Chapter 13

Soil Exploration

CHAPTER HIGHLIGHTS

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Introduction

Soil investigation or subsurface explorations are done for determining the profile of natural soil deposits at the site and, also for determining the index and engineering properties of the soil. It also includes the in situ testing of soils to determine the properties of soils in natural conditions. This chapter discusses various methods of subsurface explorations and in situ testing of soil deposits.

Objectives of Soil Exploration

1. Determination of the depth and thickness of the various soil strata and their extent in horizontal direction.
2. The location of ground water and fluctuation in ground water table.
3. Determination of the engineering properties of the soil and the rock strata that affect the performance of the structure.
4. Determination of the in-situ properties by performing field tests.

Methods of Soil Exploration

The methods available for soil exploration may be classified as follows:

1. **Direct methods:** Test pits, trial pits or trenches.
2. **Semi-direct methods:** Borings
3. **Indirect methods:** Soundings or penetration tests and geophysical methods

Test Pits

- This test is suitable only for small depths up to 3 m.
- For excavation of pervious soils at great depths, lateral supports or bracings are required.
- Useful for conducting field tests, such as plate bearing test.
- Test pits are usually made only for supplementing other methods or for minor structures.

Boring

- Boring is a method of making or drilling bore holes into the ground for obtaining soil or rock samples from known or specified depths.
- Depending upon the type of soil and the purpose of boring, the following methods are used for drilling the holes.

1. **Auger boring:**
   - This method is effective for subsurface investigations of highways, railways and airfields, where the depth of exploration is small.
   - This method is, generally, used in soils which can stay open without casing or drilling mud, such as clays, silts, etc.

- The main disadvantage of auger boring is that the soil samples are highly disturbed.

2. **Wash boring:**
   - Used for exploration below ground water table for which the Auger method is not suitable.
   - This method cannot be efficiently applied in hard soils, rocks and soils containing boulders.
   - The hole is advanced by a combination of chopping action and jetting action.
3. **Rotary drilling:**
   - It is used in clay sands and rocks. This method is not suitable if material contains large percentage of particles of gravel
   - The hole is advanced by rotating a hollow drill rod which has a cutting bit at its lower end.
4. **Percussion drilling:**
   - This method is suitable for making holes in rocks, boulders and other hard strata.
   - It is useful for drilling holes in glacial tills containing boulders.
   - In this method, a heavy chisel is alternately lifted and dropped in a vertical hole.
5. **Core drilling:**
   - This method is used for drilling holes and obtaining rock cores.
   - Diamond-cutting edge is used.

Spacing of Borings

- The spacing of borings or the number of borings depends on the type, size and weight of the proposed structure, variation in soil conditions.
- For an area of about 0.4 hectare, one bore hole or trial pit in each corner and one is the centre should be adequate.
- For smaller and less important buildings, one bore hole at the cente is sufficient.

Depth of Borings

Normally, the depth of boring should be one and half times the width of the footing below the foundation level.

Soil Sampling

- It is the process of obtaining soil samples from the desired depth at the desired location in a natural soil deposit to assess the engineering properties of soil.
- The devices used for the purpose of sampling are known as soil samplers.

Types of Soil Samples

1. **Disturbed samples:**
   - If the natural structure of the soil gets disturbed during the sampling, then they are known as disturbed samples.
   - It is used to determine the index properties of soil.
2. **Undisturbed samples:**
   - In these samples, the natural structure of the soil and the water content are retained.
   - Undisturbed samples are used for determining the engineering properties of soil.
   - In it, smaller the disturbance, greater would be the reliability of results.

Design Features Affecting the Sample Disturbance

Area Ratio (A_r)

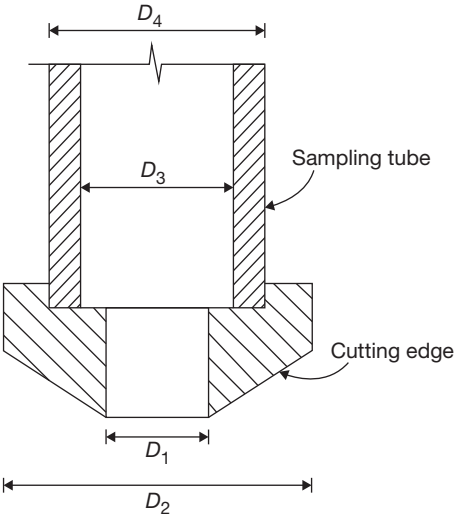
$$A_r = \frac{\text{Maximum cross} - \int\text{Sectional area of the cutting edge}}{\text{Area of the soil sample}} \times 100$$

Area ratio can be expressed as, $\boxed{A_r = \frac{D_2^2 - D_1^2}{D_1^2} \times 100}$

Where

D_1 = Inner diameter of the cutting edge

D_2 = Outer diameter of the cutting edge



For obtaining good quality undisturbed samples, the area ratio should be 10 percent or less.

Inside Clearance (C_i)

$$\boxed{C_i = \frac{D_3 - D_1}{D_1} \times 100}$$

Where, D_3 = Inner diameter of the sampling tube.

- For an undisturbed sample, the inside clearance should be between 0.5–3 percent.

Outside Clearance (C_0)

$$C_0 = \frac{D_2 - D_4}{D_4} \times 100$$

Where, D_4 = Outer diameter of the sampling tube.

Split Spoon Samplers

- Commonly used for obtaining a disturbed sample of the soil.
- Sampler is attached to the drilling rod and the soil sample is collected by jacking or by applying repeated blows of a drop hammer.
- Sample recovery becomes difficult in case of fine sand below the water table. In such case, a spring core catcher device is used.

Scraper Bucket Sampler

- Suitable for sandy deposit containing pebbles where standard split spoon sampler or split spoon sampler fitted with a spring core catcher cannot be used.
- Can also be used cohesionless soils below water table.

Shelby Tubes and Thin-walled Samplers

- Used for obtaining undisturbed samples of clay.
- The area ratio of shelby tubes is less than 15% and the inside clearance is between 0.5–3%.
- The length of tube is 5–10 times the diameter for sandy soils and 10–15 times the diameter of the clayey soil.

Piston Sampler

Used for obtaining undisturbed soil samples from soft and sensitive clays.

Dension Sampler

- Mainly used for obtaining samples of stiff to hard cohesive soils and slightly cohesive sands.
- It cannot be used for gravelly soils, loose cohesionless sands and silts below the ground water table and very soft cohesive soils.

Hand-carved Samples

- Hand-carved samples are also known as chunk samples.
- Hand-carved samples are undisturbed.

Standard Penetration Test

- Commonly used in situ-test for cohesionless soils.
- It is usefull for determining the relative density and the angle of shearing resistance of cohesionless soils.
- It can also be used to determine the unconfined compressive strength of cohesive soils.
- The test is conducted in a bore hole using a standard split spoon sampler. Standard penetration number is equal to the number of blows required for 300 mm of penetration beyond a seating drive of 150 mm.
- If the number of blows for 150 mm drive exceeds 50, it is taken as refusal and test is discontinued.

Corrections for Standard Penetration Number

Dialatancy Correction

- Correction is to be applied in case of silty fine sands and fine sands below the water table due to development of pore pressure which increases the resistance of soil and the penetration number (N).
- Terzaghi and peck recommended the following correction when the observed value of N exceeds 15.

  If $N_R \le 15$, $N_C = N_R$

  If $N_R > 15$, corrected penetration number

  $$N_C = 15 + \frac{1}{2}(N_R - 15)$$

  Where, N_R is recorded value, and N_C is the corrected value.

Overburdened Pressure Correction

- N-value depends on the overburdened pressure.
- Higher confining pressure gives a higher penetration number.
- As the confining pressure in cohesionless soils increase with the depth, the penetration number for soils at shallow depth is under estimated and that greater depth is over estimated.
- For uniformity, N-value is reported at a standard effective overburden pressure.
- Different empirical formulas are available.

Cone Penetration Tests

- Sounding methods mainly consist of the cone test and the standard penetration test.
- Cone test was developed by the Dutch Government. This test is also known as Dutch cone test.
- The test is conducted either by static method or by dynamic method.

Static Cone Penetration Test

- It is also known as Dutch cone test.
- Dutch cone has an apex angle of 60° and an overall diameter of 35.7 mm.

- For obtaining cone resistance, the cone is pushed downward at a steady rate by applying thrust.
- It is useful for determination of bearing capacity and skin friction values.
- It is useful for cohesionless soils.

Dynamic Cone Test

- The number of blows required for 30 cm of penetration is taken as the dynamic cone resistance.
- The driving energy is given by a 65 kg hammer falling from a height of 75 cm.

In-situ Tests Using a Pressure Meter

- It is also known as sub-soil deformeter.
- This method was developed by Maynand.
- It is used for determining the stress deformation characteristics of the soils in natural condition.

Geophysical Methods

The geophysical methods can be divided into two categories:

1. Seismic methods
2. Electrical resistivity methods
   - Seismic method is extremely useful for the determination of various strata and their characteristics.
   - The seismic methods are useful for obtaining preliminary information on the types and depths of various strata.
   - This method (seismic) cannot be used if a hard layer overlies a softer layer.
   - Electrical resistivity is divided into electrical profiling method and electrical sounding method.
   - The electrical profiling method is also known as the resistivity mapping method. It is, generally, used for locating sand and gravel deposits within a fine-grained soil deposit.
   - The electrical sounding method can indicate the sub-surface variation when a hard layer overlies a soft layer or vice-versa. It can also be used for locating water table.

Exercises

1. The observed value of the standard penetration number (N) at 10 m depth of a silty sand deposit is 13. The unit weight of the soil is 16 kN/m^3. The N value after correcting for the presence of fines will be
(A) 12 (B) 13
(C) 14 (D) 15

2. Match the List I (Boring methods) with List II (Field conditions) and select the correct answer using the codes given below the lists.

	List I		List II
a.	Auger boring	1.	Below water table in all soil types except hard soils and rocks
b.	Wash boring	2.	Large diameter boreholes over 150 mm in size
c.	Percussion drilling	3.	Explorations for shallow foundations and highways
d.	Rotary drilling	4.	Bouldery and gravelly strata

Codes:

	a	b	c	d
(A)	3	1	4	2
(B)	1	2	4	3
(C)	2	3	4	1
(D)	3	1	2	4

3. Consider the following properties for a soil sampler:
I. Area ratio should be low.
II. Cutting edge should be thick.
III. Inside clearance should be high.
IV. Outside clearance should be low.

The properties necessary for a good quality soil sampler would include
(A) I and IV
(B) I, II and IV
(C) II, III and IV
(D) I, III and IV

4. A good quality undisturbed soil sample is one which is obtained using a sampling tube having an area ratio of
(A) 8%
(B) 16%
(C) 24%
(D) 32%

5. A soil sampler has inner and outer radii of 25 mm and 30 mm, respectively. The area ratio of the sampler is
(A) 24% (B) 34%
(C) 44% (D) 54%

6. Match List I (Sampler) with List II (Use) and select the correct answer using the codes given below the lists:

	List I		List II
a.	Split spoon sampler	**1.**	To obtain representative samples in all types
b.	Stationary piston sampler	**2.**	To obtain undisturbed samples of stands below water table
c.	Rotary sampler	**3.**	To obtain undisturbed samples in clay and silts
d.	Compressed air sampler	**4.**	To obtain approximately undisturbed samples of hard cemented cohesive soils

Codes:

	a	b	c	d
(A)	1	3	2	4
(C)	1	3	4	2

	a	b	c	d
(B)	3	1	4	2
(D)	3	1	2	4

7. Match List I with List II and select the correct answer using the code given below the lists:

	List I		List II
a.	Geophysical methods	**1.**	Primary for cohesive soils
b.	SPT	**2.**	Clays and silts
c.	DCPT	**3.**	Reconnaissance covering large area and large depth
d.	Piston-type sampler	**4.**	Suitable for sandy soils

Codes:

	a	b	c	d
(A)	2	1	4	3
(C)	2	4	1	3

	a	b	c	d
(B)	3	1	4	2
(D)	3	4	1	2

8. Consider the following statements;

I. Undisturbed samples may be obtained with the help of augers.

II. Auger drilling is most effective in clayey soils.

III. Hollow stem augers are sometimes used to drill holes in silty sand.

Which of these statements are correct?

(A) I, II and III (B) I and II only

(C) II and III only (D) I and III only

9. Consider the following statements:

I. The static cone penetration test is unsuitable for layered deposits of sands, silts and clays.

II. The results of groundwater investigation are recorded as water-table contours over the site.

III. Closed piezometers are used to measure pore water pressure in soils having low permeability.

Which of the above statements are correct?

(A) I, II and III (B) I and II only

(C) II and III only (D) I and III only

10. Consider the following statements related to the properties of a good quality soil example:

I. Area ratio should be low.

II. Cutting edge should be thick.

III. Inside clearance should be low.

IV. Outside clearance should be low.

Which of the above statements are correct?

(A) I and II (B) II and III

(C) III and IV (D) I and IV

11. Match the items of List I with List II and select the correct answer using the codes given below the lists

	List I		List II
a.	Modulus of subgrade reaction	**1.**	Cyclic pile load test
b.	Relative density and strength	**2.**	Pressure meter test
c.	Skin friction and point bearing resistance	**3.**	Plate load test
d.	Elastic constants	**4.**	Standard penetration test
		5.	Dynamic cone penetration test

Codes:

	a	b	c	d
(A)	1	3	2	5
(C)	2	5	1	3

	a	b	c	d
(B)	1	2	4	3
(D)	3	4	1	2

12. In the context of collecting undisturbed soil samples of high quality using a spoon sampler, following statement are made:

I Area ratio should be less than 10%

II. Clearance ratio should be less than 1%

With reference to above statements, which of the following applies?

(A) Both the statements are true.

(B) Statement II is true but I is false.

(C) Statement I is true but II is false.

(D) Both the statements are false.

13. During the subsurface investigation for design of foundations, a standard penetration test was conducted at 4.5 m below the ground surface. The record of number of blows is given below:

Penetration Depth (cm)	No of Blows
0–7.5	3
7.5–15	3
15–22.5	6
22.5–30	6
30–37.5	8
37.5–4.5	7

Assuming the water table at ground level, soil as fine sand and correction for overburden as 1.0, the corrected 'N' value for the soil would be

(A) 18 (B) 19

(C) 21 (D) 33

14. Match the following:

	Compaction Equipments		Usage
1.	Tampers	i.	For cohesive and non cohesive soils
2.	Pneumatic tyred rollers	ii.	For clays
3.	Sheep foot roller	iii.	For confined trenches
4.	Vibratory compactors	iv.	For granular soils

(A) 1 – iii, 2 – i, 3 – ii, 4 – iv
(B) 1 – iv, 2 – iii, 3 – ii, 4 – i
(C) 1 – iii, 2 – ii, 3 – iv, 4 – i
(D) 1 – ii, 2 – i, 3 – iii, 4 – iv

15. If the actual observed value of standard penetration resistance N is greater than 15 in a fine sand layer below water table, then equivalent penetration resistance will be

(A) $15+\frac{(N+15)}{2}$ (B) $15+\frac{(N\times15)}{2}$

(C) $15+\frac{(N-15)}{2}$ (D) $15+\frac{(15-N)}{2}$

16. In standard penetration test conducted at site the recorded values of blow count for every 15 cm penetration at a depth of 45 cm are 5, 10, 15 respectively. The value of SPT blow count (N) that should be used is
(A) 15 (B) 17
(C) 25 (D) 19

17. Match the following

	Type of Boring		Usage
a.	Auger boring	1.	For drilling holes
b.	Rotary drilling	2.	Advancing holes in the ground
c.	Core drilling	3.	Drilling holes in clay
d.	Percussion drilling	4.	Sampling for highways, railways etc

	a	b	c	d
(A)	4	1	3	2
(C)	2	3	1	4

	a	b	c	d
(B)	4	3	1	2
(D)	1	2	3	4

18. I. Cement stabilization is done by using mixture of soil + cement + water + compaction + curing.
II. Chemical stabilization is done by using calcium chloride and sodium silicate.
(A) I and II are true
(B) I and II are false
(C) I is true and II is false
(D) I is false and II is true

19. The incorrect statement among the following is:
(A) The area ratio should be low.
(B) The cutting edge should be thick.
(C) The inside clearance should be small.
(D) The outside clearance should be small.

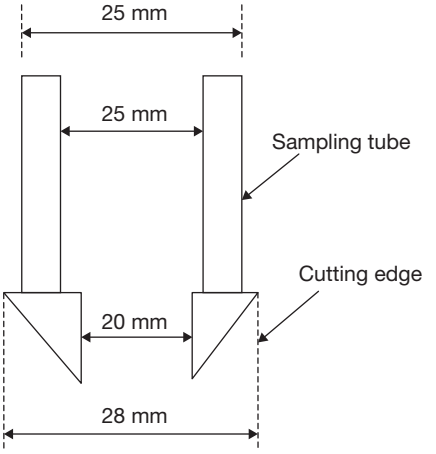
20. The seismic method of soil exploration cannot be used for
(A) sub surface investigation.
(B) hard layers.
(C) clays.
(D) sandy soils.

21. The number of blows observed in a standard penetration test for different penetration depths are given as follows:

Penetration of Sampler	Number of Blows
0–100 mm	2
100–200 mm	4
200–350 mm	7
350–400 mm	10

The observed 'N' value is _____.

22. For the sampler shown in the figure area ratio, inside clearance and outside clearance are respectively



(A) 96%, 12%, 10% (B) 49%, 11%, 9%
(C) 49%, 9%, 11% (D) 96%, 10%, 12%

23. Match List I (Roller type) with List II (Soil type):

	List I		List II
1.	Sheep foot roller	a.	Gravel in WBM road
2.	Pneumatic roller	b.	Dry sand
3.	Smooth heavy roller	c.	Hearting of earthen dam
4.	Vibratory roller	d.	Casing of earthen dam

(A) 1 – b, 2 – c, 3 – a, 4 – d
(B) 1 – c, 2 – d, 3 – a, 4 – b
(C) 1 – d, 2 – c, 3 – a, 4 – b
(D) 1 – d, 2 – c, 3 – b, 4 – a

24. The area ratio of sampler should not exceed
(A) 70% (B) 50%
(C) 10% (D) 25%

25. The SPT value is recorded for the penetration of split barrel sampler for a penetratioin of
(A) 60 cm (B) 30 cm
(C) 15 cm (D) 45 cm

26. Match List I (Roller Type) with List II (Soil Type) and select the correct answer using the codes given.

	List I		List II
a.	Vibratory roller.	**1.**	Cohesive and granular soils
b.	Smooth wheel roller	**2.**	Silty soils of low plasticity
c.	Pneumatic roller	**3.**	Cohesionless soil
d.	Sheep foot roller	**4.**	Plastic soils of moderate cohesion

Codes:

	a	b	c	d
(A)	3	1	2	4
(B)	4	1	2	3
(C)	3	2	1	4
(D)	4	2	1	3

Previous Years' Questions

1. The number of blows observed in a standard penetration test (SPT) for different penetration depths are given as follows **[GATE, 2007]**

Penetration of Sampler	Number of Blows
0–150 mm	6
150–3000	8
300–450 mm	10

The observed N value is

(A) 8 (B) 14
(C) 18 (D) 24

2. Dilatancy correction is required when a strata is **[GATE, 2009]**

(A) cohesive and saturated and also has N value of SPT > 15.
(B) saturated silt/fine sand and N value SPT < 10 after the over bourdon correction.
(C) saturated silt/fine sand and N value (SPT) > 15 after the over burden correction.
(D) coarse sand under dry condition and N value of SPT < 10 after the over burden correction.

3. The degree of disturbance of the sample collected by the sampler is expressed by a term called the 'area ratio'. If the outer diameter and inner diameter of the sampler are D_0 and D_i respectively, the area ratio is given by **[GATE, 2014]**

(A) $\frac{D_0^2 - D_i^2}{D_i^2}$ (B) $\frac{D_i^2 - D_0^2}{D_i^2}$
(C) $\frac{D_0^2 - D_i^2}{D_0^2}$ (D) $\frac{D_i^2 - D_0^2}{D_0^2}$

4. List I enlists in situ field tests carried out for soil exploration. While List II provides a list of parameters for sub soil strength characterization. Match the type of tests with the characterization parameters **[GATE, 2014]**

	List I		List II
P.	Pressure test (PMT)	**1.**	Menard's modulus (E_m)
Q.	Static cone penetration test (SCPT)	**2.**	Number of blows (N)
R.	Standard penetration test (SPT)	**3.**	Skin resistance (f_c)
S.	Vane shear test (VST)	**4.**	Undrained cohesion (C_u)

(A) P – 1; Q – 3; R – 2; S – 4
(B) P – 1; Q – 2; R – 3; S – 4
(C) P – 2; Q – 3; R – 4; S – 1
(D) P – 4; Q – 1; R – 2; S – 3

5. Which of the following statements is TRUE for degree of disturbance of collected soil sample? **[GATE, 2015]**

(A) Thinner the sampler wall, lower the degree of disturbance of collected soil sample.
(B) Thicker the sampler wall, lower the degree of disturbance of collected soil sample.
(C) Thickness of the sampler wall and the degree of disturbance of collected soil sample are unrelated.
(D) The degree of disturbance of collected soil sample is proportional to the inner diameter of the sampling tube.

Answer Keys

Exercises

1. B	**2.** A	**3.** A	**4.** A	**5.** C	**6.** A	**7.** D	**8.** C	**9.** A	**10.** D
11. D	**12.** C	**13.** C	**14.** A	**15.** C	**16.** C	**17.** B	**18.** A	**19.** B	**20.** B
21. 21	**22.** D	**23.** B	**24.** C	**25.** B	**26.** A				

Previous Years' Questions

1. C	**2.** C	**3.** A	**4.** A	**5.** A