Module 1 : Site Exploration and Geotechnical Investigation

Lecture 4 : In-situ tests [Section 4.1: Penetrometer Tests]

Objectives

In this section you will learn the following

- Penetrometer Tests
    - Standard penetration test
    - Static cone penetration test
    - Dynamic cone penetration test (DCPT)

4 In-situ tests

General

The in situ tests in the field have the advantage of testing the soils in their natural, undisturbed condition. Laboratory tests, on the other hand, make use of small size samples obtained from boreholes through samplers and therefore the reliability of these depends on the quality of the so called 'undisturbed' samples. Further, obtaining undisturbed samples from non-cohesive, granular soils is not easy, if not impossible. Therefore, it is common practice to rely more on laboratory tests where cohesive soils are concerned. Further, in such soils, the field tests being short duration tests, fail to yield meaningful consolidation settlement data in any case. Where the subsoil strata are essentially non-cohesive in character, the bias is most definitely towards field tests. The data from field tests is used in empirical, but time-tested correlations to predict settlement of foundations. The field tests commonly used in subsurface investigation are:

- Penetrometer test
- Pressuremeter test
- Vane shear test
- Plate load test
- Geophysical methods

Penetrometer Tests :

- Standard penetration test (SPT)
- Static cone penetration test (CPT)
- Dynamic cone penetration test (DCPT)

1. Standard penetration test

The standard penetration test is carried out in a borehole, while the DCPT and SCPT are carried out without a borehole. All the three tests measure the resistance of the soil strata to penetration by a penetrometer. Useful empirical correlations between penetration resistance and soil properties are available for use in foundation design.

This is the most extensively used penetrometer test and employs a split-spoon sampler, which consists of a driving shoe, a split-barrel of circular cross-section which is longitudinally split into two parts and a coupling. IS: 2131-1981 gives the standard for carrying out the test.

Procedure

- The borehole is advanced to the required depth and the bottom cleaned.
- The split-spoon sampler, attached to standard drill rods of required length is lowered into the borehole and rested at the bottom.
- The split-spoon sampler is driven into the soil for a distance of 450mm by blows of a drop hammer (monkey) of 65 kg falling vertically and freely from a height of 750 mm. The number of blows required to penetrate every 150 mm is recorded while driving the sampler. The number of blows required for the last 300 mm of penetration is added together and recorded as the N value at that particular depth of the borehole. The number of blows required to effect the first 150mm of penetration, called the seating drive, is disregarded.
- The split-spoon sampler is then withdrawn and is detached from the drill rods. The split-barrel is disconnected from the cutting shoe and the coupling. The soil sample collected inside the split barrel is carefully collected so as to preserve the natural moisture content and transported to the laboratory for tests. Sometimes, a thin liner is inserted within the split-barrel so that at the end of the SPT, the liner containing the soil sample is sealed with molten wax at both its ends before it is taken away to the laboratory.

The SPT is carried out at every 0.75 m vertical intervals in a borehole. This can be increased to 1.50 m if the depth of borehole is large. Due to the presence of boulders or rocks, it may not be possible to drive the sampler to a distance of 450 mm. In such a case, the N value can be recorded for the first 300 mm penetration. The boring log shows refusal and the test is halted if

- 50 blows are required for any 150mm penetration
- 100 blows are required for 300m penetration
- 10 successive blows produce no advance.

Precautions

- The drill rods should be of standard specification and should not be in bent condition.
- The split spoon sampler must be in good condition and the cutting shoe must be free from wear and tear.
- The drop hammer must be of the right weight and the fall should be free, frictionless and vertical.
- The height of fall must be exactly 750 mm. Any change from this will seriously affect the N value.
- The bottom of the borehole must be properly cleaned before the test is carried out. If this is not done, the test gets carried out in the loose, disturbed soil and not in the undisturbed soil.

- When a casing is used in borehole, it should be ensured that the casing is driven just short of the level at which the SPT is to be carried out. Otherwise, the test gets carried out in a soil plug enclosed at the bottom of the casing.
- When the test is carried out in a sandy soil below the water table, it must be ensured that the water level in the borehole is always maintained slightly above the ground water level. If the water level in the borehole is lower than the ground water level, ‘quick' condition may develop in the soil and very low N values may be recorded.

In spite of all these imperfections, SPT is still extensively used because

- the test is simple and relatively economical.
- it is the only test that provides representative soil samples both for visual inspection in the field and for natural moisture content and classification tests in the laboratory.

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, namely, (a) effect of overburden pressure, and (b) effect of dilatancy.

(a) Correction for overburden pressure

Several investigators have found that the penetration resistance or the N value in a granular soil is influenced by the overburden pressure. Of two granular soils possessing the same relative density but having different confining pressures, the one with a higher confining pressure gives a higher N value. Since the confining pressure (which is directly proportional to the overburden pressure) increases with depth, the N values at shallow depths are underestimated and the N values at larger depths are overestimated. To allow for this, N values recorded from field tests at different effective overburden pressures are corrected to a standard effective overburden pressure.

The corrected N values given by

$$N' = C_N N$$

in which N' corrected value of observed N; C_N = correction factor for overburden pressure.

(b) Correction for dilatancy

Di1atancy correction is to be applied when N' obtained after overburden correction, exceeds 15 in saturated fine sands and silts. IS: 2131-1981 incorporates the Terzaghi and Peck recommended dilatancy correction (when N' > 15) using the equation

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

where N'' = final corrected value to be used in design charts.

If $N' \leq 15$, $N'' = N'$

N' >15 is an indication of a dense sand. In such a soil, the fast rate of application of shear through the blows of a drop hammer, is likely to induce negative pore water pressure in a saturated fine sand under undrained condition of loading. Consequently, a transient increase in shear resistance will occur, leading to a SPT value higher than the actual one.

2 Static cone penetration test

At field SCPT is widely used of recording variation in the in-situ penetration resistance of soil in cases where in-situ density is disturbed by boring method & SPT is unreliable below water table. The test is very useful for soft clays, soft silts, medium sands & fine sands.

Procedure

- By this test basically by pushing the standard cone at the rate of 10 to 20 mm/sec in to the soil and noting the friction, the strength is determined.
- After installing the equipment as per IS-4968, part III the sounding rod is pushed in to the soil and the driving is operated at the steady rate of 10 mm/sec approximately so as to advance the cone only by external loading to the depth which a cone assembly available.
- For finding combine cone friction resistance, the shearing strength of the soil q_s , and tip resistance q_c is noted in gauge & added to get the total strength.

Limitations

This test is unsuitable for gravelly soil & soil for having SPT N value greater than 50. Also in dense sand anchorage becomes to cumbersome & expensive & for such cases Dynamic SPT can be used. This test is also unsuitable for field operation since erroneous value obtained due to presence of brick bats, loose stones etc.

Correction in SCPT test

$C_N = (m + nm_1) \times 10 kN/m^2$

Here

m = mass o cone = 1.1 Kg.

m_1 = mass of each sounding roads = 1.5 Kg

n = No. of rods used.

SCPT correlation

- **Friction ratio**

$$f_r = \frac{q_s}{q_c} \times 100\%$$

f_r = Friction ratio

q_s =measured site/slip friction

q_c = tip resistance/point resistance

Then, Sensitivity of soil is measured

$$S_t = \frac{10}{f_r} \ (f_r \text{ in } \%)$$

where, S_t = Sensitivity of soil

- **For cohesive soil (undrained shear strength)**

$$S_u = \frac{q_c - p_0}{N_k}$$

p_0 = overburden pressure = γ Z

N_k = cone factor = 15 to 20

(depends on the plasticity index of soil)

Sarvac & opovic

$$q_c = 612.6 + 587.5 I_c$$

Here I_c = consistency index of soil

q_c is measured in KPa

Schmertman

$$\frac{q_{c,ocr}}{q_{c,NC}} = 1 + K\left(\frac{K_{0,ocr}}{K_{0,NC}} - 1\right) \quad \textbf{(K=0.75)}$$

$$\frac{K_{0,ocr}}{K_{0,NC}} = (OCR)^n$$

(n = 0.32 to 0.52)

- **Relation between angle of internal friction & undrained shear strength**
  - For gravelly silt

$$\phi = \left(29 + \sqrt{q_c}\right) + 5^0$$

  - For silty sand

$$\phi = \left(29 + \sqrt{q_c}\right) - 5^0$$

SPT & SCPT relation

$$q_c = K.N$$

Table 1.2 Here K value varies 0.1 to 1.0. It depends of soil type

Sr. No.	Soil type	$K.\left(\frac{q_c}{N_{60}}\right)$
1	Silt, sand silt & slightly cohesive sand silt mix	0.1 to 0.2
2	Clean fine sand to medium sand & slightly silty sand	0.3 to 0.4
3	Coarse sand & sand with gravel	0.5 to 0.7
4	Sandy gravel & gravel	0.8 to 1.0

3 Dynamic cone penetration test (DCPT)

General

The aim is to determine the effort required to force a point through the soil and so obtain resistance value which corresponds to the mechanical properties of the soil. The preliminary use is in cohesionless soils when static penetration test is difficult to perform or dynamic properties of the soil are of special interest.

Procedure

The test set up shown in fig. 1.8. The standard 60^0 cone is connected to the drilling rod. The driving head with the guide rod is connected and properly fixed on the top of the drilled rods. This complete assembly is kept in position with the cone resting vertically on the ground where the test is to be carried out. For the circulation of the bentonite slurry the pumping unit of the bentonite slurry is properly connected to the guide rod through flexible tube. The cone is driven into the soil by blows of 65 Kg hammer falling from a height of 750mm. The blow count for every 30cm penetration is made to get a continuous record of the variation of the soil consistency with depth. The sufficient circulation of the bentonite slurry is necessary for elimination of the friction on the rods. Sometimes the bentonite slurry is not used when the investigation is required up to a depth of 6m only.

Advantages :

- The test does not need a borehole.
- It can be done quickly to cover a large area economically.
- The test helps to identify variability of subsoil profile and to locate soft pockets such as filled up ponds.
- When DCPT is carried out close to a few boreholes, suitable corrections may be obtained for a particular site and the number of bore holes can be reduced.

Disadvantages :

- The test is normally not suitable for cohesive soils or very loose cohesionless soils.
- It is normally not possible to evaluate the mechanical properties of the soil at great depths when the fric+tion along the extension rod is significant.

Correlation with SPT

The resistance N_c is correlated quantitatively to the standard penetration test value (N) by C.B.R.I. Roorkee as

N_c = 1.5N for depths upto 4m and,

N_c = 1.75N for depths 4 to 9m.

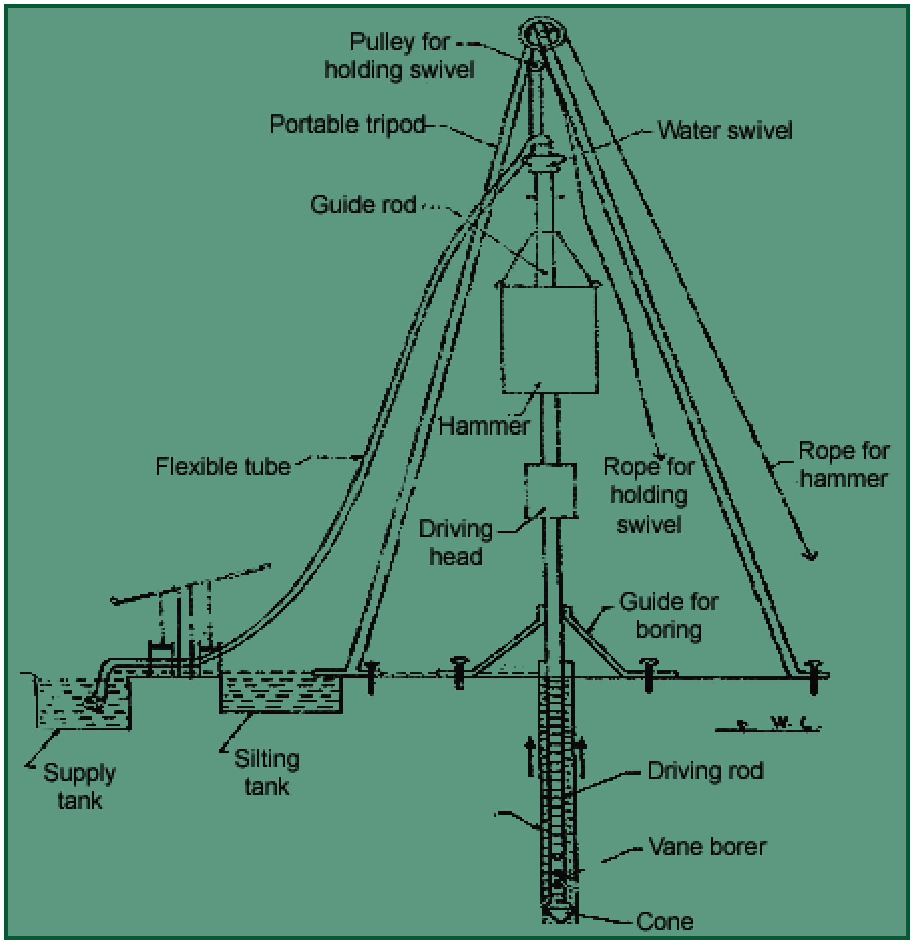

Fig.1.8 Dynamic cone penetration test set up

Recap

In this section you have learnt the following

- Penetrometer Tests
  - Standard penetration test
  - Static cone penetration test
  - Dynamic cone penetration test (DCPT)

Objectives

In this section you will learn the following

- Pressuremeter test
- Vane shear test
- Plate load test

Pressuremeter test

The bore hole Pressuremeter test is an in-situ test developed around 1956[Menard (1956)] to measure the strength and deformation characteristics of the soil. The Pressuremeter is used in Sub-soil investigation work for finding the in-situ stress-deformation characteristics of rock, gravel, sand, silt and clay deposits below ground level, below or above the ground water level. With the help of pressuremeter, continuously the stress-deformation characteristics are obtained from the natural state of soil under gradually increasing radial stress.

Before starting the actual pressuremeter test, proper planning is needed to decide about the location of the tests. The test is done at different depths in a freshly drilled borehole with the help of a pressuremeter which consists of an expandable probe with a measuring cell at the centre and two guard cells at the top and bottom. The probe is inserted (fig 1.9) in a pre-bored hole and is expanded in volume either by liquid or air pressure until the soil fails or the expanded volume of the measuring cell reaches twice the volume of the cavity. The guard cells are used to minimize the end effect on the measuring cell. To prevent caving in the borehole, M.S casing can be provided. The bottom of the casing is kept at least 1m above the desired test depth. Depending upon the soil condition it is also possible to drill the hole 2m to 5m below the casing and do successive pressuremeter test. The typical dimensions of the probe and the borehole are given below

Table 1.3 Dimensions of Pressuremeter Probe and Borehole

Hole designation	Diameter of probe(mm)	L_o (m)	L (m)	Borehole diameter(mm)	
				Nominal	Maximum
A X	44	36	66	46	52
B X	58	21	42	60	66
N X	70	25	50	72	48

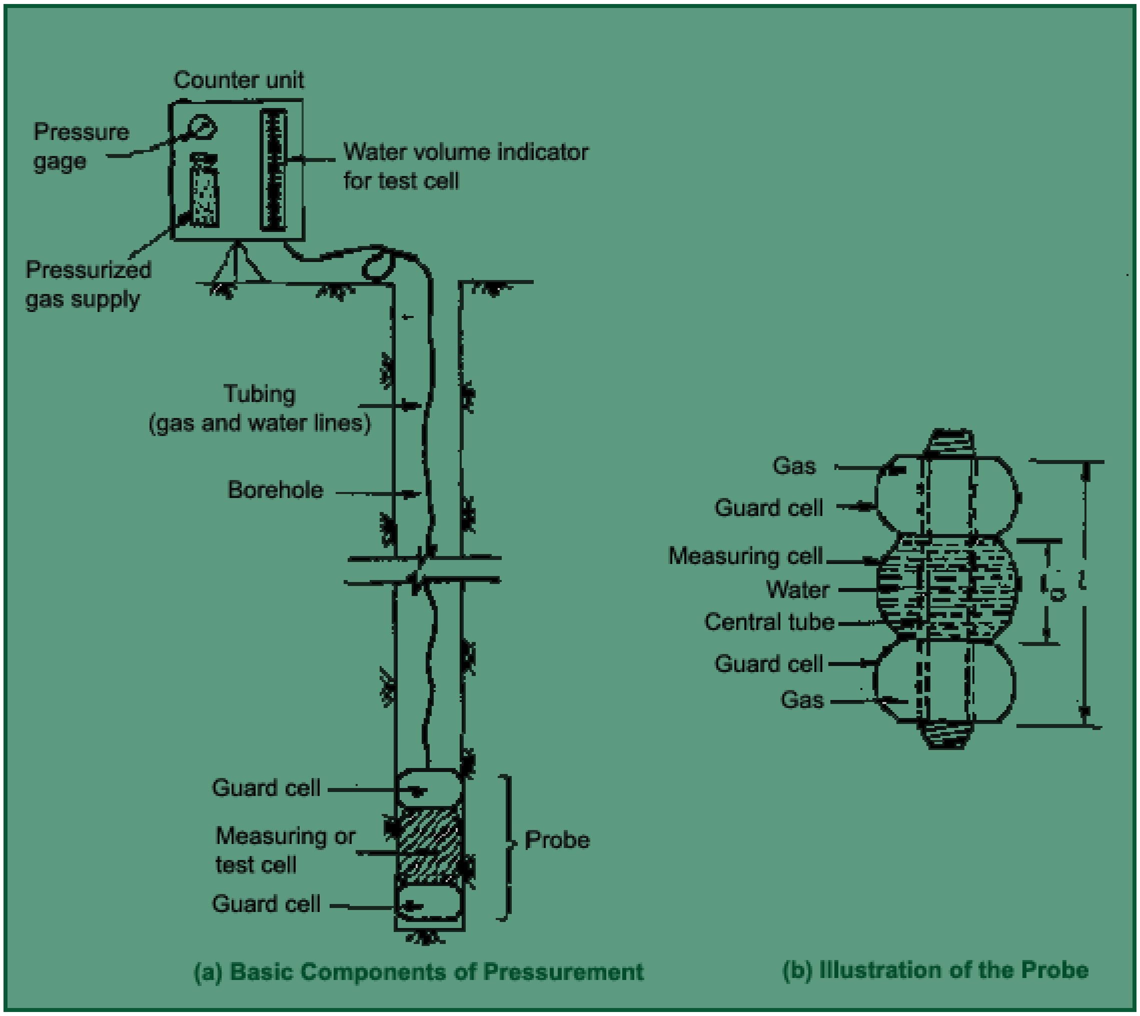

Fig: 1.9 Menard type Pressuremeter

Analysis of test results

Using the results obtained by conducting pressuremeter tests at various depths, typical pressure fields curve for stress vs. deformation is plotted (fig 1.10).

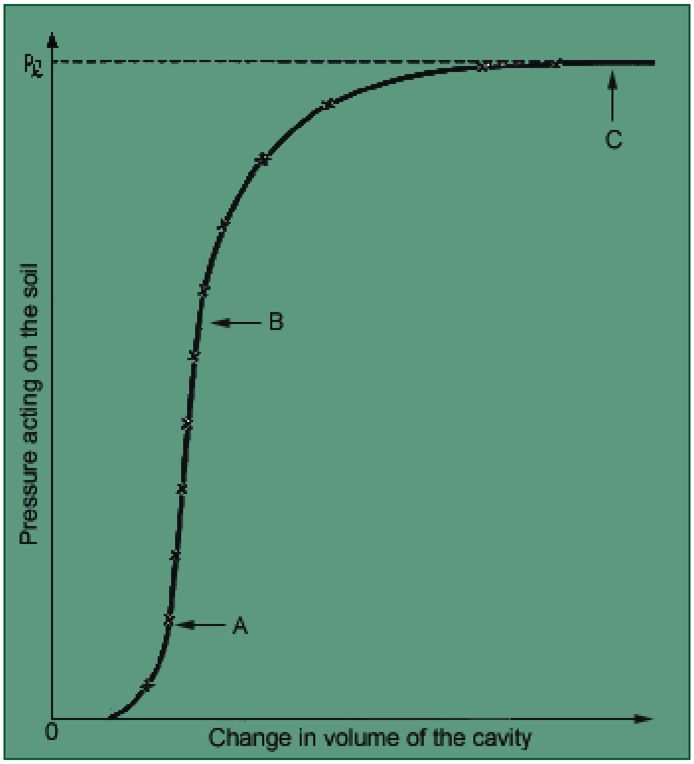

Fig. 1.10 Pressuremeter Field Curve

There are three phases of the deformation curve: (1) the re-establishing phase, from the origin to point A; (2) the pseudo-elastic phase, from point A to point B; and (3) the plastic phase, from point B to point C. After the borehole is drilled and the augers are withdrawn, the borehole walls relax, thus reducing the cavity volume. As the pressuremeter probe is initially inflated, the walls of the borehole are pushed back to their original position. Point A marks the point at which the volume of the borehole cavity has fully returned to its initial position, and is given the coordinates, v_o, p_o. The pseudo-elastic phase, the straight-line portion of the curve between points A and B, is dubbed so because of its resemblance to the elastic behavior of steel or concrete. Point B is the point

at which creep pressure has been reached, and is given the coordinates, v_f, p_f. The plastic phase begins at point B and extends to point C, which is asymptotic to the limit pressure. Point C, which is given the coordinates v_L, p_L, is defined as the point where the pressure remains constant despite increasing volume. The limit pressure is defined as the pressure required to expand the measuring cell by an amount v_o beyond the volume required to inflate the pressuremeter (v_c) and to push the borehole wall back to its original position (v_o). The pressuremeter can be used to aid in the design of foundations for all types of soils, including residual soils. The settlements of foundations can be estimated using a deformation modulus, E , which can be derived from the pseudo-elastic phase (or straight-line portion) of the load deformation diagram.

$$E = 2.66\left(V_c + \frac{v_0 + v_f}{2}\right)\frac{p_f - p_0}{v_f - v_0}$$

where, (v_o , p_o) and (v_f , p_f) are the volume and the pressure at the point A and B respectively and V_c = volume of measuring cell in its natural state (535 ml).

The value of V_c depends on the size of the borehole. The injected volume at the limit pressure (v_I) is thus:

v_I = v_o + V_c + v_o = 2 v_o + V_c where, v_o = volume required to inflate pressuremeter and push soil to its original position; and V_c = initial volume of the measuring cell. The allowable bearing capacity of clayey soils for shallow and deep foundations is generally determined from the pressure test results by the empirical and semi-empirical methods. For shallow foundations, the allowable bearing capacity may be considered as,

$$q_a = \frac{p_1}{3}$$

for deep foundations, the allowable fractional resistance may be taken as

$$f_a = \frac{p_1}{20}.$$

Thus, the pressuremeter gives in-situ lateral stresses in the ground, the stress strain behavior and the strength of the soil at different depths. The test takes only 10-15 minutes after drilling operation. Since the results are available within a short time it is possible to arrive at quick conclusions regarding the suitability of the site to be adopted.

Vane shear test

From experience it has been found that the vane shear test can be used as a reliable in-situ test for determining the shear strength of soft-sensitive clays. It is in beds of such material that the vane shear test is the most valuable, for the simple reason that there is at present no method known by which the shear strength of clays can be measured.

The vane shear test should be regarded as a method to be used under the following conditions:

- Where the clay is deep, normally consolidated and sensitive.
- Where only the undrained shear strength is required.

It has been found that the vane shear test gives similar results to that as obtained from unconfined compression tests on undisturbed samples. It is necessary that the soil mass should be in saturated conditions if the vane test is to be applied. Vane shear test cannot be applied for partially saturated soils for which the angle of shearing resistance is not zero.

Description of vane:

The vane consists of a steel rod having at one end four projecting blades or vanes parallel to the axis, and situated at 90º intervals around the rod. A posthole borer is first employed to bore a hole up to a point just above the required depth. The rod is pushed or driven carefully until the vanes are embedded at the required depth. At the other end of the rod above the surface of the ground a torsion head is used to apply a horizontal torque and this is applied at a uniform speed of about 0.1º/sec until the soil fails, thus generating a cylinder of soil. The area consists of the peripheral surface of the cylinder and the two round ends. The first moment of these areas divided by the applied moment gives the unit shear value of the soil. In India the diameter used is 50mm and height of the blade is 100mm.

Determination of Cohesion or Shear Strength of Soil:

Consider a cylinder of soil generated by the blades of the vane when they are inserted into the undisturbed soil in-situ and gradually turned and rotated about the axis of the shaft or vane axis. The turning moment applied at the torsion head above the ground is equal to the force multiplied by the eccentricity.

Let the force applied = P kg.

Eccentricity (lever arm) = x cm.

Turning moment = Px kgcm.

The surface resisting the turning is the cylindrical surface of the soil and the two end faces of the cylinder.

Therefore, the resisting moment = $2\pi r \times L \times c_u \times r + 2\pi r^2 \times c_u \times 2/3r$

$$= 2\pi r^2 \times c_u \times (L + 2/3r)$$

where, r = radius of the cylinder

c_u = the undrained shear strength.

It is apparent at failure the resisting moment of the cylinder of the soil is equal to the turning moment applied at the torsion head.

Therefore, $PX = 2\pi r^2 \times c_u \times (L + 2/3r) = T$

$$C_u = \frac{T}{2\Pi r^2 (L + 2/3r)}$$

he standard dimensions of the field vane are L = 11.25cm, r = 3.75cm.

Bjerrum(1922) back computed a number of embankment of embankment failures on soft clay and concluded that the vane shear strength tended to be too high.

A correlation is established as follows,

c_u (field) = μc_u (vane) where, μ is the correction factor.

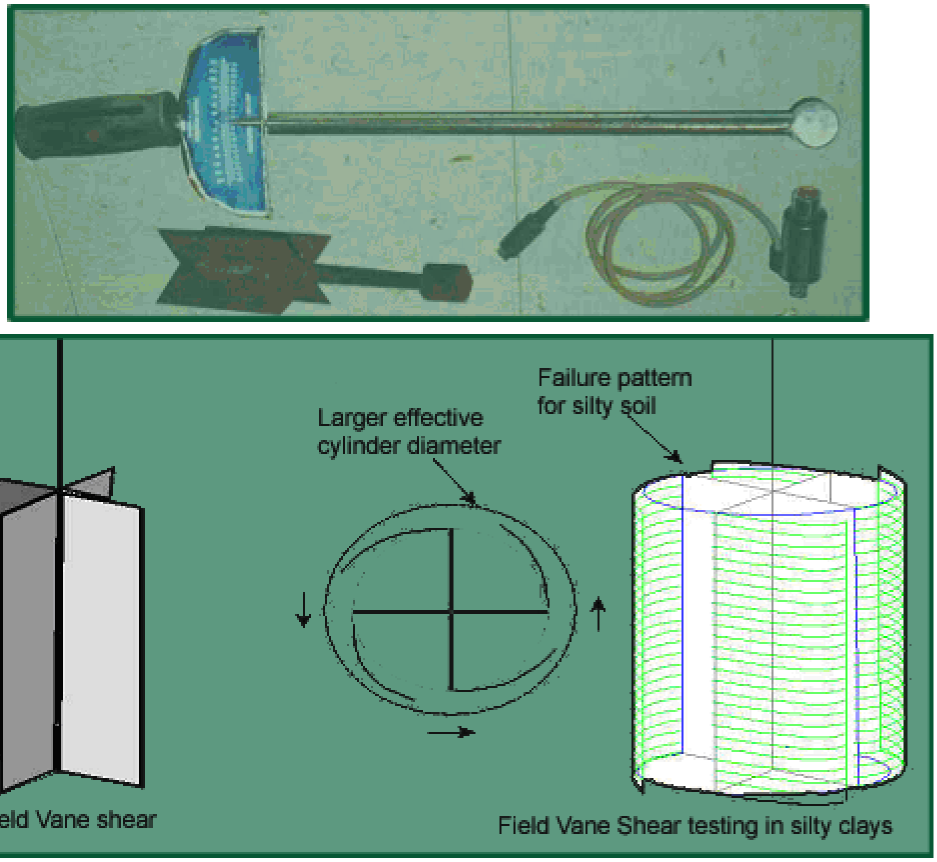

Fig.1.11 Apparatus for the vane shear test

Plate load test

The plate load test is a semi-direct method to measure the allowable pressure of soil to induce a given amount of settlement. Plates, round or square, varying in sizes, from 30 to 60 cm and thickness of about 2.5 cm are employed for the test.

The load on the plate is applied by making use of a hydraulic jack. The reaction of the jack load is taken by a cross beam or a steel truss anchored suitably at both the ends. The settlement of the plate is measured by a set of three dial gauges of sensitivity 0.02mm placed at 120º apart. The dial gauges are fixed to independent supports which do not get disturbed during the test. Fig shows the arrangement for the plate load test.

Procedure:

The method of performing the test is essentially as follows:

- Excavate a pit of size not less than 5 times the size of the plate. The bottom of the pit coincides with level of the foundation.
- If water table is above the level of foundation, pump out the water carefully and it should be kept just at the level of the foundation.
- A suitable size of the plate is selected for the test. Normally a plate of size 30cm is used in sandy soils and bigger size in clay soils. The ground should be leveled and the plate is seated over the ground.
- A seating load of about $70 gm/cm^2$ is first placed and released after sometime. A higher load is next placed on the plate and settlements are recorded by means of the dial gauges.

  Observations on every load increment shall be taken until the rate of settlement is less than 0.25mm per hour. Load increments shall be approximately one-fifth of the estimated safe bearing capacity of the soil. The average of the settlements recorded by 2 or 3 dial gauges taken as the settlements of the plate for each of the load increment.
- The test should continue until a total settlement of 2.5cm or the settlement at which the soil fails, whichever is earlier, is obtained. After the load is increased, the elastic rebound of the soil should be recorded.

Interpretation from test results:

From the test results, a load-settlement curve should be plotted as shown in the fig. The allowable pressure of the prototype foundation for an assumed settlement may be found and by making use of the following equations as suggested by Terzaghi and Peck.

For granular soils,

$$S_f = S_p\left(\frac{B(b_p + 0.3)}{b_p(B + 0.3)}\right)^2$$

For clay soils,

$$S_f = S_p\frac{B}{b_p}$$

Where, S_f = permissible settlement of the foundation in mm,

S_p = settlement of the plate in mm,

B = size of plate in metres,

b_p = size of plate in metres.

The permissible settlement S_f for a prototype foundation should be known. Normally a settlement of 2.5cm is recommended. In the equation the values of S_f and b_p are known. The unknowns are S_p and B. The value of S_p for any assumed value of B may be found out from the equation. Using the plate load settlement curve the value of the bearing pressure corresponding to the computed value of S_p is found out. This bearing pressure is the safe bearing pressure for a given permissible settlement S_f.

Limitations

Since a plate load test is of short duration, consolidation settlements cannot be predicted. The test gives the value of immediate settlements only. If the underlying soil is sandy in

nature immediate settlement can be taken as total settlement. If the soil is of clayey type, the immediate settlement is only a part of the total settlement. Load tests, therefore do not have much significance in clayey soils to determine allowable pressure on the basis of settlement criterion.

Plate load test results should be used with caution and the present practice is not to rely too much on this test. If the soil is not homogenous to a great depth, plate load tests give very misleading results.

Plate load tests is not at all recommended in soils which are not homogenous at least to a depth equal to 1.5 to 2 times the width of the prototype foundation.

Plate load tests should not be relied on to determine the ultimate bearing capacity of sandy soils as the scale effects give misleading results. However, when the tests are carried on clay soils, the ultimate bearing capacity as determined by the test may be taken as equal to that of the foundation since the bearing capacity of clay is essentially independent of the footing size.

The plate load test is possibly the only way of determining the allowable bearing pressures in gravelly soil deposits. For tests on such soil deposits the size of the plate should be bigger to eliminate the effect of grain size.

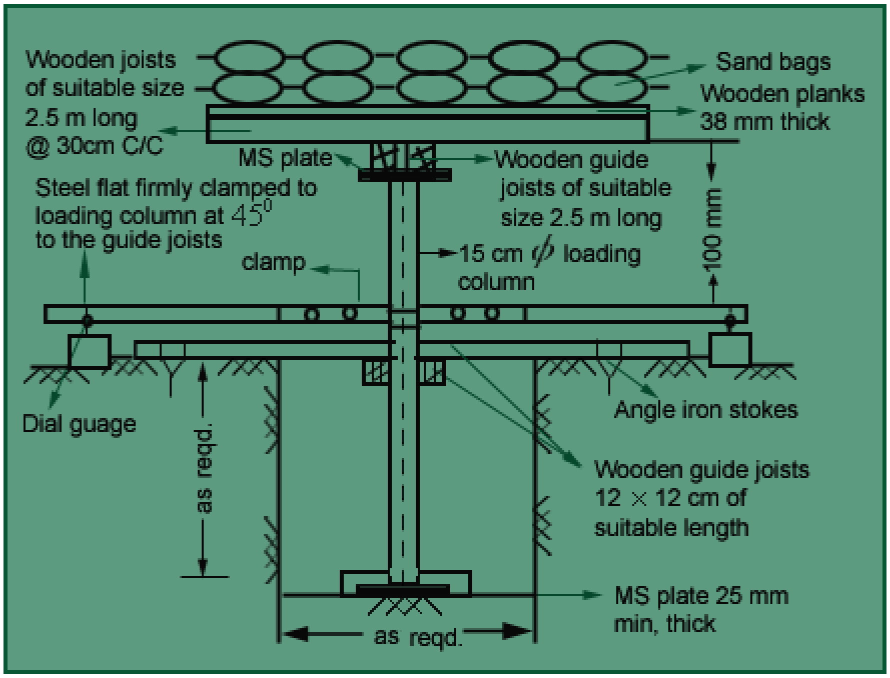

Fig: 1.12 Plate Load Test setup

Recap

In this section you have learnt the following

- Pressuremeter test
- Vane shear test
- Plate load test

Congratulations, you have finished Lecture 4. To view the next lecture select it from the left hand side menu of the page