untrained shear strength Su (or Cu) of **clay** (according to Terzaghi et al. 1996)

Soil Consistency	SPT N	S_u (psf)	S_u (kPa)
Very Soft	< 4	< 250	< 12
Soft	2 – 4	250 – 500	12 – 25
Medium	4 - 8	500 – 1000	25 – 50
Stiff	8 – 15	1000 – 2000	50 – 100
Very Stiff	15 – 30	2000 – 4000	100 – 200
Hard	> 30	> 4000	> 200

Terzaghi et al. (1996)

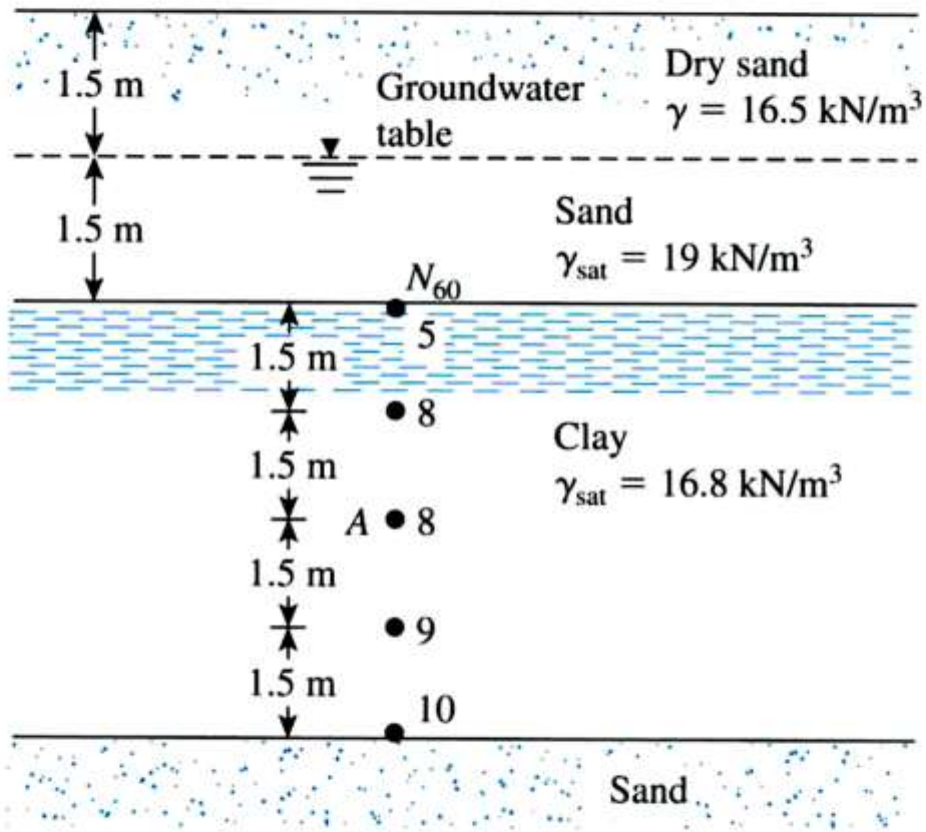
Standard Penetration Test (SPT)

Class Example

A soil profile is shown in **the Figure** along with the standard penetration numbers in the clay layer. Use Eqs. **shown below** to determine the variation of c_u and OCR with depth. What is the average value of c_u and OCR?

$$\frac{c_u}{p_a} = 0.29N_{60}^{0.72}$$

$$\text{OCR} = 0.193\left(\frac{N_{60}}{\sigma'_o}\right)^{0.689}$$



Standard Penetration Test (SPT)

Solution

Z, m	N_{60}	σ_0' (kPa)	C_u (kPa)	σ_0' (MPa)	OCR
3	5	1.5x16.5+ 1.5x(19-9.81) = 38.5	100x0.29 x$5^{0.72}$ =92.3	38.5/1000= 0.0385	0.193x(5/ 0.038)$^{0.689}$ = 5.5
4.5	8	38.5+1.5x(16.5- 9.81) = 48.5	129.6	0.0485	
6	8				
7.5	9				
9	10				

$C_{u\text{ -av}}$ =

OCR_{av} =

$$\frac{c_u}{p_a} = 0.29 N_{60}^{0.72}$$

$$OCR = 0.193\left(\frac{N_{60}}{\sigma'_o}\right)^{0.689}$$

Standard Penetration Test (SPT)

Correlation between N and Relative Density Dr

- correlation between N_{60} and Relative Density of Granular Soil

$$D_r(\%) = \left[\frac{N_{60}\left(0.23 + \frac{0.06}{D_{50}}\right)^{1.7}}{9}\left(\frac{1}{\frac{\sigma'_o}{p_a}}\right)\right]^{0.5}(100)$$

General

$$D_r = \left\{\frac{N_{60}}{\left[17 + 24\left(\frac{\sigma'_o}{p_a}\right)\right]}\right\}^{0.5}$$

For Clean sand only

where

D_r = relative density

σ'_o = effective overburden pressure

D_{50} = sieve size through which 50% of the soil will pass (mm)

p_a = atmospheric pressure ($\approx$ 100 kN/m^2,

Standard Penetration Test (SPT)

Correlation between N and Relative Density Dr

Table 2.8 Relation between the Corrected $(N_1)_{60}$ Values and the Relative Density in Sands

Standard penetration number, $(N_1)_{60}$	Approximate relative density, D_r (%)	
0–5	0–5	**Very loose**
5–10	5–30	**Loose**
10–30	30–60	**Medium**
30–50	60–95	**Dense**

Standard Penetration Test (SPT)

Correlation between Modulus of Elasticity and Standard Penetration Number

- The modulus of elasticity of granular soils (E_s) is important parameter in estimation the elastic settlement of foundation.
- An approximate estimation for E_s was given by Kulhawy and Mayne (1990) as:

$$\frac{E_s}{p_a} = \alpha N_{60}$$

where

p_a = atmospheric pressure (same unit as E_s)

$$\alpha = \begin{cases} 5 \text{ for sands with fines} \\ 10 \text{ for clean normally consolidated sand} \\ 15 \text{ for clean overconsolidated sand} \end{cases}$$