2.5 Bearing capacity from in-situ tests:

1. **Standard Penetration Test (SPT)**
2. **Cone Penetration Test (cPT)**
3. **Plate load Test**

1. Standard Penetration Test (SPT)

The standard penetration test is an in-situ test that is coming under the category of penetrometer tests. The standard penetration tests are carried out in borehole. The test will measure the resistance of the soil strata to the penetration undergone. A penetration empirical correlation is derived between the soil properties and the penetration resistance.

The test is extremely useful for determining the relative density and the angle of shearing resistance of cohesionless soils. It can also be used to determine the unconfined compressive strength of cohesive soils.

The requirements to conduct SPT are:

- Standard Split Spoon Sampler
- Drop Hammer weighing 63.5kg
- Guiding rod
- Drilling Rig.
- Driving head (anvil).

Procedure for Standard Penetration Test

The test is conducted in a bore hole by means of a standard split spoon sampler. Once the drilling is done to the desired depth, the drilling tool is removed and the sampler is placed inside the bore hole.

By means of a drop hammer of 63.5kg mass falling through a height of 750mm at the rate of 30 blows per minute, the sampler is driven into the soil. This is as per IS - 2131:1963.

The number of blows of hammer required to drive a depth of 150mm is counted. Further it is driven by 150 mm and the blows are counted.

Similarly, the sampler is once again further driven by 150mm and the number of blows recorded. The number of blows recorded for the first 150mm not taken into consideration. The number of blows recorded for last two 150mm intervals are added to give the standard penetration number (N). In other words,

N = No: of blows required for 150mm penetration beyond seating drive of 150mm.

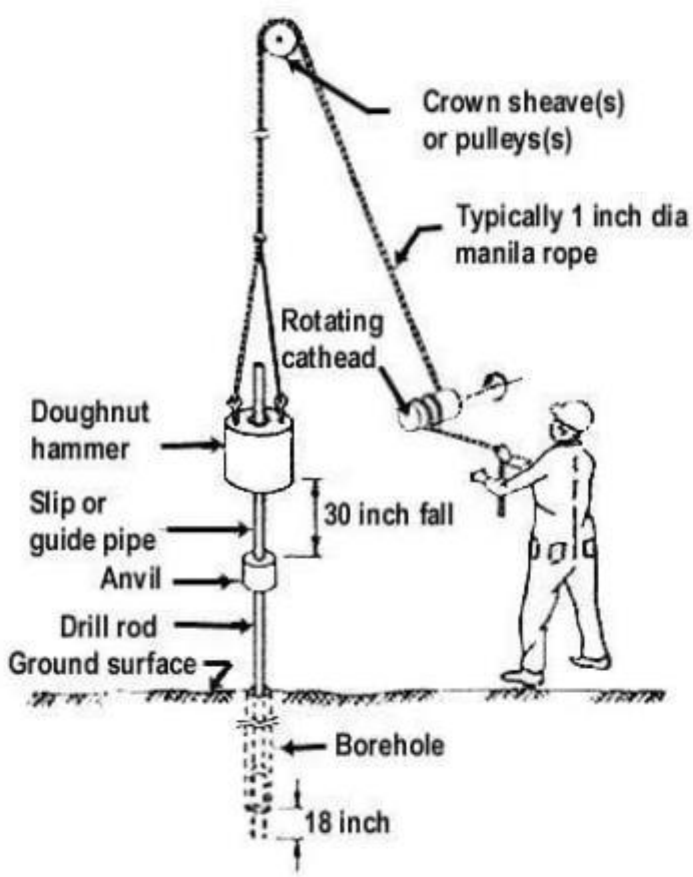


Fig.1: Standard penetration Test

[Fig 1 https://theconstructor.org/geotechnical/standard-penetration-test-procedure-precautions-advantages/4657/]

If the number of blows for 150mm drive exceeds 50, it is taken as refusal and the test is discontinued. The standard penetration number is corrected for dilatancy correction and overburden correction.

Corrections in Standard Penetration Test:

Before the SPT values are used in empirical correlations and in design charts, the field 'N' value have to be corrected as per IS 2131 – 1981. The corrections are:

1. Dilatancy Correction
2. Overburden Pressure Correction

1. Dilatancy Correction

Silty fine sands and fine sands below the water table develop pore water pressure which is not easily dissipated. The pore pressure increases the resistance of the soil and hence the penetration number (N).

Terzaghi and Peck (1967) recommend the following correction in the case of silty fine sands when the observed value is N exceeds 15.

The corrected penetration number,

$$N_C = 15 + 0.5\,(N_R - 15)$$

Where NR is the recorded value and NC is the corrected value.

If N_R less than or equal to 15, then $N_c = N_R$

2. Overburden Pressure Correction

From several investigations, it is proven that the penetration resistance or the value of N is dependent on the overburden pressure. If there are two granular soils with relative density same, higher 'N' value will be shown by the soil with higher confining pressure.

With the increase in the depth of the soil, the confining pressure also increases. So the value of 'N' at shallow depth and larger depths are underestimated and overestimated respectively.

Hence, to account this the value of 'N' obtained from the test are corrected to a standard effective overburden pressure.

The corrected value of 'N' is

$$Nc = C_N\, N$$

Here C_N is the correction factor for the overburden pressure.

Precautions taken for Standard Penetration Test

- Split spoon sampler must be in good condition.
- The cutting shoe must be free from wear and tear
- The height of fall must be 750mm. Any change from this will affect the 'N' value.
- The drill rods used must be in standard condition. Bent drill rods are not used.
- Before conducting the test, the bottom of the borehole must be cleaned.

Advantages of Standard Penetration Test

The advantages of standard penetration test are:

- The test is simple and economical
- The test provides representative samples for visual inspection, classification tests and for moisture content.
- Actual soil behavior is obtained through SPT values
- The method helps to penetrate dense layers and fills
- Test can be applied for variety of soil conditions

Disadvantages of Standard Penetration Test

- The limitations of standard penetration tests are:
- The results will vary due to any mechanical or operator variability or drilling disturbances.
- Test is costly and time consuming.
- The samples retrieved for testing is disturbed.
- The test results from SPT cannot be reproduced
- The application of SPT in gravels, cobbles and cohesive soils are limited

Cone Penetration Test:

Dynamic Cone Penetrometer, or DCP, is a tool used for evaluating the strength of soils on site. It also helps with monitoring the condition of granular layers and subgrade soils in pavement sections over time. It can be used to determine the right solutions for the sites, especially when soft soils are involved.

It is also applied when the CBR value of compacted soil sub-grade beneath the existing road pavement is to be determined. Continuous readings can be taken down to a depth of 800 mm or, when an extension rod is fitted, to a depth of up to 1200 mm.

The DCP is a simple and portable instrument. It consists of a hardened conical tip, standard diameter steel rod, and a standard weight hammer(8kg), which is dropped from the top of the rod against an anvil to advance the tip into the ground.

Apparatus for DCP

The apparatus of the instrument involves the following parts:

- Handle
- Top Rod
- Hammer(8kg)

- Anvil
- Handguard Cursor
- Bottom Rod
- 1m rule
- 60 degree Cone
- bars and spanners(to ensure that the screwed joints are kept tight at all times)

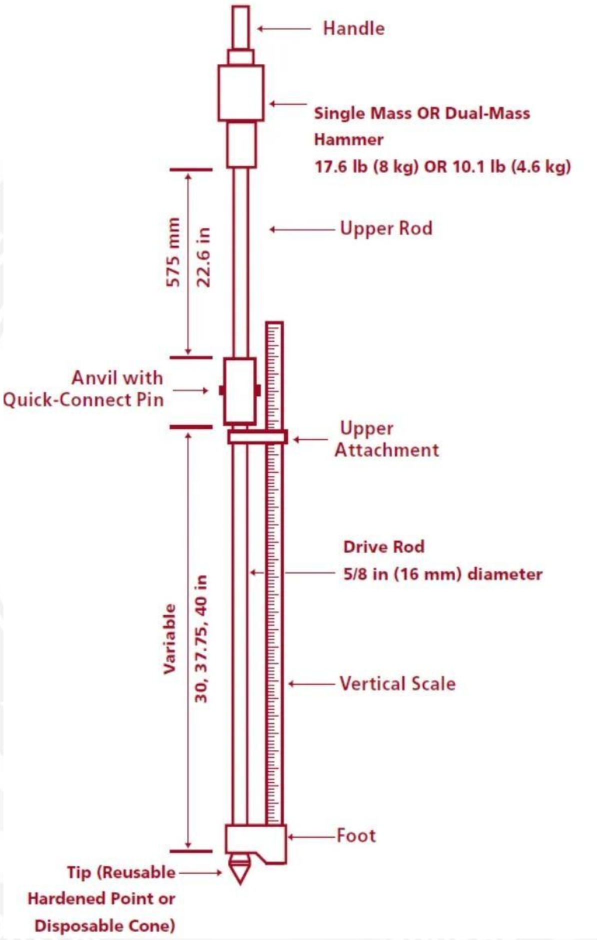


Fig 2 Dynamic Cone Penetrometer

[Fig 2 https://theconstructor.org/geotechnical/soils/what-dynamic-cone-penetrometer/40239/]

The following joints should be secured with a strong adhesive or similar non-hardening thread-locking compound prior to use:

(i) Handle/top rod

(ii) Anvil/bottom rod

(iii) Bottom rod/cone

The hammer is lifted to the top of the rod and released in order to drive the rod into the ground. With the help of the embedded vertical scale, the penetration (in inches or millimeters) is recorded after the blows of the hammer.

Correlations have been established between measurements with California Bearing Ratio (CBR) and DCP so that the outcome can be interpreted and compared with CBR specifications for pavement design.

Procedure

After the instrument is set up, the zero reading of the apparatus is recorded. This is done by placing the DCP on a hard surface, ensuring its verticality, and then noting down the zero reading.

The instrument is held vertical, and the weight is carefully raised to the handle. The weight should not touch the handle before it is allowed to drop, and that the operator should let it fall freely and does not lower it with his hands.

It is advised that a reading should be taken at increments of penetration of about 10mm. However, it is usually easier to take a scale reading after a set number of blows. It is, therefore, necessary to change the number of blows between readings according to the strength of the layer being penetrated. For good quality granular bases, readings after every 5 or 10 blows are normally satisfactory, but for weaker sub-base layers and sub-grades, readings after every 1 or 2 blows may be appropriate.

After the completion of the test, DCP is removed by gently tapping the weight upwards against the handle. It should be done with caution as if done vigorously, the life of the instrument will be reduced.

Benefits of DCP:

- Soil information is often limited, and is often collected from within the extents of the foundation area, but one may also need to assess the soils somewhere else on the site.
- Information regarding the variation of soil strength with depth can be obtained, which can be critical for developing the best solution for unsuitable subgrade soils.
- One can collect information from a lot of points relatively quickly, so you can see how soil conditions vary across the site and respond accordingly.
- One gets accurate and precise information on the soil conditions in the field and at construction time.

Advantage:

1. Continuous resistance with depth is recorded
2. Static resistance is more appropriate to determine static properties of soil

Disadvantage:

1. If a small rock piece is encountered resistance shown is erratic and incorrect
2. 3.involves handling heavy equipment

Plate Load Test:

The allowable bearing pressure can be determined by conducting a plate load test at the site. The conduct a plate load test, a pit of the size 5Bp X 5Bp, where Bp is thesize of the plate, is excavated to the depth equal to the depth of foundation(D_f).The size of the plate is usually 0.3m square. It is made of steel and is 25mm thick. Occasionally circular plates are also used. Sometimes large size plates of 0.6m square are used.

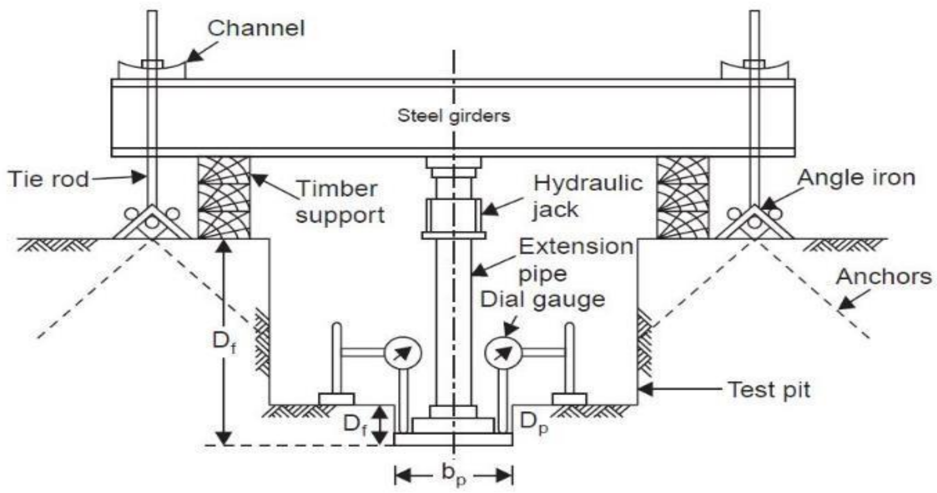


Fig 3 plate load test setup

[Fig3 https://structville.com/2021/03/how-to-determine-the-bearing-capacity-of-soils-from-plate-load-test.html]

A central hole of size Bp X Bp is excavated in the pit the depth of the centralhole(D_p)is obtained from the following relation

$$\frac{D_p}{B_p} = \frac{D_f}{B_f}$$

$$D_p=(D_f/B_f)B_p$$

$$=(B_p/ B_f)D_f$$

Where,

B_f-width of the pit

B_p-size of plate

The conducting the plate load test, the plate is placed in the central hole and the load is applied by means of a hydraulic jack. the reaction to the jack is provided by means of a reaction beam. Sometimes truss is used instead of a reaction beam to take up the reaction. Alternatively, a loaded platform can be used to provide reaction.

Varieties in Plate load test and their durations: -

Plate load test is performed under two variations:

1) Gravity load test (Reaction Loading method)

2) Reaction truss method

The total duration required to perform a complete test varies from 6-7 days which includes installations, test, dismantling. The results of the test in case of soft strata can be obtained within a few hours whereas in case of hard strata it might take close to a couple of days.

1. Gravity load test

In this type of method, a rigid platform is utilized to transfer loads through loading of sandbags or concrete blocks. These blocks and sandbags act as a dead weight, and whole arrangement rests upon vertical columns. The hydraulic jack is provided in between the rigid plate and top of the column to transfer the load properly.

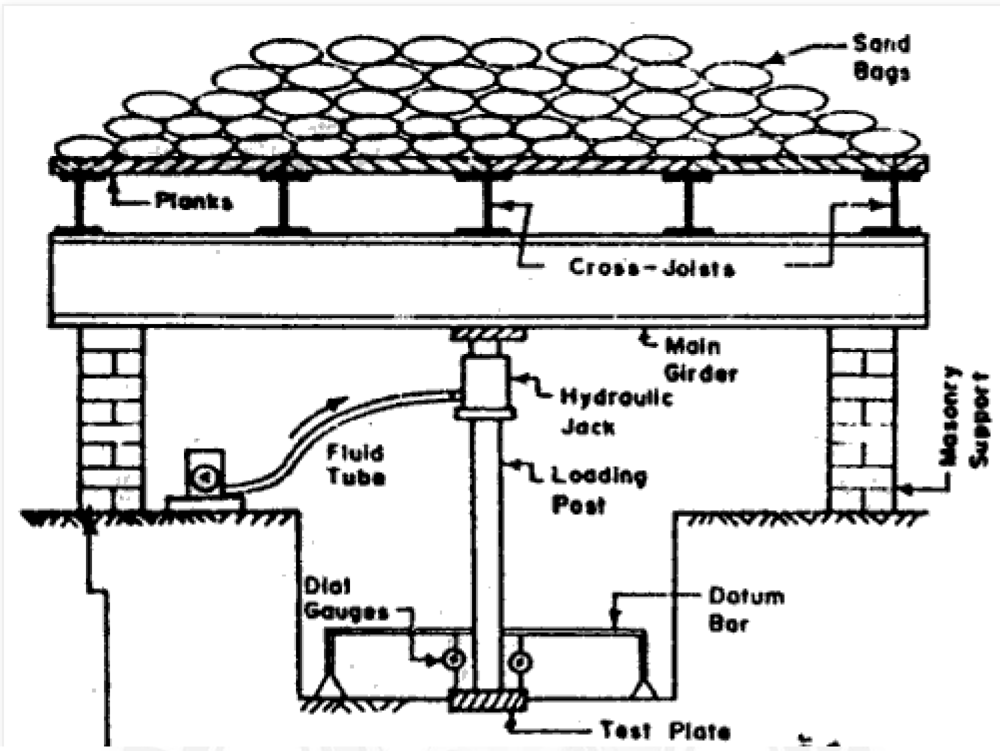


Fig 4 Sand bag method

[Fig4 http://www.abuildersengineer.com/2012/10/plate-load-test-foundation-site.html]

2. Reaction truss method

In this method, the reaction generated through jack is borne by reaction truss installed over it. The undesirable movement of truss is controlled by soil anchors or nails fixed into the soil with the help of hammers. The most commonly observed truss is made of mild steel sections. In order to curb later movement, truss is locked with guy ropes.

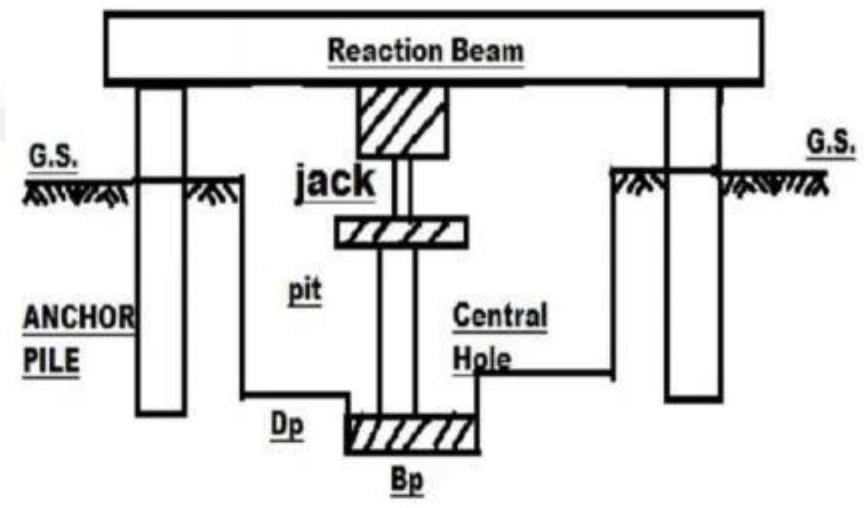


Fig 5Reaction truss method

[Fig5 https://www.ww-99.top/products.aspx?cname=plate+bearing+test&cid=6/]

A seating load of KN/m^2 is first applied, which is released after the sometimes. The is then applied in increments of about 20% of the estimated safe load or $1/10^{th}$ of the ultimate load. The settlement is recorded after 1,5,10,20,40,60 minutes and further after an internal of one hour. These hourly observations are continued for clayey soils, until the rate of settlement is less than 0.2mm per hour. The test is conducted until failure or at least until the settlement of 25mm has occurred

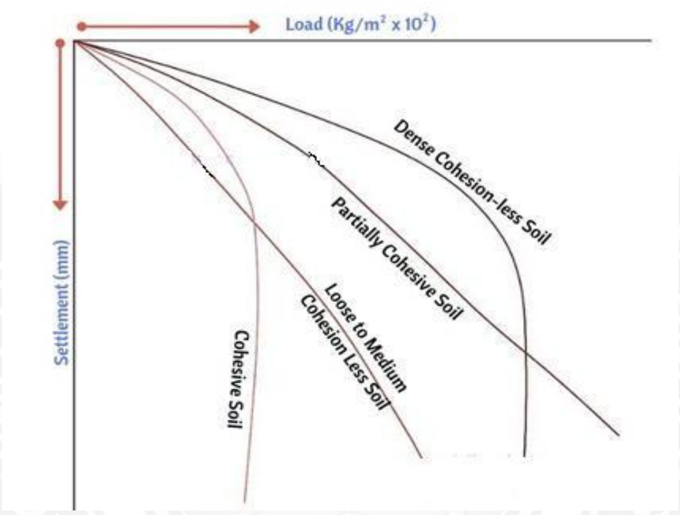


Fig 6 Load settlement Curve

[Fig 6https://civilread.com/plate-load-test/]

The ultimate load for the plate is indicated by a break on the log-log between the load intensity q and the settlements. If the break is not will defined the ultimate load is taken as the corresponding to the settlement of $1/5^{th}$ of the plate width(Bp) onthe natural plot. The ultimate load is obtained from the intersection of the tangents drawn

Determination of bearing capacity:

1.The ultimate bearing capacity of the proposed foundation $q_u(f)$ can be obtained fromthe following relations

a) For sandy or gravel soil:

$$q_f = q_p \frac{B}{B_p}$$

b) For clay soil

$$q_f \cong q_p$$

c) For $C - \varphi\ Soil$:

$$Q = q.A + PS$$

where,

B_f –foundation width

B_p –Plate width

$q_f = bearing\ capacity\ of\ foundation$

$q_p = bearing\ capacity\ of\ plate$

Q=Total load

A=Area of footing or plate

P=perimeter of footing or plate

Q=bearing Pressure

S=perimeter area

Determination of settlement:

2. The plate load test can also be used to determine the settlement for a given intensity ofloading (q_0). The relations between the settlement of the plate (s_p)and that of the foundation (s_f) for the same load intensity

a) For clayey soils, $s_f = s_p(B_f/B_p)$ -----------(3)

where s_p is obtained from the load intensity settlement curve for q_0

b) For sandy soils

$$S_f = S_p \left[\frac{B_f(B_p+30)}{B_p(B_f+30)}\right]^2 \text{ ----------(4)}$$

Where B_f – width of foundation in meters

B_p – width of the plate in meters

3. For designing a shallow foundation for an allowable settlement of s_f,A trial and errorprocedure is adopted. First of all, a value of B_f is assumed and value of q_0 is obtained as

$$q_0 = Q/A_f \text{ ---------- } (5)$$

where A_f - area of footing

Q – Load

For the computed value of q_0 the plate settlement(s_p) is determined from the load – settlement curve obtained from the plate load test the values of s_f is computed equation 3if the soil is clay and using 4 if sand. The computed with the allowable settlement. The procedure is repeated till the computed value is equal to the allowable settlement

The plate load test is can be also be used for the determination of the influence factor I_f,

$$S_i = \left(\frac{1-\mu^2}{E}\right) qBI_f$$

The above graph shows a plot between settlements and the load qB,The slope of the line is equal to $\frac{1-\mu^2}{E}$

LIMITATIONS OF PLATE LOAD TEST:

1. SIZE EFFECT:

   The results of the plate load test reflect the strength and the settlement characteristics of the soil within the pressure bulbs. As the pressure bulb depends upon the size of the loaded area it is much deeper for the actual foundation as compared to that of plate. The plate load test does not truly represent the actual conditions to a large depth.

2. SCALE EFFECT:

   The ultimate bearing capacity of saturated clays is independent of the size of the plate but for cohesionless soils. It increases with the size of the plate to reduce scale effect, it is desirable to repeat the plate load test with plates of two or three different sizes and the average of the bearing capacity values obtained.

3. TIME EFFECT:

   A plate load test is essentially a test of short duration for clayey soils it does not give the ultimate settlement. The load settlement curve is not truly representative.

4. INTERPRETATION OF FAILURE:

The failure load is not well defined except in the case of a general shear failure an error of personal interpretation may be involved in other type of failures

5. REACTION LOAD:

It is not practicable to provide a reaction of more than 250KN.Hence the test on a plate of size larger than 0.6m width is difficult.

6. WATER TABLE:

The level of water table affects the bearing capacity of the sandy soils.If the water table is above the level of the footing it has to be lowered by pumping before placing at the water table level if it is within about 1m below the footing.

Advantages of Plate Load Test:

- Bearing able to evaluate the actions of the base under loading conditions.
- Assessing soil capability at a certain depth and predicting settlement over a certain load.
- A shallow foundation could be determined on the basis of the permissible bearing size, which can be estimated in the context of a plate load test.
- Time and cost-effective
- It's easy to execute.

Disadvantages of Plate Load Test:

- Depth of impact is small and can hardly offer soil power.
- It does not have details on the prospects for long-term consolidation of the base soil.
- The scale of the test plate is smaller than the real base, hence why there is a scale impact.
- Significant land disturbance happens after drilling is finished.

Problems:

1.The following data were obtained from a plate load test carried out on a 60cm square test plate at a depth of 2m below ground surface on a **sandy** soil which extends upto a large depth. Determine the settlement of foundation 3x3m carrying a load of 1100KN .

Load intensity(KN/m²)	50	100	150	200	250	300	350	400
Settlement mm	2.0350	4.0	7.5	11.0	16.3	23.5	34.0	45.0

Given data:

B_p=60cm=0.6m

D=2m

sandy soil

B=3m

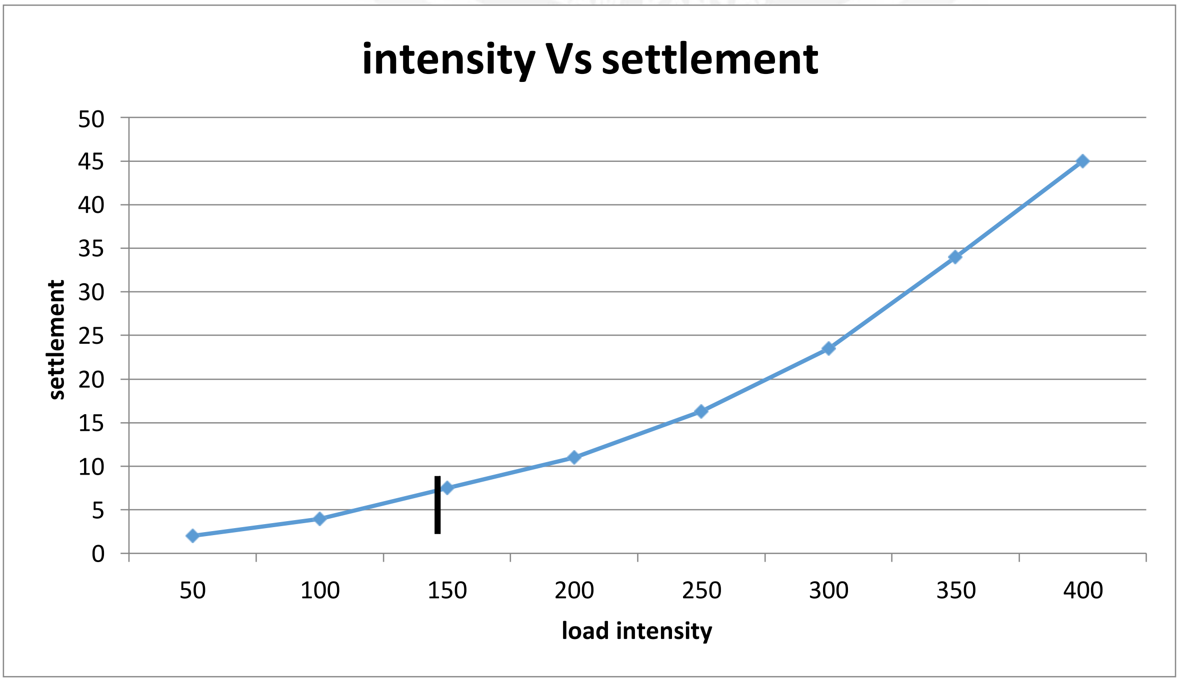
load = 1100KN

To find:

Settlement=?

Solution:

$$intensity = \frac{Load}{area} = \frac{1100}{3^2} = 122.22Kn/m^2$$



For load intensity 122.22 the settlement is 7mm

S_p=7mm

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

$$S_f = 7 \left[\frac{3(0.6 + 0.3)}{0.6(3 + 0.3)}\right]^2$$

$$S_f = 13.01\text{mm}$$

2.A plate load test was conducted on a uniform deposit of sand at a depth of 1.5m below the natural ground level and the following data were obtained

Pressure(Kpa)	0	50	100	200	300	400	500
Settlement(mm)	0	2	4.5	10	17	30	50

The size of plate was 600x600mm and that of pit 3mx3mx1.5m

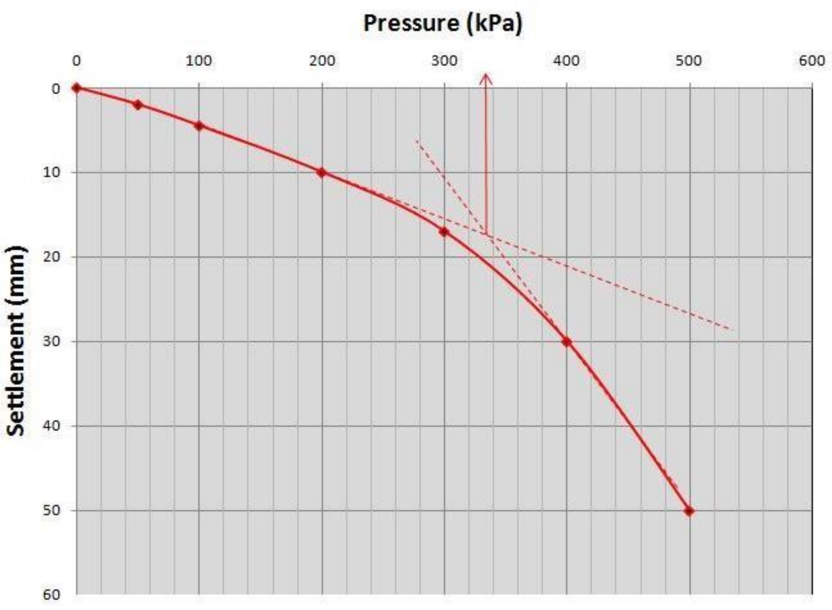
i)Plot the pressure settlement curve and determine the failure stress

ii) A square footing,1.5x1.5m is to be founded at 1.5m depth in this soil. Assuming the FOS against shear failure as 3 and maximum permissible settlement as 25mm Determine the allowable bearing pressure

iii) Design of footing for a load of 600KN if the water table is at a great depth.

Solution:

Draw a graph between load and settlement. The failure is obtained by tangent the line. From the graph the failure pressure is q_p=335KN/m^2.



For sandy or gravel soil:

$$q_f = q_p \frac{B}{B_p}$$

$$= 335x\frac{1.5}{0.6} = 837.5KN/m^2$$

$$q_a = \frac{q_f}{F} = \frac{837.5}{3} = 279.16KN/m^2$$

From settlement consideration:

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

$$= 25 \left[\frac{1.5(0.6 + 0.3)}{0.6(1.5 + 0.3)}\right]^2 = 16mm$$

From the load settlement curve, the settlement corresponds to a pressure of 290KN/m^2

$$The\ maximum\ allowable\ service\ column\ load = 1.5x1.5x290$$

$$= 652.5KN.$$

This shows that a column load of 600KN can be safely supported on footing of 1.5x1.5m on the soil

Net allowable bearing pressure:

For settlement 25mm

$$q_p = 35(N-3)\left(\frac{B+0.3}{2B}\right)^2 .Rw_2.R_d$$

For settlement 40mm

$$q_p = 55(N-3)\left(\frac{B+0.3}{2B}\right)^2 .Rw_2.R_d$$

N=standard penetration number

$$Rw_2 = 0.5\left[1 + \frac{Zw_2}{B}\right]$$

$$R_d = depth\ factor = \left[1 + 0.2\frac{D}{B}\right] \leq 1.2$$

1.A strip footing 1.5m wide is located at a depth of 2m over a cohesionless soil.The standard penetration test was conducted having corrected N value of 20.If the depth of water table is 3m below the ground level Then determine the allowable bearing pressure for the soil.

Given data:

strip footing

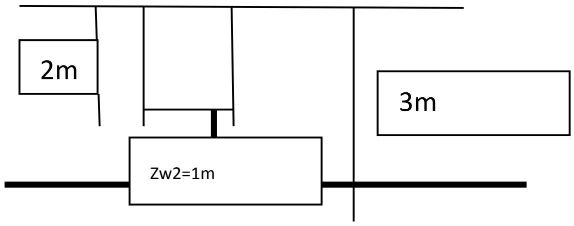
B=1.5m

D=2m

cohesionless soil

standard penetration test

N=20



To find:

q_a=?

Solution:

$$q_f = 35(N-3)\left(\frac{B+0.3}{2B}\right)^2 . Rw_2 . R_d$$

$R_{w2} = 0.5\left[1 + \frac{Z_{w2}}{B}\right]$=1.3

$$R_d = depth\ factor = \left[1 + 0.2\frac{D}{B}\right] \leq 1.2$$

$R_d = \left[1 + 0.2\frac{2}{1.5}\right] =$ 1.26

$$q_f = 35(20-3)\left(\frac{2+0.3}{2x1.5}\right)^2 . 1.3x1.26$$

=573.35KN/m^2