SOIL EXPLORATION

The field and laboratory studies carried for obtaining information about the subsoil characarteristic including the location of GWT are termed a s soil exploration.

Site Investigation should provide

1. Information to determine the type of foundation
2. Information to determine the allowable load capacity of the foundation
3. Sufficient data to make settlement prediction
4. Location of GWT and its fluctuation
5. Information regarding identification and solution of construction problems (sheathing, dewatering, rock excavation etc)
6. Identification of potential problems concerning adjacent property
7. Identification of environmental problems and their solutions

Planning the exploration program

The purpose of exploration program is to determine the stratification and engineering properties of the soils underlying the site.

Principal properties of interest are

(i) Strength
(ii) Deformation
(iii) Hydraulic characteristics

Actual planning of subsurface investigation includes some or all of the following

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

   Foundation regulations in local building code should be consulted for any special requirements.

   For bridges, information about type and span lengths as well as pier loadings and their tentative locations

2. Reconnaissance of the area
   (i) General topography of the site , existence of drainage ditches, dumps of debris, sanitary fills etc.
   (ii) Existence of settlement cracks in the structure already built near the site.
   (iii) Evidence of landslides, creep of slopes, shrinkage cracks etc.
   (iv) Stratification of souls as observed from deep cuts near the site.
   (v) Location of high flood marks on the nearby buildings and bridges
   (vi) Depth of GWT as observed in the wells
   (vii) Existence of springs, swamps. etc.
   (viii) Drainage pattern existing at the site
   (ix) Type of vegetation existing at the site
   (x) Existence of underground water mains, power conduits, abandoned mines etc.

Reconnaissance study also includes obtaining data from various sources of information like geological maps, agronomy studies, aerial photographs, water and or well well logs, hydrological data, soil manuals etc.

3. Preliminary site investigation
   Aim of preliminary site investigation is to determine the depth, thickness, extent and composition of each soil stratum at the site. Depth of bedrock and GWT are also determined.

   Preliminary investigations are general y in the form of few borings or test pits, tests conducted with cone penetrometers and sounding rods and geophysical studies

4. Detailed site investigation
   Aim of detailed site investigation is to determine the engineering properties of the soil in different strata. This includes extensive boring, sampling, laboratory and field testing, including vane shear test, plate load test, permeability tests etc.

Borehole layout and frequency
The borehole layout and frequency is partly controlled by the complexity of the geological condition. The complexity of geological structure and the variability of each soil or rock units should at least be partially known.

(i) For isolated small structures like pylons, radio masts and small houses one bore hole is sufficient.
(ii) For compact projects like buildings, bridges etc., at least four boreholes are required. These should normally be deep and closely spaced.
(iii) Extended projects like motorways, railways, reservoirs, land reclamation schemes require more widely spaced boreholes.

Spacing of borings

Highways	300 – 600 m	These spacings are doubled for uniform soil conditions and halved for irregular conditions
Earthdams	30 -60 m	
Borrow pits	30 – 120 m	
Multi-storey buildings	15 - 30 m	
Single storey buildings	30 – 90 m	

Depth of borings

Reservoir	Up to impermeable stratum or not less than two times the maximum hydraulic head expected	
Foundations	Up to depth at which total vertical stress increase due to foundation is 10 % of stress applied at foundation	
Roads	2 – 4 m below the finished road level	
Dams	Earth structures	1.5 times base width of dam
	Concrete Structures	1.5 to 2.0 times height of dam
Retaining walls	0.75 to 1.5 times the wall height below the bottom of the wall	
Embankments	Up to a minimum depth equal to the height of the embankment	

Soil samples

Soil samples are of two categories, namely, disturbed samples and undisturbed samples.

Disturbed sample: A soil sample in which the natural soil structure gets modified or destroyed during sampling operation is termed as a disturbed sample.

> Disturbed samples can be representative samples or non-representative samples.
>
> Representative samples are those samples in which the natural moisture content and proportion of mineral constituents can be preserved. They are useful for soil identification.
>
> Representative samples can be used for determining
>
> a. Specific gravity
> b. Grain Size Distribution
> c. Atterberg limits
>
> Non-representative samples are those samples in which in addition to alteration of original soil structure, soils form other layers get mixed up. They are useless.

Undisturbed sample: A soil sample in which the original soil structure is preserved and material properties do not undergo any alteration or modification is termed as undisturbed sample. Such samples are practically impossible to obtain. For all practical purposes, undisturbed sample is one in which material has been subjected to minimum disturbance.

Undisturbed samples are required for the determination of

a. Natural water content
b. Density
c. Coefficient of permeability
d. Consolidation parameters
e. Shear strength parameters

The disturbances can be classified in following basic types:

- Change in the stress condition
- Change in the water content and the void ratio
- Disturbance of the soil structure
- Chemical changes
- Mixing and segregation of soil constituents

The causes of the disturbances are listed below:

- Method of advancing the borehole
- Mechanism used to advance the sampler
- Dimension and type of sampler

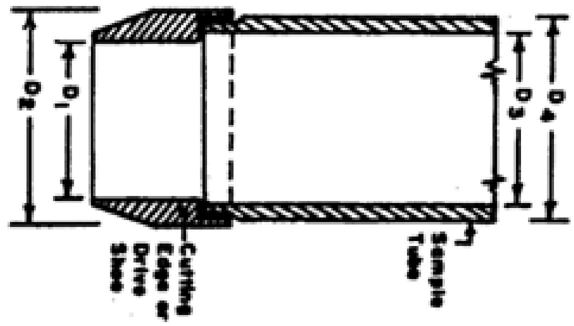
Sample disturbance

The extent of disturbance to sample due to sampler depends on three features of its design.

(i) Cutting edge
(ii) Inside wall friction

(iii) Non-return valve – should have a large orifice to allow the air and water to escape quickly and easily when driving the sample.

The following ratios are related to the dimensions of the cutting edge and the sampler



Inside clearance (C_i)

$$C_i = \frac{D_3 - D_1}{D_1} \, x \, 100 \, \%$$

- Inside clearance is meant to reduce friction between soil sample and sampler
- Allows elastic compression of sample
- If the inside clearance is too large, there will be too much of lateral expansion
- IS:1892 – 1979: C_i should be between 1 and 3 %.

Outside Clearance (C_o)

$$C_o = \frac{D_2 - D_4}{D_4} \, x \, 100 \, \%$$

- Outside clearance will help reduce friction while the sampler is being driven and when it is being withdrawn.
- Outside clearance should not be much greater than inside clearance
- IS:1892 – 1979: C_o should be between 0 and 2 %.

Area Ratio (A_r)

$$A_r = \frac{D_2^2 - D_1^2}{D_1^2}$$

- A_r should be kept as low as possible
- Should be consistent with strength requirements of the drive shoe and sampling tube
- A_r should not be greater than 20% for stiff formations and 10% or less for soft sensitive clays

D_1 = inside diameter of cutting edge/driving shoe
D_2 = outside diameter of cutting edge/driving shoe
D_3 = inside diameter of cutting sampling tube
D_4 = outside diameter of cutting sampling tube

Recovery ratio (L_r)

$$L_r = \frac{recovered\ length\ of\ the\ sample}{penetration\ length\ of\ the\ sampler}$$

- $L_r = 1$ indicates a good recovery
- $L_r < 1$ indicates that the soil is compressed
- $L_r > 1$ indicates that the soil has swelled

To reduce friction sampling tube should have a smooth finish and should be properly oiled before use

Soil samplers and sampling
Commonly used samplers can be classified into three categories:

(a) Open drive samplers
Samplers consist of a seamless open end steel tube with cutting edge. Steel tube is connected through a head to the drill rod. Sampler head is provided with vents (ports) to permit water and air to escape during sampling, and has a ball check-valve to retain sample during withdrawal. These are suitable for all soils possessing some cohesion. Sampling tube may be thick walled or thin walled.

Thick walled tubes can be used to obtain disturbed but representative samples. Thick walled tubes may be in the form of solid tube or split tube with or without liner.

Thin walled tube may be used to obtain undisturbed samples. The area ratio is less than 15%. Thin walled tubes are not suitable for too hard or gravelly or too soft or too wet soils.

(b) Piston sampler
Piston sampler consists of a sampling cylinder and a piston system that fits tightly in the sampling cylinder. During driving and up to start of of sampling, bottom of piston is maintained flush with the cutting edge of the sampler. During sampling, piston is fixed in relation to ground and sampler cylinder is forced into the soil. Sampler slides past the tight fitting piston during sampling and a negative pressure develops above the sample during withdrawal which holds the sample in the sampler.

(c) Rotary samplers
Rotary sampler is a double walled tube sampler with an inner removable liner. The outer tube of the rotating barrel is provided with a cutting bit. The inner tube which is stationery slides over the cylindrical sample cut by the outer rotating barrel. The sample is collected in the inner liner. This is useful for sampling in firm to hard cohesive soils and particularly in rocks.

Block or chunk samples

These can be obtained from open excavations like test pits, shafts etc. For obtaining such samples, soil must have a trace of cohesion. During excavation, a block of soil 40 cm x 40 cm, in plan, is left undisturbed. A 30 cm x 30 cm x 30 cm block is trimmed and an open ended box is slid over the trimmed block. The space between the sides of the box and sample is filled with dry sand and the open end of the box is sealed with wax.

Soil exploration methods

- Test pits
- Boreholes
- Probes (in-situ), Geophysical methods

Choice of method depends on budget, sampling requirements, extent of investigation and site conditions.

Test Pits

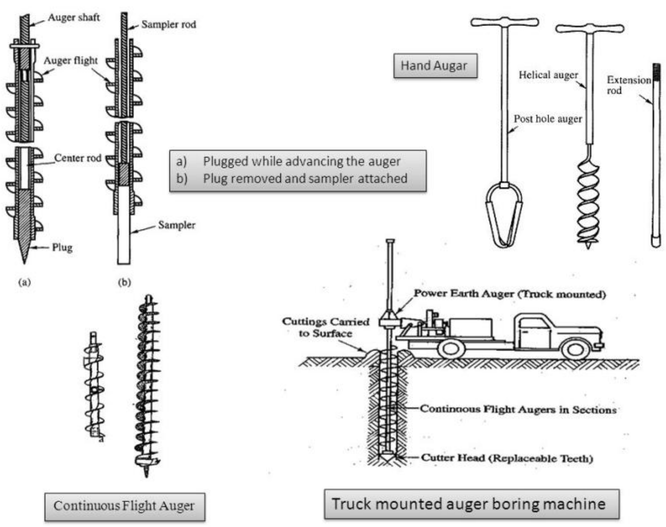
- Cheap method of investigation to shallow depth (backhoe to 4m depth, excavator to 5.5m depth
- Allows visual inspection of strata
- Limitations: undisturbed sampling difficult, collapse in granular soils or below GWT

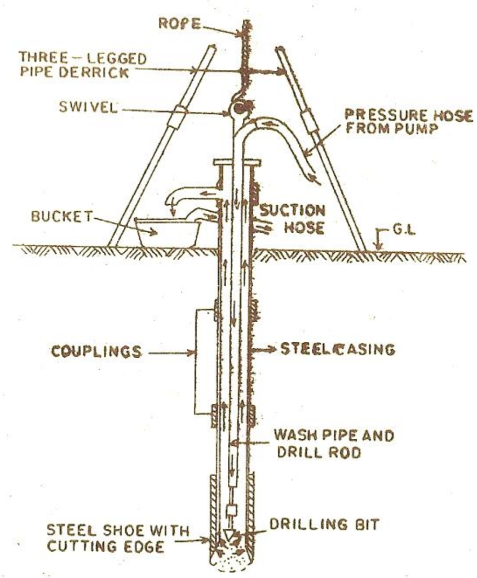
Soil Boring and drilling

Boring is carried out in relatively soft and uncemented ground. Drilling is used in the more competent and cemented, deeper deposits. Most common methods of boring and drilling are

(a) Augering

- Augers are classified as either bucket augers or flight augers
- Hand augers cannot be used for advancing holes exceeding 3- 5 m.
- They can be used for soil exploration work on some highways and small structures.
- The soil samples obtained from such borings are highly disturbed.
- When power is available, continuous flight augers are the most common method used for advancing boreholes up to about 60 – 70 m.





(b) Wash boring

- The method consists of driving a casing pipe about 2- 3 m long into the ground, usually by a heavy drop hammer supported on a tripod and pulley.
- The soil inside the casing is removed by means of a chopping bit attached to a drilling rod.
- Water is forced through the drilling rod and exits at a very high velocity through the holes at the bottom of the chopping bit.
- The water and the chopped soil particles rise in the drill hole and overflow at the top of the casing through a T-connection.
- The wash water is collected in a container.

(c) Light percussion drilling (also known as shell and auger drilling)

- A heavy drilling bit is raised and lowered to chop the hard soils.
- The chopped soil particles are brought up by the circulation of water.
- Percussion drilling may require casing.
- In clays, hole is advanced by dropping a steel tube known as clay cutter in to the soil.
- In granular soils a shell is dropped on the bottom of the hole. The mixture of soil and water passes up the tube of the shell past a non-return valve.

(d) Rotary drilling

- Boring is effected by the cutting action of a rotating bit kept in firm contact with the bottom of the hole.
- The bit is attached to the bottom end of a hollow drill rod which is rotated.
- Drilling mud is continuously forced down through the hollow drill rods.
- The drilling mud is slurry of water and bentonite.
- When soil samples are required, the drilling bit is raised and replaced by a sampler.

Penetration Testing

Many forms of in situ penetration test are in use worldwide. Penetrometers can be divided into two broad groups. The simplest are dynamic penetrometers. They consist of tubes or solid points driven by repeated blows of a drop weight. 'Static' penetrometers are more complex, being pushed hydraulically into the soil. The two most common penetration tests, which are used virtually worldwide, are the dynamic SPT, and the static CPT.

Standard Penetration Test

The Standard Penetration Test (SPT) is a common in situ testing method used to determine the geotechnical engineering properties of subsurface soils. It is a simple and inexpensive test to estimate the relative density of soils (cohesionless) and approximate shear strength parameters.

SPT, involves driving a standard thick-walled split spoon sample tube into the ground at the bottom of a borehole by blows of drop hammer of weight 65 kg freely falling from a height of 750 mm. The sample tube is driven 150 mm into the ground and then the number of blows needed for the tube to penetrate each 150 mm up to a depth of 450 mm is recorded. The sum of the number of blows required for the second and third 150 mm of penetration is reported as SPT blow count value, commonly termed as standard penetration resistance.

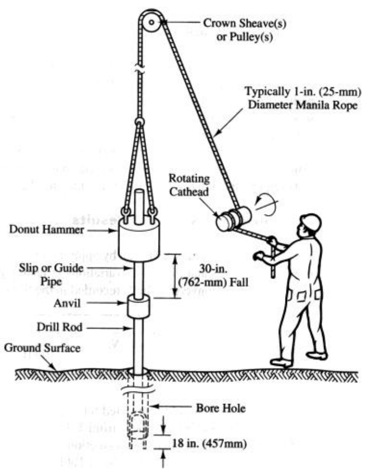
If rocks or boulders are present and 450 mm penetration is not possible, then N value is recorded for the first 300 mm. Boring log shows refusal and test is halted when

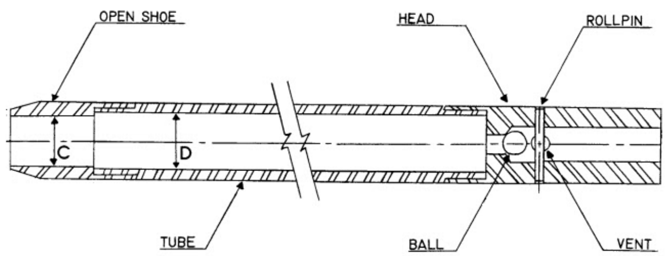
(a) 50 blows are required for any 150 mm penetration
(b) 100 blows to drive the required 300 mm penetration
(c) 10 successive blows produce no advance

SPT is carried out at every 0.75 m vertical intervals o even 1.5 m intervals for deep boreholes.

The N-value provides an indication of the relative density of the subsurface soil, and it is used in empirical geotechnical correlation to estimate the approximate shear strength properties of the soils. The use of N values for cohesive soil is limited, since the compressibility of such soil is not reflected by N values.

Correlation between SPT-N value and friction angle and Relative density (Meyerhoff 1956)			
SPT N3 [Blows/0.3 m - 1 ft]	Soil packing	Relative Density [%]	Friction angle [°]
< 4	Very loose	< 20	< 30
4 -10	Loose	20 - 40	30 - 35
10 - 30	Compact	40 - 60	35 - 40
30 - 50	Dense	60 - 80	40 - 45
> 50	Very Dense	> 80	> 45





SPLIT SPOON SAMPLER

SPT values obtained in the field for sand have to be corrected before they are used in empirical correlations and design charts. IS:2131 – 1981 recommends that the field value of N be corrected for two effects:

(a) Effect of overburden pressure
(b) Effect of dilatancy

Correction for overburden pressure

N value in a granular soil is influenced by the overburden pressure. If two granular soils possessing the same relative density but having different confining pressures are tested, the one with a higher confining pressure gives a higher N value. Since the confining pressure increases with depth, N values at shallow depths are underestimated and those at larger depths are overestimated. Hence, N values recorded from field tests at different effective overburden pressures are corrected to a standard effective overburden pressure.

The corrected N value is given by

$$N' = C_N N$$

Where N' is the corrected value for observed N and C_N is the correction factor for overburden pressure.

$$C_N = 0.77 \log_{10} \frac{2000}{p'}$$

Where p' is the effective overburden pressure at the depth at which N value is measured.

Correction for dilatancy

Dilatancy correction is to be applied when N′ obtained after overburden correction exceeds 15 in *saturated fine sands and silts.* The correction for dilatancy is

$$N'' = 15 + 0.5(N' - 15)$$

Where N″ is the final correction value to be used in design charts. If N′ ≤ 15, N″ = N′.

Cone Penetration Test (CPT)

The ‘Cone Penetration Test’, normally referred to as the ‘CPT’, is carried out in its simplest form by hydraulically pushing a 60° cone, with a face area of 10 cm^2 (35.7 mm dia.), into the ground at a constant speed (2 ± 0.5 cm/s) whilst measuring the force necessary to do so. Most commonly, however, a friction cone is used. The shear force on a 150 cm^2 ‘friction sleeve’, with the same outer diameter as the cone and located immediately above the cone, is then also measured. Both electrical and mechanical means of measuring cone resistance and side friction are currently used, with the shape of the cone differing considerably according to the method in use. The cone is driven from ground surface, without making a borehole, using a special mobile hydraulic penetrometer rig. CPT gives a continuous record of variation of both cone resistance and friction resistance with depth.

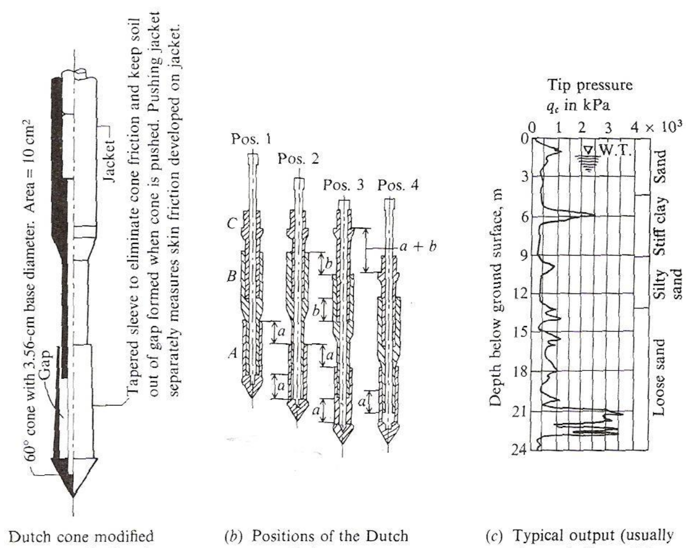
The static cone penetration test is widely used in place of SPT, particularly for soft clays and silts and fine to medium sand deposits. This test is also known as Dutch cone test.

Position 1. The cone and friction jacket assembly is in a stationery position.

Position 2. The cone is pushed into the soil by the inner sounding rod to a depth *a*, at a steady rate of 20 mm/s, tilla collar engages the cone.

Position 3: The sounding rod is pushed further to a depth *b*. This has the effect of pushing the friction jacket and the cone assembly together.

Position 4: The outside mantle tube s pushed down to a distance *(a+b)*, bringing the cone and the friction jacket to position 1.



Dutch cone modified to measure both point resistance q_c and skin friction q_f.

(*b*) Positions of the Dutch cone during a pressure record.

(*c*) Typical output (usually electronically made).

Mechanical (or Dutch) cone, operations sequence, and tip resistance data.

Comparison between SPT and CPT

S No	Factor	SPT	CPT
1	Empirical data base	Best historical database	Limited but growing; SPT database can be used through correlation
2	Repeatability	Not repeatable	Repeatable
3	Accuracy	Numerous sources of error	Accurate
4	Soil sample	Provided	Not provided
5	Sample distribution	Infrequent sampling	Continuous data
6	Equipment	Equipment variability	Standardized
7	Testing cost	More	Less

Geophysical Methods

Geophysical techniques can contribute very greatly to the process of ground investigation by allowing an assessment, in qualitative terms, of the lateral variability of the near-surface materials beneath a site. Non-contacting techniques such as ground conductivity, magnetometry, and gravity surveying are very useful, as are some surface techniques (for example, electrical resistivity traversing).

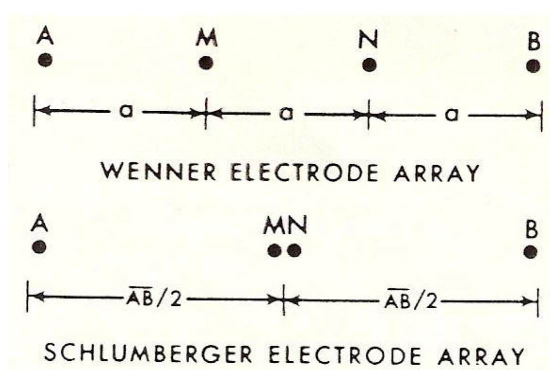
Electrical resistivity methods

The electrical properties of most rocks in the upper part of the earth's crust are dependent primarily upon the amount of water in the rock, salinity of the water, and the distribution of the water in the rock. Saturated rocks have lower resistivities than unsaturated and dry rocks. The higher the porosity of the saturated rock, the lower its resistivity, and the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clays and conductive minerals also reduces the resistivity of the rock.

In making resistivity surveys a commutated direct current or very low frequency (<1 Hz) current is introduced into the ground via two electrodes. The potential difference is measured between a second pair of electrodes. If the four electrodes are arranged in any of the several possible patterns, the current and potential measurements may be used to calculate resistivity.

Wenner Array

This array was first proposed by Wenner. The four electrodes A, M, N and B are placed at the surface of the ground along a straight line so that $\overline{AM} = \overline{MN} = \overline{NB} = a$.



Schlumberger array

This array is the most widely used in electrical prospecting. Four electrodes are placed along a straight line on the earth surface in the same order AMNB, as in the Wenner array but with $\overline{AB} \geq 5\overline{MN}$.

Vertical exploration or depth sounding

A series of measurements of resistivity are made by increasing the electrode spacing in successive steps about a fixed point. This method of vertical exploration is known as the expanding electrode method or depth probing or vertical electrical sounding. If the ground consists of two or more layers having different resistivities and the electrode separation "*a"* is less than the thickness of the first layer, the measured resistivity value will pertain to the first layer; on increasing the separation top say, *2a,* the second layer having a different resistivity will make itself felt in the apparent resistivity measured. Therefore, by successively increasing the electrode spacing about a central point, deeper layers of the earth may be involved in the measurement.

Lateral exploration or profiling

A series of measurements of resistivity are made with a constant electrode spacing, moving the whole of the electrode arrangements consecutively to a number of points along a given line. Thus the lateral variations of resistivities of the ground can be measured. The resistivities so obtained are plotted on the central points along a profile. This method is exploration is termed as "constant depth probing".