1.5 Penetration Test:

Standard Penetration Test (SPT):

Standard penetration test (SPT) is the most commonly used in situ test for sub-surface investigation. In SPT a split spoon sampler is made to penetrate 15 cm by light blows of a 65 kgs drop hammer on the top of the drill rod. The drill rod is connected to the top of the split spoon sampler.

After initial penetration of 15 cm of the sampler, the drop hammer is allowed to fall from a height of 75 cm and number of blows required for 30 cms penetration of sampler is recorded. This number of blows is called N-value or penetration number. In this method the driving energy is supplied by the fail of the drop weight. Hence it is essentially a dynamic sounding method.

Detailed procedure of SPT is as follows:

Apparatus required:

(i) Split spoon sampler:

It has an outside diameter of 50 mm, inside diameter of 35 mm and minimum open length (cutting edge to air vent) of 600 mm. The coupling head has four 10 mm (minimum diameter) vent ports or a ball check value.

(ii) Drive assembly:

It consists of a tripod as hoisting equipment-one of the leg is provided with ladder, a drive mass (hammer) of 65 kgs, a guide to ensure a 75 cm free fall of the drivemass and an anvil (attached to the guide) for transmitting the blow to the sampler rod.

In general practice four methods of releasing the hammer are used:

(a) Normal lifting and releasing of the rope passing through a pulley.

(b) A trip hammer, such as the Pilcon or Dando hammers

(iii) Extension rods:

These rods are used to transmit the driving energy from the anvil to the sampler.

(iv) Drilling equipment:

Drilling equipment should be for making a reasonably clear hole of 60-75 mm diameter so as to ensure that the test is performed in undisturbed soil and not in the fall in material. Casing or drilling mud may have to be used where the boring sides fall in.

In general, hand operated auger of 75 mm diameter are used for drilling boreholes.

Procedure:

(1) A borehole is drilled to the required depth and is cleaned thoroughly.

(2) The sampler attached to the extension rods is lowered to the bottom of the hole and is allowed to rest under the self weight.

(3) The drive assembly is then connected to the rod and the sampler is driven with light blows from the drive mass to a seating penetration of 15 cm.

(4) The sampler is then driven to an additional penetration of 30 cm by blows from 65 kgs drive mass falling from a height of 75 cm. The number of blows required for 30 cm penetration is recorded as standard penetration resistance, N.

(5) The sampler is then lifted from the hole and opened. The undisturbed sample is removed from the sampler and sealed from both sides.

(6) The test is performed in each identifiable soil layer or at a interval of 1.5 m whichever is smaller. As per IS:2131, for a foundation of width B, penetration test has to be carried out at an interval of 0.75 m up to a depth of B from the bottom of the footing and at 1.5 m interval for the rest depth up to a depth of 1.5 to 2 B.

(7) The measured N-value may indicate more than the actual value in some cases and so they are to be corrected.

The standard penetration resistance i.e., N-value has been correlated to different soil properties by different investigators.

Some of the correlation is given in the following tables:

a)Dilatancy Correction.

Silty fine sands and fine sands below the water table develop pore pressure which is not easily dissipated. The pore pressure increases the resistance of the soil and hence the Penetration number (N).Terzaghi and peck recommend the following correction when the observed N value exceeds 15. The corrected Penetration Number,

$Nc = 15 + \frac{1}{2} [N_R - 15]$

Where,

Nc – corrected value

N_R – Recorded Value

If $N_R \leq 15$, then $Nc = N_R$

b)Over burden Pressure Correction:

In granular soils, the overburden pressure affects the penetration resistance. Generally, the soil with high confining pressure gives higher penetration number. As the confining pressure in cohesion soil increases with depth, the penetration number for the soils at shallow depths is under estimated and that at greater depths is over estimated for uniformity, the N values obtained from field tests under different effectiveoverburden pressure are corrected to a standard effective overburden pressure.

For dry or moist clean sand, (Gibbs and Holtz)

$$N_c = N_R x \frac{350}{\bar{\sigma}_0 + 70}$$

Where, Nc - corrected value

NR - Recorded Value

$\bar{\sigma}_0$ - effective over burden pressure

It is applicable for $\bar{\sigma}_0 \leq$ 280kN/m2. Usually the overburden correction is applied first and then dilatancy correction is applied first and then dilatancy correction is applied.

The correction given by Bazara& peck is

$N = 4N_R$ if $\bar{\sigma}_0 <$ 71.8 kN/m2 1+ 0.0418$\bar{\sigma}_0$

$N = 4N_R$ if $\bar{\sigma}_0 >$ 71.8 kN/m2 3.25+ 0.0104$\bar{\sigma}_0$

$N = N_R$ if $\bar{\sigma}_0 =$ 71.8 kN/m^2

For cohesive soil:

Table 1 Relation between N and q_u

Penetration resistance N(blows)	**Unconfined compressive strength (t/m^2) q_u**	**Consistency**
<2	<2.4	Very soft
2-4	2.4-4.8	Soft
4-8	4.8-9.6	Medium
8-15	9.6-19.2	Stiff
15-30	19.2-38.8	Very Stiff
>30	>38.8	Hard

(From terzaghi and peck ,1948)

The relationship between q_u and N proposed by murthy1982

$$q_u = \frac{N}{7.5} Kg/cm^2$$

Sanglerat(1972) has proposed the following relationship between q_u and N

$$For\ clay\ ,\ q_u = \frac{N}{4} Kg/cm^2$$

$$For\ silty\ clay\ ,\ q_u = \frac{N}{5} Kg/cm^2$$

For cohesionless Soil:

Table 1 Relation between N and angle of shear resistance (φ)

Corrected N value	5	10	15	20	25	30	35	40	45	50
φ(degree)	28.5	30	32	33	35	36	37.5	39	40	41

(peck el at,1974)

N value	Density Index(%)	Degree of compaction
<4	0-15	Very loose
4-10	15-35	Loose
10-30	35-65	Medium
30-50	65-85	Dense

(Mitchell and Katti,1981)

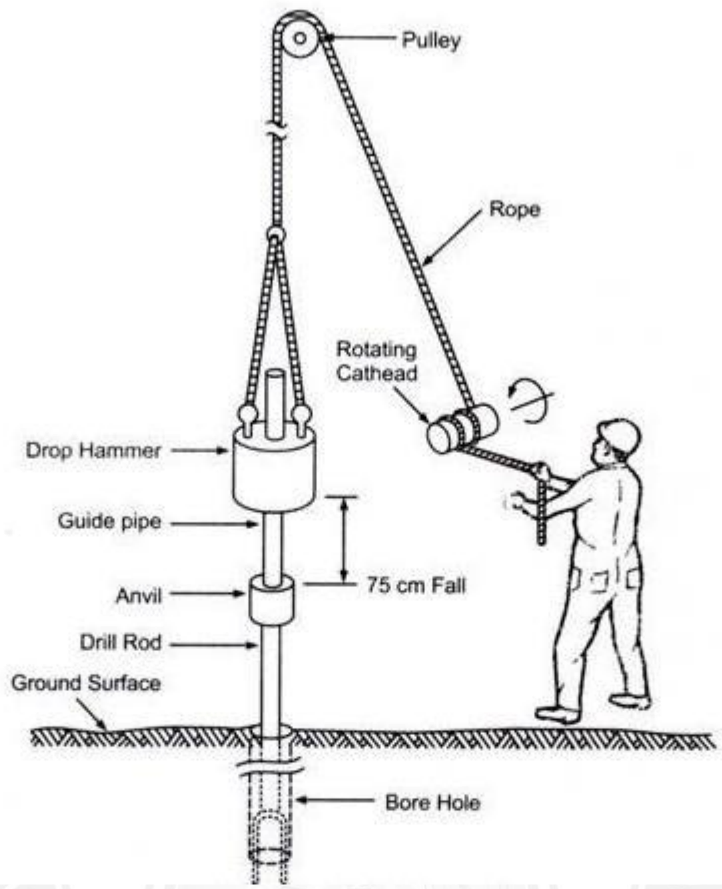


Fig 1 SPT

[Fig1https://www.researchgate.net/figure/Standard-Penetration-TestArrangements_fig 3_280572148]

Effect of Submergence:

Terzaghi and Peck (1948) recommended that where the soil consists of very fine or silty sand below the water table, the measured N-value, if greater than 15, should be corrected for increased resistance due to excess pore water pressure set up during driving and unable to dissipate immediately. The corrected value of N, Nc is given by

$$N_c = 15 + I/2\ (N-15)$$

where, both the overburden and submergence corrections are necessary, the overburden correction is applied first.

Effect of Rod Length:

Wave equation studies (Schmertman and Palacios, 1979) indicate that the theoretical maximum ratio decreases with decreasing rod length below a rod length of 10 m. The weight or stiffness of the rod stem, of a given length, appears to have little effect (Brown, 1977; Matsumo to and Matsubara, 1982).

Effect of Borehole Diameter:

In its original form the SPT was carried out from the bottom of 62.5 mm or 100 mm diameter wash borings (Skempton, 1986). The best modern practice still adheres to this dimension. In many countries 150 mm test boreholes are common and even 200 mm bore holes are permitted (Nixon, 1982). The effect of testing from relatively large bore holes in cohesive soils is probably negligible but in sands there is indication that appreciable lower N- values may results (Lake, 1974; Sanglerat and sanglerat, 1982). The minimum correction factors to allow for the effect of testing over large boreholes is suggested (Skempton, 1986) as given in Table 10.7.

Description	Correction factors
Rod Length	
10metres	1.00
6-10 metres	0.95
4-6 metres	0.85
3-4 metres	0.75
Standard Sampler	1.00
Us sampler without Lines	1.20
Bore hole Diameter	
65-115mm	1.00
150mm	1.05
200mm	1.15

Table 2.Approximate correction factor to measured N(after skempton1986)

Static Cone Penetration Test (CPT):

The static cone penetration test is normally called as the cone penetration test (CPT). CPT is a direct sounding test which gives a continuous record of variation of penetration resistance with depth. No sample is obtained from this test. A cone is used which has an apex angle of 60° and overall base diameter of 35.7 mm giving a cross-sectional area of 10 cm^2.

It is made of steel and tip hardened. The cone is attached to the lower end of a 15 mm diameter steel sounding rod passing through a steel mantle tube of uniform or non-uniform diameter. The external diameter of mantle tube is equal to the cone diameter. The cone is pushed into the ground manually or by using hydraulically operated driving mechanism. For obtaining cone resistance qc, the cone alone is pushed vertically at the rate of 2 cm/s through a depth of 4 cm each time.

The pressure required for pushing is recorded as q_c. The outer mantle tube is then pushed down to the level of cone. The resistance due to friction on the mantle tube is then measured separately. The cone resistance variation with depth is then plotted to identify the different strata.

In recent year, the static cone penetrometer had been modified to incorporate Piezo cone. Piezoncone penetrometer gives simultaneous measurement of cone resistance, side friction and the pore water pressure as the cone is advanced in the soil. Piezocone penetrometer (CPTU) gives a more reliable determination of stratification and soil type than a standard CPT.

The CPT has three main applications:

1. To determine subsurface stratification and identify materials present.
2. To estimate geotechnical parameters.
3. To provide results for direct geotechnical design.

For fine grained soil as clay, the preliminary untrained shear strength (Cu) can be estimated from:

$$Cu = q_c/N_k$$

where

qc = measured cone resistance

N_k = 17 to 18 for normally consolidated clays or,

20 for over consolidated clays.

Table 10.8: Correlation between cone penetration test and SPT

S.No	Soil Type	$q_u/N(q_u$ in Kg/cm$^2)$
1	Silts, Sandy silts, slightly ,cohesive ,silt sand mixtures	2
2	Clean,fine to medium sands and slightly silty sands	3-4
3	Coarse sands and sands with little gravel	5
4	Sandy gravels and gravels	6

Dynamic Cone Penetration Test (Dcpt):

DCPT is similar to SPT as the use, except that there is no borehole for DCPT. This test is done by driving a standard 60° cone attached to a string of drill rods into thesoil by blows of 65 kgs hammer falling from a height of 75 cm. The number of blows for every 30 cm penetration of the cone is recorded.

The number of blows required for 30 cm of penetration of cone is referred as cone resistances, N_c

DCPT is performed in two ways:

(i) Using 50 mm cone without benetonite slurry (IS-4968, part I)

(ii) Using 62.5 mm cone with bentonite slurry (IS-4968, part II)

For a 50 mm diameter cone without bentonite slurry, the cone is fitted to the driving rod (A-rod). The hammer head is joined to the other end of the A-rod with a A- rod coupling and a guide rod 150 cm long is connected to the hammer head. This assembly is kept vertical with the cone resting vertically on the ground at the point to betested. The cone is then driven by the drop of the hammer and the driving is continued till the cone reaches the required depth.

For 62.5 mm cone with bentonite slurry, the setup should have arrangements for circulating slurry so that the friction on the driving rod is eliminated.

The Nc value of DCPT and N-value of SPT can be compared and an approximate correlation can be established for the site. With the help of these correlations, the data from DCPT at other locations can be deduced to know to the value of N. This type of work is adequate for small structures and is useful in the preliminary exploration for extensive sites.

Geophysical Method:

(i) SESMIC REFRACTION METHOD

General:

This method is based on the fact that seismic waves have different velocities in different types of soils and besides the wave refract when they cross boundaries between different types of soils. In this method an artificial impulse are produced either by detonation of explosive or mechanical blow with a heavy hammer at ground surface or at the shadow depth within a hole.

These shocks generate three types of waves.

- Longitudinal or compressive wave or primary (p) wave
- Transverse or shear waves or secondary (s) waves
- Surface waves

It is primarily the velocity of longitudinal or the compression waves which is utilized in this method. The equation on the p-waves (Vc) and s-waves (Vs) is given as

$$V_c = \sqrt{\frac{E(1-\mu)}{(1+\mu)(1-2\mu)\rho}}$$

$$V_s = \sqrt{\frac{E}{2\rho(1+\mu)}}$$

Where E is the dynamic modulus of the soil μ is the Poisson‟s ratio

ρ is density

G is the dynamic shear modulus

These waves are classified as direct, reflected and refracted waves. The direct waves travel in approximately straight line from the source of impulse. The reflected and refracted wave undergoes a change in direction when they encounter a boundary separating media of different seismic velocities. This method is more suited to the shallow explorations for civil engineering purpose. The time required for the impulse to travel from the shot point to various points on the ground surface is determined by means of geophones which transform the vibrations into electrical currents and transmit them to a recording unit or oscillograph, with a timing mechanism.

Assumptions

The various assumptions involved are

- All the soil layers are horizontal
- The layers are sufficiently thick to produce a response
- Each layer is homogeneous and isotropic
- Velocity should increase with depth following the Snell‟s law as given

i_1 is the angle of incidence

i_2 is the angle of refraction

v_1 and v_2 are velocity in two different mediums

Procedure

The detectors are generally placed at varying distance from the shot point but along the straight line. The arrival time of the first impulse at each geophone is utilized. If the successfully deeper strata transmit the waves with increasingly greater velocities the path travelled by the first impulse will be similar to those. Those recorded by the nearest recorders pass entirely through the overburden, whereas those first reaching the after detectors travel downward through the lower velocity material, horizontally withinthe higher velocity stratum and return to the surface.

(A T_1 and A T_2) as the function of the distances between the geophones and the shot points (L_1 and L_2). A curve obtained which indicates the wave velocity in each stratum and which may be used to determine the depths to the boundaries between the strata.Where H_1 and H_2 are the depths of the strata

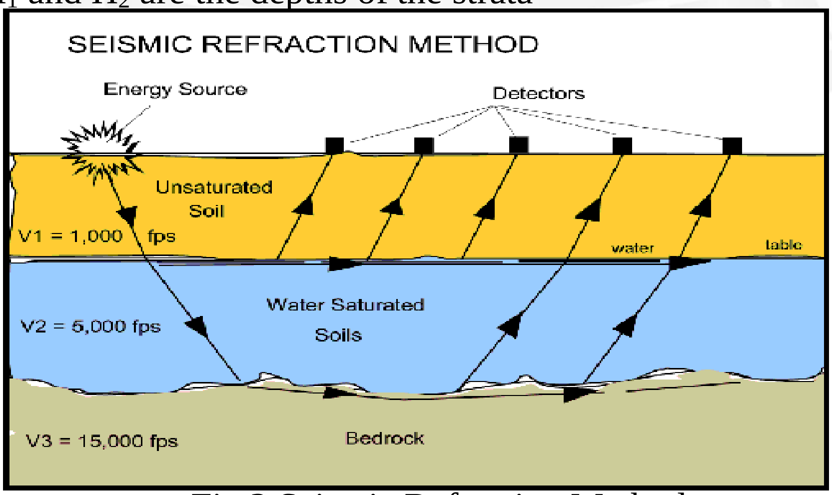
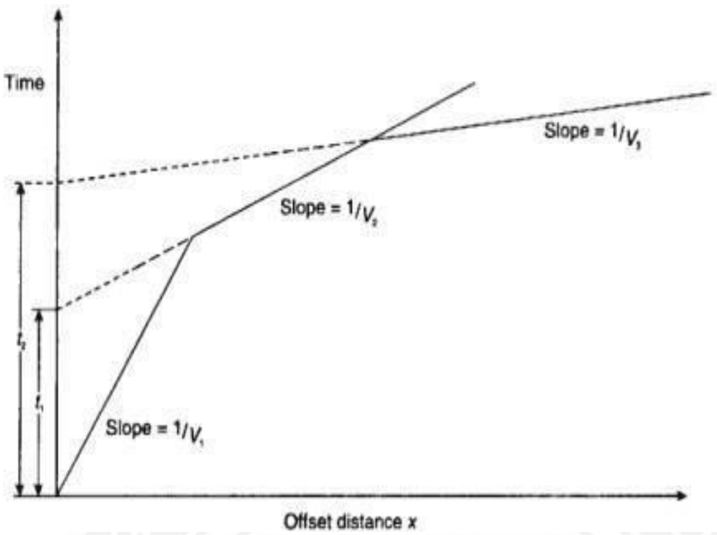


Fig 2 Seismic Refraction Method

[Fig 2 https://www.sumoservices.com/seismic-refraction-case-study]



$$H_1 = \frac{l_1 V_1}{2cos\alpha} = \frac{L_1}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

$$H_2 = \frac{l_2 V_2}{2cos\beta} = 0.85 H_1 + \frac{L_2 - L_1}{2}\sqrt{\frac{V_3 - V_2}{V_3 + V_2}}$$

Where H_1 and H_2 are the depths of the strata

$l_1 = AB_1$

$l_2 = AC_1 - AB_1$

sin α= $(V_1 – V_2)$ sin β=(V_2/V_3)

Applications

- Depth and characterization of the bed rock surfaces.
- Buried channel location.
- Depth of the water table.
- Depth and continuity of stratigraphy interfaces.
- Mapping of faults and other structural features.

Advantages

- Complete picture of stratification of layer up to 10 m depth.

- Refraction observations generally employ fewer source and receiver location and thus relatively cheap to acquire.

- Little processing is done on refraction observations with the exception of trace scaling or filtering to help in the process of picking the arrival times of the initial ground motion.
- Because such a small portion of the recorded ground motion is used developing models and interpretations is no more difficult than our previous efforts with other geophysical surveys.
- Provides seismic velocity information for estimating material properties.
- Provides greater vertical resolution than electrical, magnetic or gravity methods.
- Data acquisition requires very limited intrusive activity is non- destructive.

Disadvantages

- Blind zone effect: If $v2 < v1$, then wave refracts more towards normal then the thickness of the strata is neglected.
- Error also introduced due to some dissipation of the velocity as longer the path of travel, geophone receives the erroneous readings.
- Error lies in all assumptions.

(ii) ELECTRICAL RESISTIVITY METHOD

Electrical resistivity method is based on the difference in the electrical conductivity or electrical resistivity of different soils. Resistivity is defined as the resistance in ohms between opposite phases of a unit cube of a material.

$$\rho = RA/L$$

ρ is resistivity in ohm-cm R is resistance in ohms

A is the cross sectional area (cm2)

L is the length of the conduction (cm)

Procedure:

In this method the electrodes and driven approximately 20 cms in to the ground and a dc or a very low frequency ac current of known magnitude is passed between the outer electrodes thereby producing within the soil an electrical field and the boundary conditions. The electrical potential at point C is Vc and at the point D is Vd which is measured by means of the inner electrodes respectively.

$$\rho = \frac{2\pi R r_1}{I}$$

Where,

Resistances $R = V_{CD}/I$

Thus the apparent resistivity of the soil to the depth approximately equal to the spacing r1 of the electrode can be computed. The resistivity unit is often so designed that the apparent resistivity can be read directly on the potentiometer.

In resistivity mapping or transverse profiling the electrodes are moved from place to place without changing their spacing and the apparent resistivity and any anomalies within a depth a depth equal to the spacing of the electrodes can thereby be determined for a number of points.

In resistivity sounding or depth profiling the center point of the set up is stationary whereas the spacing of the electrode is varied. A detailed evaluation of the results of the resistivity sounding is rather complicated, but preliminary indications of the subsurface conditions may be obtained by plotting the apparent resistivity as a function of electrode spacing. When the electrode spacing reaches a value equal to the depth to a deposit with a resistivity materially different from that of overlying strata, theresultant diagram will generally show a more or less pronounced break in the strata depth beyond A_2 .

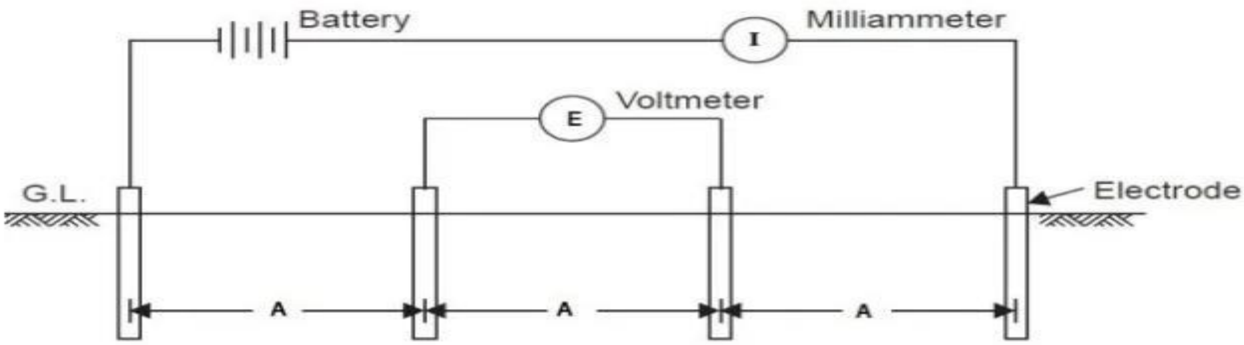


Fig 3 Electrical resistivity Method

[Fig 3 https://civilblog.org/2015/04/18/electrical-resistivity-test-of-soil-geophysical-method-of-soil-exploration/]

For simple sounding a Wenner array is used. Then the resistivity is given as

$$\rho = \frac{2\pi Ra}{I}$$

Where a is the spacing between the electrodes.

Applications

- Characterize subsurface hydrogeology.
- Determine depth to bedrock /over burden thickness.
- Determine depth to ground water.
- Map stratigraphy.
- Map clay aquitards.
- Map salt water intrusion.
- Map vertical extent of certain types of soil and ground water contamination.

Resistivity profiling

- Map faults.
- Map lateral extent of conductive contaminant process.
- Locate voids.
- Map heavy metals soil contamination.
- Delineate disposal areas.
- Map paleochannels.
- Explore for sand and gravels.
- Map archaeological sites.

Advantages of this method are

- It is very rapid and economical method.
- It is good up to 30 m depth.
- The instrumentation of this method is very simple.
- It is a non destructive method.

Disadvantages

- It can only detect absolutely different strata like rock and water.
- It provides no information about the sample.
- Cultural problems cause interference.
- Data acquisition can be slow compared to other geophysical methods, although

that difference is disappearing with the very latest techniques.