Objectives

In this section you will learn the following

- General Overview
- Different methods of geophysical explorations
- Electrical resistivity method
- Seismic refraction method

5 Geophysical exploration

General Overview

Geophysical exploration may be used with advantage to locate boundaries between different elements of the subsoil as these procedures are based on the fact that the gravitational, magnetic, electrical, radioactive or elastic properties of the different elements of the subsoil may be different. Differences in the gravitational, magnetic and radioactive properties of deposits near the surface of the earth are seldom large enough to permit the use of these properties in exploration work for civil engineering projects. However, the resistivity method based on the electrical properties and the seismic refraction method based on the elastic properties of the deposits have been used widely in large civil engineering projects.

Different methods of geophysical explorations

1 Electrical resistivity method

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

$$\rho = \left(\frac{RA}{L}\right)$$

ρ is resistivity in ohm-cm,

R is resistance in ohms,

A is the cross sectional area (cm ^{2}),

L is length of the conductor (cm).

The resistivity values of the different soils are listed in table 1.4

Material	Resistivity (Ω -cm)
Massive rock	> 400
Shale and clay	1.0
Seawater	0.3
Wet to moist clayey soils	1.5 - 3.0

Table 1.4 : Resistivity of different materials

Procedure

The set up for the test is given in figure 1.13. In this method, the electrodes are driven approximately 20cms in to the ground and a dc or a very low frequency ac current of known magnitude is passed between the outer (current) electrodes, thereby producing within the soil an electrical field and the boundary conditions. The electrical potential at point C is V_c and at point D is V_d which is measured by means of the inner (potential) electrodes respectively.

$$V_c = \frac{I\rho}{2\Pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \qquad \text{---------(1.1.1)}$$

$$V_D = \frac{I\rho}{2\Pi}\left(\frac{1}{r_3} - \frac{1}{r_4}\right) \qquad \text{---------(1.1.2)}$$

where,

ρ is resistivity,

I is current,

r_1 , r_2 , r_3 and r_4 are the distances between the various electrodes as shown in fig. 1.13.

Potential difference between C and D = V_{CD} = V_C - V_D =

$$\frac{I\rho}{2\Pi}\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right] \qquad \text{--------- (1.1.3)}$$

$$\rho=\frac{2\Pi V_{CD}}{I}\left[\frac{1}{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)}\right] \qquad \text{--------- (1.1.4)}$$

If $r_1 = r_4 = (r_2/2) = (r_3/2)$ then resistivity is given as,

$$\rho=\frac{2\Pi R r_1}{I} \qquad \text{---------(1.1.5)}$$

where ,

Resistance $R=(V_{CD}/I)$

Thus, the apparent resistivity of the soil to a depth approximately equal to the spacing r_1 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 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, as shown in fig.1.14. 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 the 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, the resultant diagram will generally show a more or less pronounced break or change in curvature as shown in fig. 1.15. As the slope of the line varies at A_2 , this indicates that there is change in the strata beyond depth A_2 .

In practice, many several different arrays are used. For simple sounding, a *Wenner array* is used as shown in fig. 1.16. Then, the resistivity is given as,

$$\rho = \frac{2\Pi Ra}{I} \qquad \text{--------(1.1.6)}$$

where,

a is the spacing between the electrodes.

The *Schlumberger array* is used for profiling and sounding as shown in fig. 1.17. In a sounding configuration, the current electrodes separated by *AB* are symmetric about the potential electrodes *MN* . The current electrodes are then expanded, and the resisitivity can be given as,

$$\rho = \frac{\Pi(s^2 - a^2/4)R}{a} \text{ (Refer fig. 1.17)} \qquad \text{--------(1.1.7)}$$

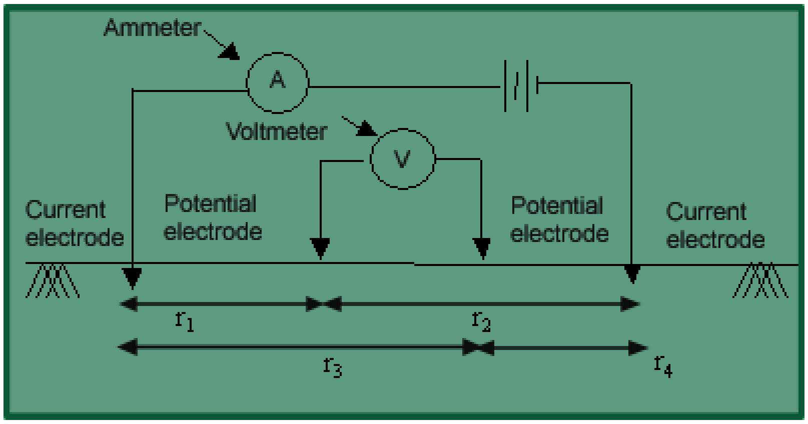


Fig.1.13 Test set up for electrical resistivity method

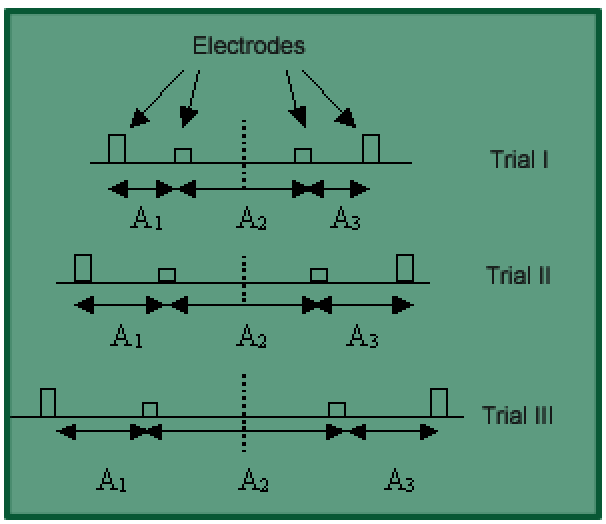


Fig 1.14 Resistivity Sounding

Fig. 1.15 Graph of Resistivity (ρ) vs distance between the electrodes (A) for different trials

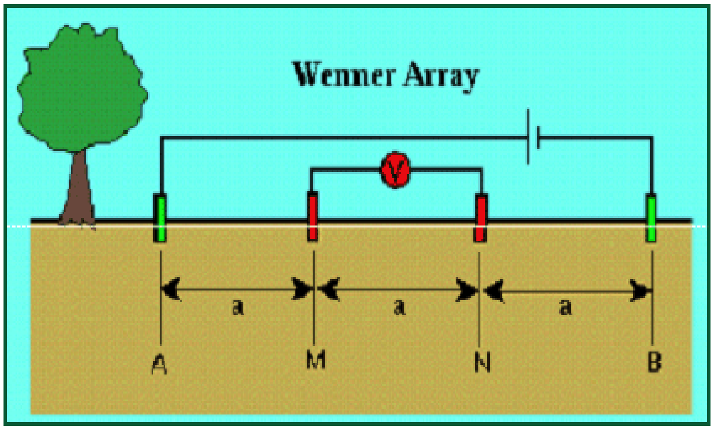


Fig. 1.16 Wenner arrangement

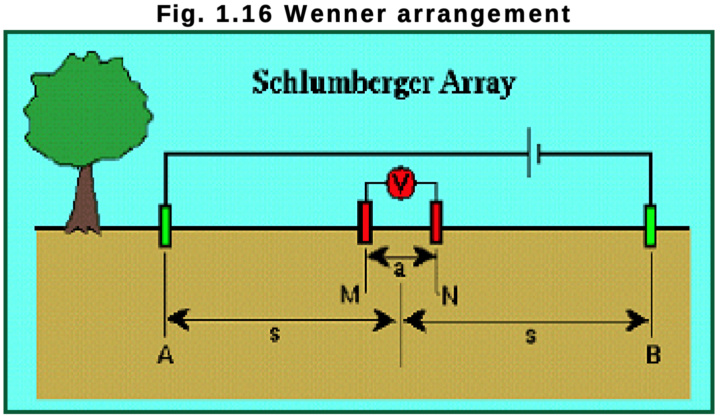


Fig. 1.17 Schlumberger array

Application

Applications of resistivity soundings are:

- Characterize subsurface hydrogeology
- Determine depth to bedrock/overburden thickness
- Determine depth to groundwater
- Map stratigraphy
- Map clay aquitards
- Map salt-water intrusion
- Map vertical extent of certain types of soil and groundwater contamination
- Estimate landfill thickness

Resistivity profiling is used to:

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

Advantages of this method are:

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

Disadvantages of this method are:

- It can only detect absolutely different strata like rock and water.
- It provides no information about the sample.
- Cultural problems cause interference, e.g., power lines, pipelines, buried casings, fences.
- Data acquisition can be slow compared to other geophysical methods, although that difference is disappearing with the very latest techniques.

2 Seismic refraction method

General

This method is based on the fact that seismic waves have different velocities in different types of soils (or rock) 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 shallow 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) wave,
- Surface waves.

It is primarily the velocity of longitudinal or the compression waves which is utilized in this method. The equation for the velocity of the p-waves (V_c) and s-waves (V_s) is given as,

$$V_c = \sqrt{\frac{E(1-\mu)}{(1+\mu)(1-2\mu)\rho}} \qquad \text{------- (1.2.1)}$$

$$V_s = \sqrt{\frac{E}{2\rho(1+\mu)}} \qquad \text{------- (1.2.2)}$$

Where,

E is the dynamic modulus of the soil,

μ is the Poisson's ratio,

ρ is density and,

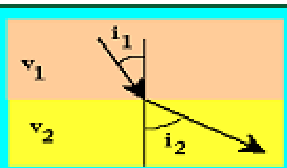
G is the dynamic shear modulus.

These waves are classified as direct, reflected and refracted waves. The direct wave 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 (Refer fig. 1.19). 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, equipped with a timing mechanism.

Assumptions

The various assumptions involved are:

- All soil layers are horizontal.
- The layer is sufficiently thick to produce a response.
- Each layer is homogeneous and isotropic.
- Velocity should increase with depth, following the Snell's law as given in fig. 1.18.



$$\frac{\sin i_1}{v_1} = \frac{\sin i_2}{v_2}$$

Fig. 1.18 Snell's law

i_1 is the angle of incidence,

i_2 is the angle of refraction,

v_1 and v_2 are the velocity in two different mediums.

The assumption made is v_2 > v_1.

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 traveled by the first impulse will be similar to those shown in fig. 1.19. Those recorded by the nearest recorders pass entirely through the overburden, whereas those first reaching the farther detectors travel downward through the lower- velocity material, horizontally within the higher velocity stratum, and return to the surface as shown in the fig. 1.19.. By plotting the travel times

(AT_1 and AT_2) as a function of the distances between the geophones and the shot points (L_1 and L_2) as shown in fig. 1.20, a curve is obtained which indicates the wave velocity in each stratum and which may be used to determine the depths to the boundaries between the strata.

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

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

Where,

H_1 and H_2 are the depths of the strata,

$l_1 = AB_1$,

$l_2 = AC_1 - AB_1$,

Sin $\alpha = (V_1 - V_2)$

Sin $\beta = (V_2 / V_3)$

(Refer figs. 1.19 and 1.20)

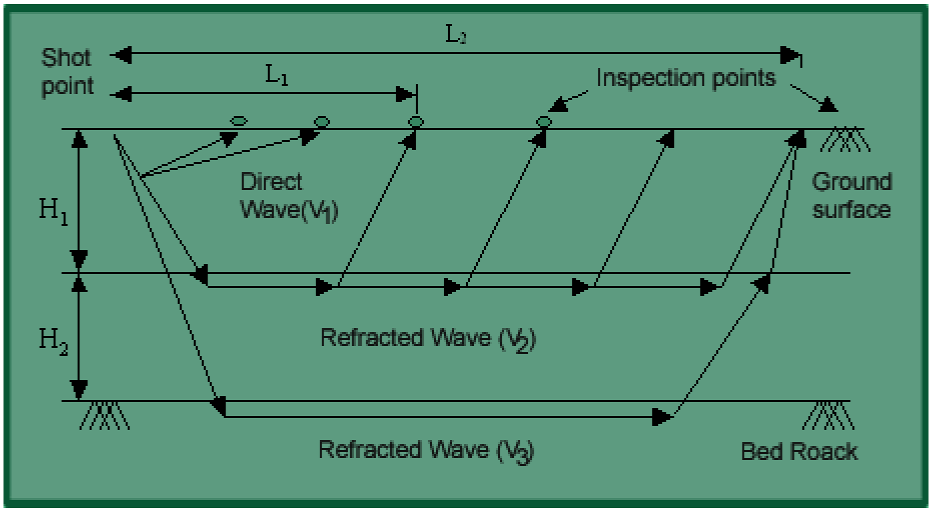


Fig. 1.19 Seismic refraction method

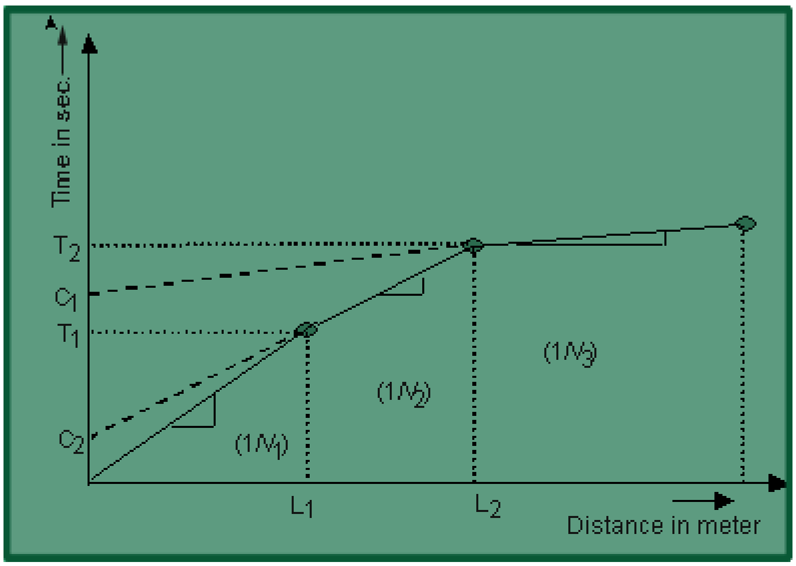


Fig. 1.20 Graph of Time vs Distance

Applications

- The various applications are:
- Depth and characterization of the bed rock surfaces,
- Buried channel location,
- Depth of the water table,
- Depth and continuity of the stratigraphy interfaces,
- Mapping of faults and other structural features.

- **Advantages :**

- Complete picture of stratification of layer upto 10m depth.
- Refraction observations generally employ fewer source and receiver locations and are 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 acquistion requires very limited intrusive activity is non-destructive.

Disadvantages :

- Blind zone effect: If v_2 < v_1, 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 errorous readings.
- Error lies in all the assumptions.

Role of geophysical methods in solving geotechnical problems

- Gravitational and magnetic methods are used in mining and petroleum engineering. In geotechnical engineering, the gravitational method has very limited use for survey of unconsolidated sediments over the dense bedrock.
- Magnetic method is applied to locate dikes, faults and buried pipes and other concealed magnetic metal works.
- For dam and bridge sites, to locate depth of the solid rock, seismic and resistivity methods are used.
- For design of the underwater foundation resistivity method is used.
- For building sites to locate hard rock strata/ soft strata seismic method is used.
- Slope design and the landslide investigation can be done using seismic and the resistivity methods.
- To locate the shallow deposits, seismic and the resistivity methods can be used as in excavation work in sand, gravel deposits etc.
- Ground water investigation can be done using seismic and resistivity method.

In the insitu evaluation of concrete, geophysical methods are used to determine uniformity of concrete. detection of cracking, assessment of rate of corrosion etc.

Recap

In this section you have learnt the following

- General Overview
- Different methods of geophysical explorations
- Electrical resistivity method
- Seismic refraction method

Module 1 : Site Exploration and Geotechnical Investigation

Lecture 5 : Geophysical Exploration [Section 5.1 : Water table location, Pumping -in test, Common soil tests]

Objectives

In this section you will learn the following

- Water table location
- Pumping -in test
- Common soil tests
- Soil investigation report

Water table location

This method is also known as Hvorslev method (1949). As per this method, the water table can be located in a borehole used for soil investigation. The borehole should have the same casing to stabilize the sites. The method normally used is the Rising water level method for determining the water table locations.

This method most commonly referred to as the time lag method consists of bailing the water out of the casing and observing the rate of rise of water table in the casing at intervals of time until the rise of water table becomes negligible. The rate is observed by measuring the elapsed time and the depth of water surface below the top of the casing. The intervals at which the readings are required will vary somewhat with the permeability of the soil. In no case the elapsed time for the readings should be greater less than 5 minuites. In freely draining material such as sands, gravels, etc. the interval of time between the successive readings may not exceed more than 1 to 2 hours, but in soils of low permeability such as fine sands, silts and clays, the intervals may rise from 12 to 24 hours, and it may take a few days to determine the stabilized water table level.

Let the time be t_o, when the water table was at the depth of H_o, below the normal water table level . Let the successive rise in water table levels be h_1, h_2, h_3, etc. at times t_1, t_2, t_3 respectively wherein the difference in time is kept constant.

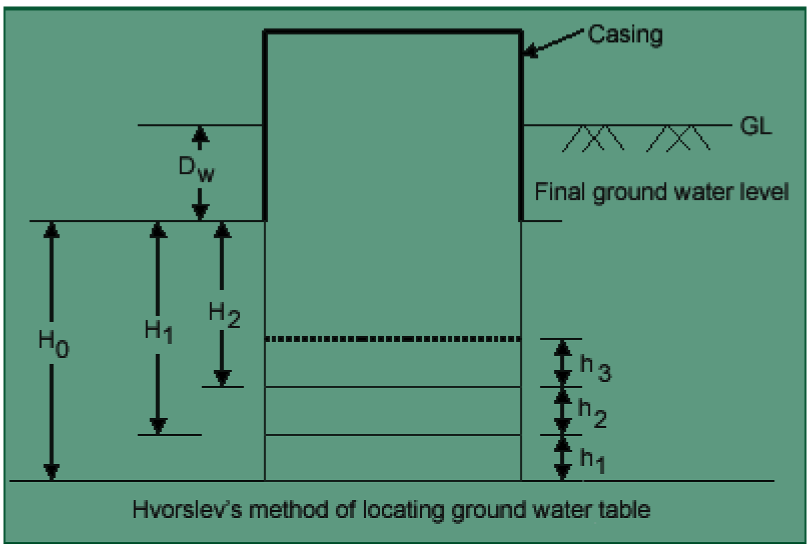


Fig.1.21 Hvorslev's method of locating ground water table

Now from the fig.

$H_o - H_1 = h_1$, $H_1 - H_2 = h_2$, $H_2 - H_3 = h_3$

Let $t_1 - t_o = t_2 - t_1 = t_3 - t_2$ **,etc. =** Δt

The depths H_1, H_2, H_3 of the water level in the casing from the normal water table D_W level can be computed as follows,

$H_o = h_1^2(h_1 - h_2)$ $H_1 = h_2^2(h_1 - h_2)$ $H_o = h_3^2(h_2 - h_3)$

let the corresponding depths of the water table level below the ground surface be h_{w1}, h_{w2}, h_{w3}, etc. we have

$h_{w1} = H_w - H_o$

$h_{w2} = H_w - (h_1 + h_2) - H_2$

$h_{w3} = H_w - (h_1 + h_2 + h_3) - H_3$

where, H_w is the depth of water table in the casing from the ground surface at the start of the test. Normally $h_{w1} = h_{w2} = h_{w3} = h_w$; if not average value gives h_w.

Pumping –in test

The pumping –in tests are carried out to determine the field permeability.

The two tests that fall in this category are :

- **Constant head test :**

This test is applicable for coarse-grained soils.

for this case **$k = Q / (5.5\, rH)$,** where, r = internal radius pipe, Q = inflow rate.

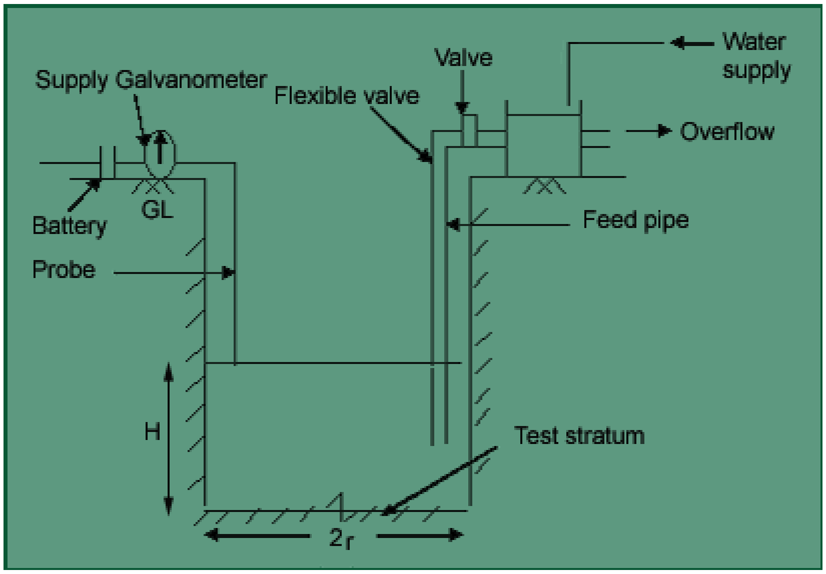


Fig.1.22 Constant Head test

- **Falling head test**

  This test is also known as the packer test.

  The value of coefficient of permeability here can be found by the following equation:

$$k = q/(2\pi LH)*\log_e(L/R)\ if\ L \geq 10R$$

$$k = q/(2\pi LH)*\sin g^{-1}(L/2R)\ if\ 10R > L \geq R$$

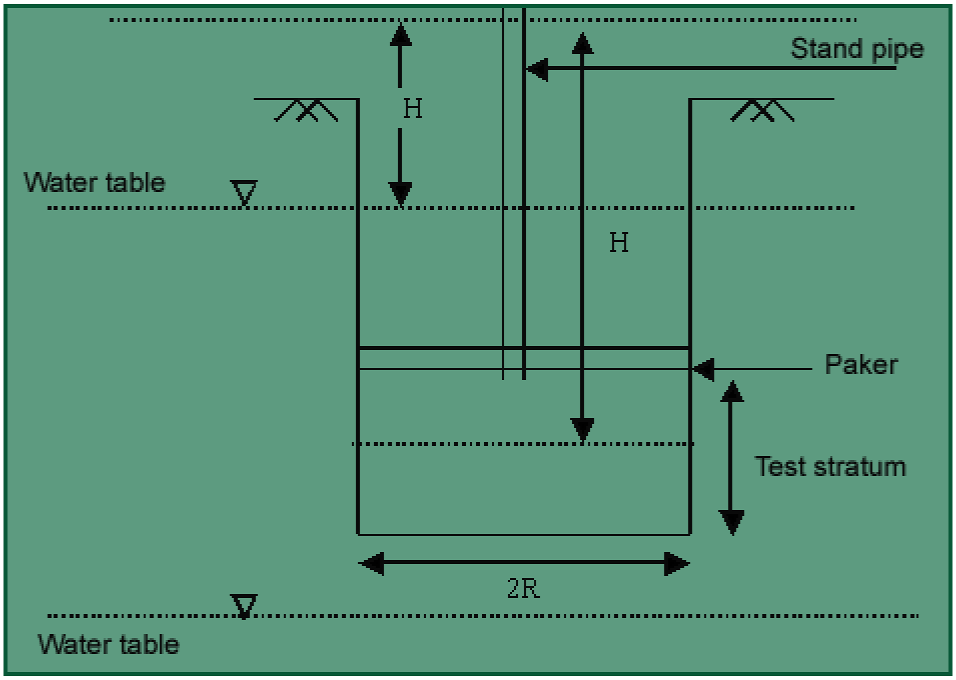


Fig.1.23 Packer test

Common soil tests

1 Laboratory tests

• **Identification** :	Visual soil classification
• **Grain size distribution** :	Sieve analysis, Wet sieve analysis
• **Consistency limits:**	Liquid limit, Plastic limit, and Shrinkage limit
• **Moisture content:**	Moisture content test
• **Unit weight test:**	Specific gravity test
• **Shear strength:**	UC, Direct shear, Triaxial (UU/CU/CD)
• **Compressibility:**	Oedometer, Triaxial test
• **Permeability:**	Constant head test and Falling head test.
• **Compaction:**	Procter test and CBR
• **Chemical & mineralogical test:**	X-ray diffraction, Chemical tests characteristics

2 Field tests

• **Relative density :**	SPT, DCPT
• **Shear strength on cohesive soil:**	Vane shear and Direct shear, SCPT
• **Bearing capacity & settlement:**	Plate load test, Pile load test
• **Permeability:**	Pumping, Piezometer test
• **Compaction characteristics:**	CBR
• **In-situ strength and Deformation characteristics:**	Pressure meter and Dilatometer test

Soil investigation report

A soil investigation report should contain the data obtained from the boreholes, site observations & laboratory results. It should also give the recommendations about the suitable type of foundation, allowable soil pressure & expected settlements.

It is essential to give a complete and accurate record of data collected. Each borehole should be identified by a code number. The location of each borehole should be fixed by measurement of its distance or angles from some permanent feature. All relevant data for the borehole is recorded in a boring log.

A boring log gives the description or classification of various strata encountered at different depths. Any additional information that is obtained in the field, such as soil consistency, unconfined compression strength, standard penetration test, is also indicated on the boring log. It should also show the water table. If the laboratory tests have been conducted, the information about index properties, compressibility, shear strength, permeability etc. should also be provided.

he data obtained from a series of boreholes is presented in the form of a sub-surface profile. A subsurface profile is a vertical section through the ground along the line of exploration. It indicates the boundaries of different strata along with their classification. It is important to remember that conditions between boreholes are estimated by interpolation, which may not be correct. Obviously the larger the no. of the boreholes, the more accurate is the sub-surface profile.

The site investigation report should contain the discussion of the results. The discussion should be clear & concise. The recommendations about the type & depth of foundation, allowable soil pressure & expected settlements should be specific. The main findings of the report are given in conclusions.

Module 1 : Site Exploration and Geotechnical Investigation

Lecture 5 : Geophysical Exploration [Section 5.2 : Water table location, Pumping –in test, Common soil tests]

A soil exploration report generally consists of the following.

- Introduction, which gives the scope of the investigations.
- Description of the proposed structure, the location & geological condition of the site.
- Details of the field exploration programme, indicating the number of the borings, their locations & depths.
- Details of the methods of exploration.
- General description of the sub-soil conditions as obtained from in-situ test, such as standard penetration test, cone test.
- Details of the laboratory test conducted on the soil samples obtained & the results obtained.
- Depth of ground water table & the changes in water levels.
- Discussions of the results.
- Recommendations about the allowable bearing pressure, the type of foundation or structure.
- Conclusions: The main findings of the investigations should be clearly stated.

It should be brief but should mention the salient points.

Conclusion

Geotechnical engineering is one of the most promising fields in engineering whereby, insitu investigation is the most powerful tool at the disposal of a geotechnical Engineer with which he can combat any unfavourable circumstance and solve any problem. No other technique can apprehend the behaviour of soils as meticulously as insitu investigation does because it tests the soil in its natural habitat which simulates its most probable response behaviour to external loading or disturbance. In this report the various methodologies involved in insitu investigation of soil, on land has been discussed with reference to the various sample collection techniques. This report also discusses in brief how the data collected from site investigations are to be represented in a borehole log.

Recap

In this section you have learnt the following

- Water table location
- Pumping -in test
- Common soil tests
- Soil investigation report

Congratulations, you have finished Lecture 5. To view the next lecture select it from the left hand side menu of the page