UNIT-1

INTRODUCTION TO SOIL EXPLORATION

Site investigation or Sub-Soil explorations are done for obtaining the information about subsurface conditions at the site proposed for construction. Soil exploration consists of determining the profile of the natural soil deposits at the site, taking the soil samples and determining the engineering properties of soils using laboratory tests as well as in-situ testing methods.

Objectives of Site Investigation

Following are the objectives of site investigation or subsurface exploration.

1. To know about the order of occurrence of soil and rock strata.
2. To know about the location of the groundwater table level and its variations.
3. To determine engineering properties of soil.
4. To select a suitable type of foundation.
5. To estimate the probable and maximum differential settlements.
6. To find the bearing capacity of the soil.
7. To predict the lateral earth pressure against retaining walls and abutments.
8. To select suitable soil improvement techniques.
9. To select suitable construction equipment.
10. To forecast problems occurring in foundations and their solutions.

Stages in Site Investigation

Site investigation or sub-soil exploration is carried out stage-wise as given below.

1. Site Reconnaissance
2. Preliminary site exploration
3. Detailed exploration
4. Preparation of soil investigation report

1. Site Reconnaissance

Site reconnaissance is the first stage of site investigation. In this stage, visual inspection of the site is done and information about topographical and geological features of the site are collected. The general observations made in site reconnaissance are as follows:

1. Presence of drainage ditches and dumping yards etc.

2. Location of groundwater table by observing well in that site.
3. Presence of springs, swamps, etc.
4. High flood level marks on the bridges, high rise buildings, etc. are observed.
5. Presence of vegetation and nature of the soil.
6. Past records of landslides, floods, shrinkage cracks, etc. of that region.
7. Study of aerial photographs of the site, blueprints of present buildings, geological maps, etc.
8. Observation of deep cuts to know about the stratification of soils.
9. Observation of Settlement cracks of existing structures.

Fig 1: Topographical Study of Site

2. Preliminary Site Exploration

Preliminary site exploration is carried out for small projects, light structures, highways, airfields, etc. The main objective of preliminary exploration is to obtain an approximate picture of sub-soil conditions at low cost. It is also called general site exploration.

The soil sample is collected from experimental borings and shallow test pits and simple laboratory tests such as moisture content test, density, unconfined compressive strength test, etc. are conducted. Simple field tests such as penetration methods, sounding methods, geophysical methods are performed to get the relative density of soils, strength properties, etc.

Fig 2: Collecting Soil Sample for Preliminary Soil Exploration

The data collected about subsoil should be sufficient enough to design and build light structures. Following are some of the general information obtained through primary site exploration.

3. Detailed Site Exploration

Detailed exploration is preferred for complex projects, major engineering works, heavy structures like dams, bridges, high rise buildings, etc. A huge amount of capital is required for a detailed site exploration hence; it is not recommended for minor engineering works where the budget is limited. For such type of works, data collected through preliminary site exploration is enough.

In this stage, numerous field tests such as in-situ vane shear test, plate load test, etc. and laboratory tests such as permeability tests, compressive strength test on undistracted soil samples are conducted to get exact values of soil properties.

Fig 3: Detailed Site Exploration

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Different methods of site exploration which are used in both preliminary and detailed site exploration are explained in the link given below.

4. Preparation of Report of Sub-Soil Exploration

After performing preliminary or detailed site exploration methods a report should be prepared. A sub-soil investigation or exploration report generally has the following sections:

1. Introduction
2. Scope of site investigation
3. Description of the proposed structure, purpose of site investigation
4. Site reconnaissance details
5. Site exploration details such as number, location and depth of boreholes, sampling details etc.
6. Methods performed in site exploration and their results.
7. Laboratory tests performed and their results.
8. Details of Groundwater table level and position.
9. Recommended improvement methods if needed.
10. Recommended types of foundations, structural details, etc.
11. Conclusion.

BORING METHODS

Boring methods are widely used for subsurface investigations to collect samples, in almost all types of soil, for visual inspection or laboratory testing. There are several boring techniques like auger boring, rotary drilling, wash boring, percussion drilling, auger drilling, and test pits that are employed to collect disturbed and undisturbed samples of soils.

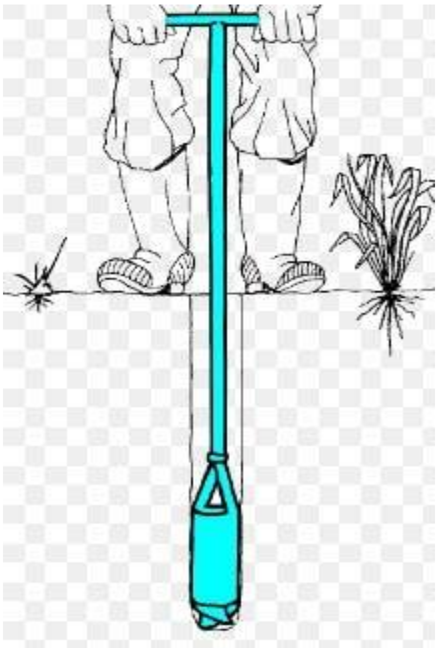
These boring methods are selected based on the soil types, the efficiency of boring technique, types of soil sample (disturbed or undisturbed), and the availability of facility and accuracy by which soil and groundwater variations can be determined.

Boring Methods for Soil Sampling

1. Auger Boring

It is a simple and cost-effective boring technique which can be used for almost all types of soil apart from gravelly soil and rocks. This technique encounters difficulty in gravelly soil and special drilling bits are needed for rocks.

Auger boring is used to collect disturbed soil specimen. It collects the soil sample from a maximum practical depth of nearly 35m based on the available time and equipment type.

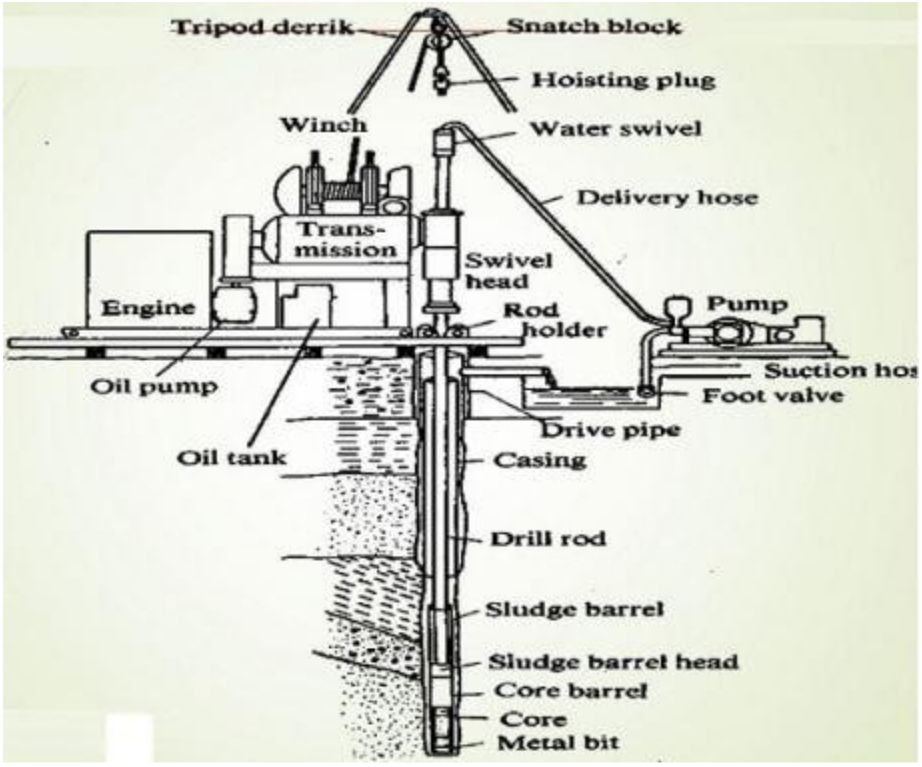


AUGER BORING

2. Rotary Drilling

Rotary drilling method of boring is suitable for all types of soil including rocks. It is used to take disturbed as well as undisturbed soil sample. So, it is specifically applicable for stiff soil layers. The practical depth of sampling is around 70m and greater depth based on the type of utilized equipment.

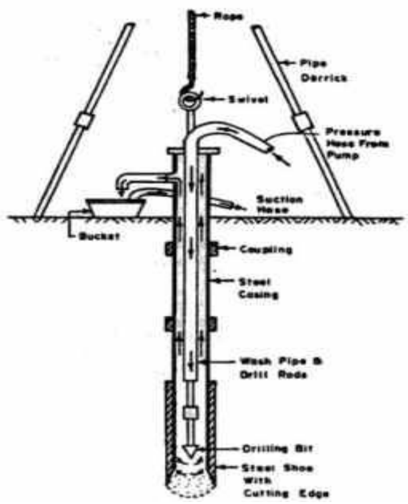
Generally, thin-walled tube samplers and various piston samplers are used to collect undisturbed soil specimen. The diameter of the undisturbed soil sample is around 100 mm and ranges from 150mm to 200mm for rocks.



Rotary boring

WASH BORING

Wash boring method is used to collect disturbed and undisturbed samples in almost all types of soils except rocks. In this technique, portable, cheap, and limited equipment is used which is an advantage of wash boring. Similar to rotary drilling, thin-walled tube samplers and piston samplers are used to recover undisturbed soil samples with minimum 50 mm diameter and maximum 100 mm diameter.



WASH BORING

4. Percussion Drilling

It is used for all types of soils and rocks including stiff soils and rocks. Percussion drilling is used to take disturbed and undisturbed specimen but the quality of undisturbed samples is not that good because of the heavy blows of the chisel.

Similar to rotary drilling and wash boring, the soil specimen can be taken from a depth of 70m and more based on the utilized equipment. The diameter of disturbed soil samples is about 100 mm and greater, and obtaining smaller diameter samples would be uneconomical.

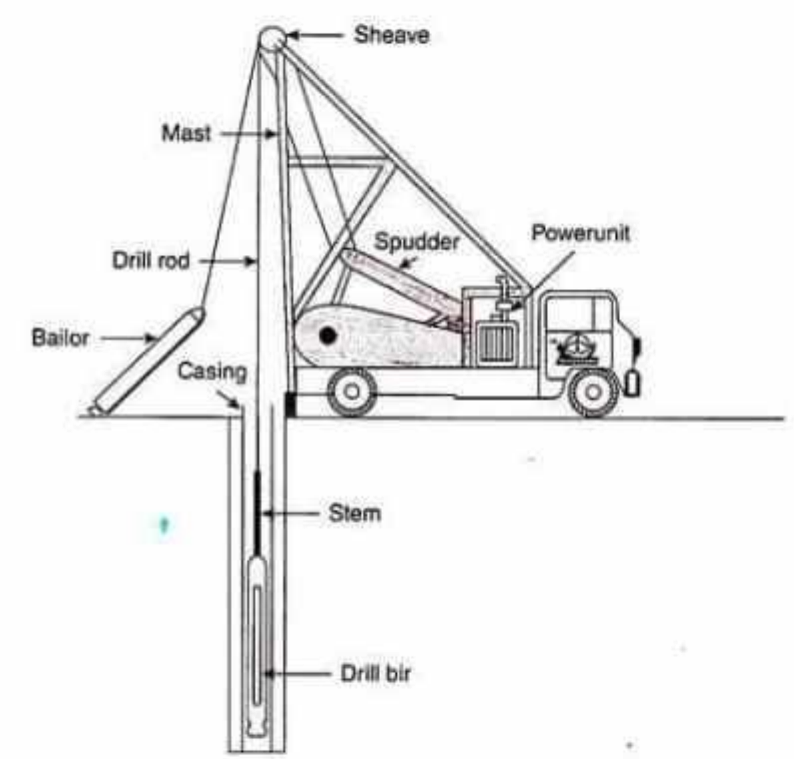


Fig. 4: Percussion Drilling

5. Test Pits and Open Cut

This type of soil sample collection technique is used for all kind of soils. It is used to take out disturbed and undisturbed soil samples from the earth with a maximum practical depth of 6m using power equipment. Samples are subsequently hand trimmed.

In-situ Soil testing

In-situ soil testing is necessary to obtain the soil property information, to measure groundwater pressure, to gather the moisture content and other important data points. In-situ soil testing can be accomplished in a variety of different ways. Every soil test has its own place and benefit. Following are the in-situ tests which are used to determine the soil properties:

oil samples and sampling for Boring Method of Soil Exploration

1. Disturbed sample

In disturbed sampling, the natural structures of soils get partly or fully modified or destroyed, although with suitable precaution the natural water content may be preserved. Disturbed sample can be obtained by direct excavations by auger and thick wall samplers.

2.Undisturbed sample

In undisturbed sample, the natural structure and properties remain preserved. These samples are used to tests for shear, consolidation and permeability.

3. Non-representative sample

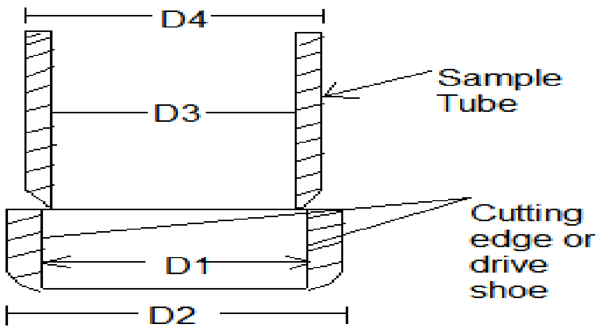
It consists of a mixture of soil from different soil strata. Size of the soil grains as well as the mineral constituents, might thus, have changed in such samples. Soil samples obtained from auger cuttings and settling in some well of wash borings, can be classified in this category. Such samples may help in determining the depths at which major changes may be occurring in subsurface soil strata.

Sample Disturbance

This depends on the design of samplers and methods of samplings.

Design factors governing the degree of disturbances:

i. **Cutting edge**: A typical cutting edge of a sampler is shown in the figure



The important design features of the cutting edge are a) Area ratio

$$A_r = \frac{D_2^2 - D_1^2}{D_1^2} \times 100$$

Where D1 and D2 are internal and external diameters of the cutting edge respectively. The area ratio should not exceed 25%. For soft sensitive soils, it should not exceed 10%. b) **Inside clearance**: It allows elastic expansion of sample when it enters the tube.

$$\text{Inside Clearance} = \frac{D_3 - D_1}{D_1} \times 100$$

Where D3= inside diameter of the sample tube. The inside clearance must lie between 1 to 10%, for undisturbed sample it should be between 0.5 and 3%. c) **Outside clearance**: It should not be much greater than the inside clearance. Normally it lies between 0 and 2 percent. It helps in reducing the

$$\text{Outside clearance} = \frac{D_2 - D_4}{D_4} \times 100$$

force required to withdraw the tube.
Where D4 is the external diameter of the sample tube.

ii. **Inside wall friction**: The walls of the sampler should be smooth and kept properly oiled.
iii. **Non-return valve**: The non-return valve should permit easy and quick escape of water and air when the sample is driven.

3. Subsurface Sounding Tests These tests are carried out to measure the resistance to penetration of a sampling spoon, a cone or other shaped tools under dynamic or static loading. These tests are used for exploration of erratic solid profiles for finding depth to bedrock or stratum and to get approximate indication of the strength and other properties of soil.

Standard Penetration Test(SPT)

SPT test for soil has been carried out inside the boreholes, which is generally 150mm diameter and at specified location as per IS:2131-1981 "Method of Standard Penetration Tests for soils". In the test mentioned above, a split spoon sampler is being used to collect the soil sample from the specified borehole. With the help of the standard penetration test(SPT), we can measure soil resistance.

Geotechnical Investigation Objectives and Guidelines

- First of all, the split spoon sampler holding on the bottom of the borehole is allowed to sink under its self-weight, then the sampler is seated with the help of a hammer blows falling through 750mm height.
- The driving arrangement consists of a driving head and a 63.50 kg weight.
- After that, a split spoon sampler is finally driven by 30cm. The number of blows required to drive every 15cm penetration is noted.
- The first 15cm of the drive is recognised as a seating drive, and the total blows needed for the second and third 15cm penetration is termed a penetration resistance, N value.

Site Preparations, SPT Test for Soil:

- Proper Safety barricading is to be provided before the start of activities.
- Arranging facilities for water and electricity supply before SPT test of soil.
- Arranging suitable working platforms where boring rigs have to operate on unstable ground.

- Inspection of all machinery and plant before start of SPT test for soil.
- The boring sites will be monitored by the SHE managers.
- The borehole locations shall be covered with adequate warning signs to avoid any accidents.
- **List of Major Equipment for SPT Test**:
- The following equipment will be used during the SPT test for soil and provided at each worksite
- The N-values for each borehole is given in bore logs data.
- Soil Investigation Assembly
- Split spoon sampler
- Shelby tube
- Sampler storage box

- Drop weight
- Casing pipe
- Guide rod
- Storage tank – 1 no.
- Drilling Mud Pump— 1 no

SPT Test Procedure:

In the first stage of the SPT test for soil, we have to penetrate the sampler by 15cm, and accordingly, we have to count the number of blows required to penetrate that soil sampler into the soil by 15cm.

Next stage, we have to penetrate that sampler into the soil again by 15cm.

Again, we have to penetrate the soil sampler into the soil by 15cm in the third stage. So, in three stages, a total of 45cm penetration is required.

We have to count and record the number of blows needed to penetrate 15cm separately in each stage of the SPT test for soil.

The First 15cm penetration number is generally ignored due to the existing disturbance at the bottom of the drill hole.

Furthermore, the summation of the following two stages penetration value, 30cm penetration, is designated as the standard penetration number for the SPT test of soil.

Corrections for SPT Test of Soil:

Hammer efficiency correction(N'70)

Overburden correction(CN)

Correction for hammer efficiency(n1)

Correction for drill rod length(n2)

Correction for the sampler(n3)

Correction for borehole diameter(n4)

Hammer Efficiency Correction:

SPT test for soil is standardized into some energy ratios. The energy ratio, expressed in percentage, is the ratio between the actual hammer energy to sampler and input energy.

Ultimately, the input energy will be the hammer's weight multiplied by free fall height.

So, if we know the hammer's weight and the height of free fall, we can determine that particular hammer's input energy.

This input energy may not be transferred to drive that soil sample into the test condition in the field.

So, we have to apply some corrections considering the standard energy ratio as 70. Now in the field, we generally express the N value as N'70(CN x N x n1x n2 x n3 x n4) after applying all the above corrections

Overburden Correction:

Overburden pressure plays a vital role in determining the SPT for the granular soil type.

The effective overburden pressure is less near the ground surface, and when we go into the deeper strata, the effective overburden pressure is very high.

So, there is some correction due to this less and more effective overburden pressure in different soil strata. The CN is the correction due to effective overburden pressure.

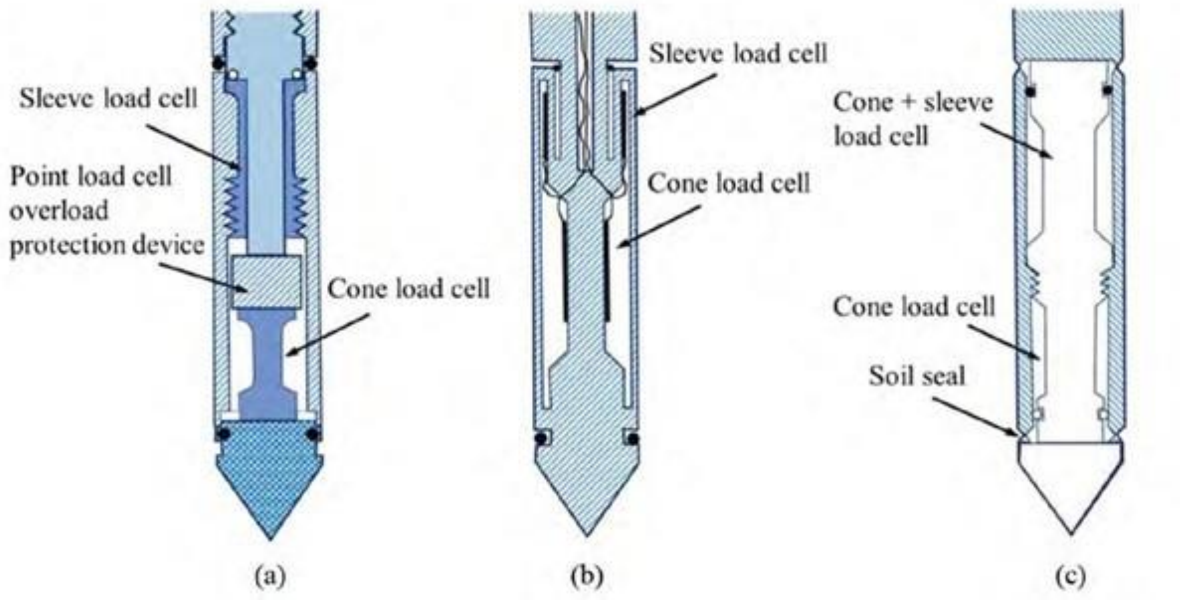
Introduction

In the Cone Penetration Test (CPT), a cone on the end of a series of rods is pushed into the ground at a constant rate and near-continuous measurements are made of the resistance to penetration of the cone and of a surface sleeve. Figure 2 illustrates the main terminology regarding cone penetrometers.

The total force acting on the cone, Q_c, divided by the projected area of the cone, A_c, produces the cone resistance, q_c. The total force acting on the friction sleeve, F_s, divided by the surface area of the friction sleeve, A_s, produces the sleeve resistance, f_s. In a *piezocone*, pore pressure is also measured, typically behind the cone in the u_2 location, as shown in Figure 2. If pore pressures are measured on the face of the cone, it is the u_1 location. Some cones can measure both u_1 and u_2 pore pressures simultaneously.

Cone Design

Penetrometers use strain gauge load cells to measure the resistance to penetration. Basic cone designs use either separate load cells or subtraction load cells to measure the tip resistance (q_c) and sleeve resistance (f_s). In subtraction cones the sleeve friction is derived by 'subtracting' the tip load from the tip + friction load. Figure 20 illustrates the general principle behind load cell designs using either separated load cells or subtraction load cells.



In the 1980's subtraction cones became popular because of improved overall robustness of the penetrometer. However, in soft soils, subtraction cone designs suffer from a lack of accuracy in the determination of sleeve resistance due primarily to variable zero load stability of the two load cells. In subtraction cone designs, different zero load errors for each load cell can produce cumulative errors in the derived sleeve resistance values. For accurate sleeve resistance measurements in soft sediments, it is recommended that cones have separate (compression) load cells.

With good design (separate load cells, equal end area friction sleeve) and quality control (zero load measurements, tolerances, and surface roughness) it is possible to obtain very repeatable tip and sleeve resistance measurements. However, f_s measurements, in general, will be less accurate than tip resistance, qc, especially in soft sensitive fine-grained soils, where the sleeve resistance values can be smaller than the accuracy of some cones (e.g., $f_s < 5$kPa). In soft soils, cones with smaller capacity (i.e., smaller FSO) can be used for improved accuracy.

Pore pressure (water) effects

Due to the inner geometry of the cone the ambient water pressure acts on the shoulder behind the cone and on the ends of the friction sleeve. This effect is often referred to as the unequal end area effect. Figure 21 illustrates the key features for water pressure acting behind the cone and on the end areas of the friction sleeve. In soft clays and silts and in over water work, the measured q_c must be corrected for pore water pressures acting on the cone geometry, thus obtaining the corrected cone resistance, q_t:

$$q_t = q_c + u_2 (1 - a)$$

Where 'a' is the net area ratio determined from laboratory calibration with a typical value between 0.70 and 0.85. In sandy soils $q_c = q_t$ due to higher values of q_c and smaller values of u_2.

A similar correction should be applied to the sleeve resistance.

$f_t = f_s - (u_2 A_{sb} - u_3 A_{st})/A_s$

where: f_s = measured sleeve resistance

u_2 = water pressure at base of sleeve

u_3 = water pressure at top of sleeve A_s = surface area of sleeve

A_{sb} = cross-section area of sleeve at base A_{st} = cross-sectional area of sleeve at top

However, most standards requires that cones have an equal end area friction sleeve (i.e., $A_{st} = A_{sb}$) that reduces the need for such a correction. For $15cm^2$ cones, where A_s is large compared to A_{sb} and A_{st}, (and $A_{st} = A_{sb}$) the correction is generally very small. All cones should have equal end area friction sleeves to minimize the effect of water pressure on the sleeve resistance measurements. Careful monitoring of the zero load readings is also required.

For deeper overwater CPTs, it is common to record the zero load readings at the mudline line (soil surface) since the effective stress at the mudline is always zero. For some shallow over water work the zero load readings are sometimes taken at the water surface. In this case, the cone will record readings through the water which can be helpful to identify when soil is encountered. In some cases, there can be a transition from heavy mud to a soil boundary. When interpreting overwater CPT data, it is importance to know where the zero load readings were made to ensure that the calculated effective stress is zero at the mudline.

In the offshore industry, where CPT can be carried out in very deep water (> 1,000m), cones are sometimes compensated (filled with oil) so that the pressure inside the cone is equal to the hydrostatic water pressure outside the cone. For compensated cones the correction for cone geometry to obtain q_t is slightly different than shown above, since the cone can automatically record zero q_c at the mudline.

The dynamic cone penetration test

is a test carried out to find the resistance value of the cone against the soil that helps us to determine different mechanical properties of soil such as strength, bearing capacity, and so on?

Principle

The basic principle of this test is to measure the resistance offered by the soil layers to the cone used for conducting the test.

Apparatus required for DCP test

- A cone (50 mm without bentonite slurry)
- Driving rods
- Driving head
- Hoisting equipment
- A hammer (made up of mild steel or cast-iron with a base plate of mild steel weighing 640N i.e. 65kg).

Procedure

1. The initial reading on the dynamic cone penetrometer is recorded.
2. Then, the dynamic cone penetrometer is kept with the cone resting vertically on the ground where the test is to be carried out.
3. Now, the cone is driven into the soil by the freefall of hammer of 750 mm each time.
4. Then the number of blow of every 10mm penetration is recorded.
5. This process is repeated until when the cone does not reach the required depth.

Observation Table

No. of blows	Cumulative no. of blows	Penetration depth (mm)
0	0	20 (say)
12	12	30
12	24	40
		And so on until required depth is reached

Calculation

Calculation of this test relies on correlations based on blow counts.

$CBR = 292/DPI^{1.12}$

$\log(DPI) = -1.05 + 2.03 * \log(SPT)$

where CBR = California Bearing Ratio

DPI = DCP penetration index = penetration depth per blow

SPT = Standard Penetration Test

- Now the penetration curve is made by placing DCP penetration (in mm) in Y-axis and no. of blows in X-axis.
- Also, for knowing the CBR variation with depth, a semi-log graph is plotted between depth of penetration in ordinary scale in X-axis and CBR value in log scale in Y-axis.

Advantages of Dynamic Cone Penetration Test

- This test does not need a borehole.
- This test can be performed quickly so that it covers a large area making it economical.

Disadvantages

- This test cannot be performed on cohesive soils or very loose cohesionless soil.
- It is not possible to determine the mechanical properties of soil by this test if the soil is at a great depth and friction along the extension rod is significant.

Factors affecting DCP test

There is a various factor which affects this test such as:

- Alignment of DCP rods
- Damaged cone tip
- Depth of testing
- The apex angle of the cone
- Hammer weight
- Freefall height of hammer
- Moisture content
- Material composition
- Intensity of compaction

Precaution

1. The reading should be taken numbers of time to reduce the error.
2. During freefall of hammer, it should be raised to a standard height otherwise the penetration value will decrease.
3. DCP test should not be done during monsoon because it will decrease the strength of the soil and test result will not be accurate.

Geo-Physical Method of Soil Exploration

Geo-physical methods are used when soil exploration is to be carried out over large area and where speed is of prime importance. These soil exploration methods are based on principle that physical properties like electrical conductivity, elasticity or seismicity, magnetic susceptibility, density etc. vary for different types of soils. There are four soil exploration methods of geo physical survey, namely, (1) Seismic refraction method (it) Electrical resistivity method, (iit Magnetic method and (ivy Gravitational method. However, out of these only two methods namely (1) Seismic refraction method and (ii) Electrical resistivity method are widely used.

(i) Seismic Refraction Method:

This soil exploration method is based on the principle that sound waves travel faster in rock than in soil. This is on account of the fact that velocity of sound waves is different in different media. In this method shock waves (or sound waves of vibration) are created into the soil at ground level or at a certain depth below it, either by striking a plate on the soil with the hammer or by exploding small charge in the soil. The shock waves so produced travel down in the sub-soil strata and get refracted after striking a hard rock surface below. The refracted or radiated shock waves are picked up by the vibration detector (also known as geophone) where the time of travel of the shock waves gets recorded. Knowing the time of travel of the primary and refracted waves at various geophones, tune and distance graphs are drawn based on which it is possible to evaluate the depth of various strata in the sub-soil. Different materials such as clay, gravel, silt rock, hard rock etc. have characteristics seismic velocities and hence it is possible to establish their identity in the sub-soil based on time distance graph.

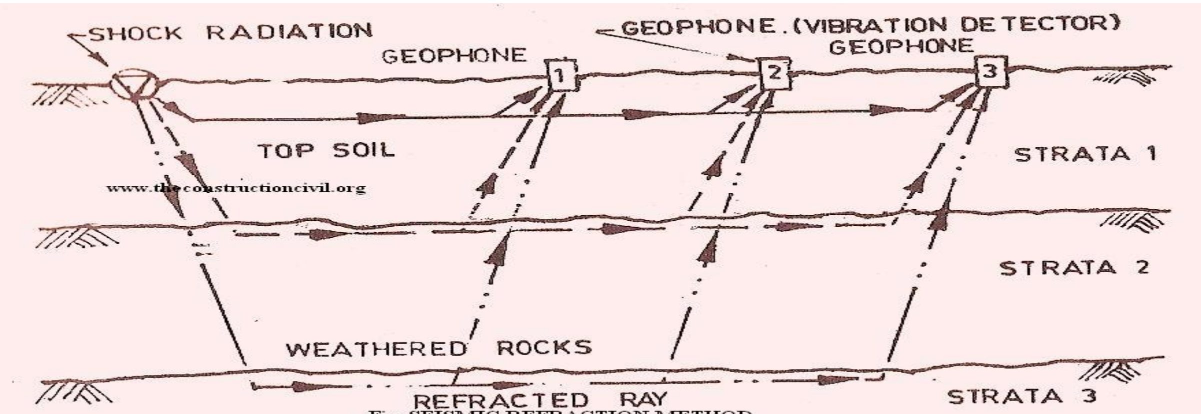


Fig. SEISMIC REFRACTION METHOD

(ii) Electrical Resistivity Method:

This soil exploration method is based on the principle that each soil has different electrical resistivity, depending upon the type of soil, its water content, compaction and composition. Thus saturated soil has lower electrical resistivity as compared to loose dry gravel or solid rock. In this method 4 electrodes are driven in the ground at equal distance apart and in a straight line. The distance between two electrodes being the depth of exploration or depth up to which the ground resistance is to be measured. A current is passed between the two outer electrodes and the potential drop between the inner electrodes is measured by use of potentiometer.

The mean resistivity is calculated by the following formula:

$P = 2\pi D (E/I)$

Where,

P = mean resistivity (ohm.cm)

D = distance between electrodes (cm)

E =potential drop between inner electrodes (volts)

I = current flowing between outer electrodes (amperes)

Average value of resistivity for various types of soils have already been established based on tests. Thus on knowing the values of change in mean resistivity of sub-soil strata at site, it is possible to establish the nature and distribution of different type of soils in the formation.