# Foundation Engineering

## CE – 6502 FOUNDATION ENGINEERING

### Important Questions and Answers

1. **What are the types of shear failure? (AU NOV/DEC 2014)**

The types of shear failure are general shear failure, local shear failure, punching shear failure.

2. **What are assumptions in terzaghi's bearing capacity theory? (AU APR/MAY 2015)**

The base of the footing is rough

The load on footing is vertical and uniformly disturbed

The footing is continuous

3. **Define allowable bearing capacity? (AU APR/MAY 2012)**

It is the net loading intensity at which neither the soil fails in shear nor there is excessive settlement detrimental to the structure.

4. **What are the factors which depends depth? (AU NOV/DEC 2014)**

Type of soil, size of structure, magnitude of loads, environmental conditions etc.

5. **Define shallow foundation. ( AU APR/MAY 2012)**

If the depth of the foundation is less than its breath, such foundation is known as shallow foundation.

6. **Define significant depth? ( AU NOV/DEC 2015)**

Exploration depth, in general it should be carried out to a depth upto which increase in the pressure due to structural loading is likely to cause a shear failure, such depth is known as significant depth.

7. **What is the difference between disturbed sample and undisturbed sample? (AU APR/MAY 2016)**

Disturbed soil sample

a. Natural structure of soil get partly or fully modified and destroyed

Undisturbed soil sample

b. Natural structure and properties remain preserved

8. **What are the methods of boring? (AU APR/MAY 2014)**

Auger borings, shell boring, wash boring, rotary boring, percussion boring.

**9. Define area ratio (AU NOV/DEC 2015)**

Area ratio is defined as the ratio of maximum cross sectional area of the cutting edge to the area of the soil sample.

**10. Under what circumstances, a strap footing is adopted? (AU APR/MAY 2013)**

When the distance between the two columns is so great, so that trapezoidal footing is narrow and so it is uneconomical. It transfers the heavy load of one column to other column.

**11. What is a mat foundation? (AU APR/MAY 2013)**

It is a combined footing that covers the entire area beneath a structure and supports all the walls and columns.

**12. Define spread footing? (AU APR/MAY 2014)**

It is a type of shallow foundation used to transmit the load of isolated column, or that of wall to subsoil. The base of footing is enlarged and spread to provide individual support for load.

**13. Define floating foundation?(AU NOV/DEC 2015)**

It is defined as a foundation in which the weight of the building is approximately equal to the full weight of the soil including water excavated from the site of the building.

**14. What is meant by proportioning of footing? (AU APR/ MAY 2014)**

Footings are proportional such that the applied load including the self weight of the footing including soil. The action are not exceeding the safe bearing capacity of the soil.

**15. List out the type of pile based on material used? (AU APR/MAY 2010)**

Timber pile, concrete pile, steel pile and composite pile

**16. How is the selection of pile carried out? (AU NOV/DEC 2014)**

The selection of the type, length, and capacity is usually made from estimation based on the soil condition and magnitude of the load.

**17. What are the factors consider while selecting the type of pile? (AU APR/MAY 2012)**

The loads

Time available for completion of the job

Availability of equipment

The ground water conditions

The characteristic of the soil strata involved

**18. What are methods to determine the load carrying capacity of a pile? (AU APR/MAY 2014)**

Dynamic formulae

Static formula

Pile load test

Penetration tests

**19. How do you check the stability of retaining walls? (AU APR/MAY 2014)**

The wall should be stable against sliding

The wall should be stable against overturning

The base of the wall should be stable against bearing capacity failure

**20. Define angle of repose? (AU NOV/DEC 2014)**

Maximum natural slope at which the soil particles may rest due to their internal friction, if left unsupported for sufficient length of time.

**21. Define theory of plasticity? (AU NOV/DEC 2012)**

The theory on which the condition of the stress in a state of a plastic equilibrium is called as theory of plasticity.

**22. What are the assumptions in coulomb wedge theory? (AU APR/MAY 2010)**

The backfill is dry, cohesionless, isotropic, homogenous,

The slip surface is plane which passes through the head of the wall

**23. How to prevent land sliding? (AU APR/MAY 2015)**

Sheet piles, retaining wall may be used to prevent the land sliding.

**24. Write down any two assumptions of rankine's theory? (AU NOV/DEC 2016)**

The soil mass is semi infinite soil, cohesionless backfill, homogenous soil, the top surface is a plane which may be inclined or horizontal.

PART B

1. (i) Explain the arrangements and operation of stationary piston sampler. State its advantages over other samplers.

(*) A piston sampler consist of two seperate parts

(a) Sampler cylinder &

(b) Piston system.

(*) The piston which is actuated seperately, fits tightly in the sampler cylinder.

(*) It contains a piston (or) plug attached to a long piston rod extending upto the ground surface through the drill rod.

(*) During lowering of the sampler through the hole, the lower end of the sampler is kept closed with the piston.

(*) At the proposed sampling depth, the piston is fixed in relation to the ground and the sampler cylinder is forced into the soil independently, cutting a sample out of the soil.

(ii) Explain in detail the sailent features of bore log report. **(AU Nov / Dec 2014)**

BOREHOLE LOG

Location :
Project :
Boring method : Shell and auger
Diameter : 150 mm

BH No. 1
Ground RL : 46.3 m
Date of start : 1.1.1998
Completed on : 4.1.1998

| Description of start | R.L. | Legend | Depth | Samples | N | $q_u$ kN/m$^2$ | Remarks |
|---|---|---|---|---|---|---|---|
| Loose, light brown SAND (SP) | | | | R | 6 | | |
| | 43.7 | | 2.6 | | | | |
| Medium dense brown gravelly SAND (SW) ∇ W.T. | | | | R | 18 | | |
| | 42.5 | | | | | | Water level : 1.1.98 42.8 m; 2.1.98 42.5 m; 3.1.98 42.5 m |
| | 41.9 | | 4.4 | R | 20 | | |
| Firm to stiff, yellowish-brown, CLAY of high plasticity (CH) | | | | U | | 160 | |
| | | | | U | | 180 | |
| | | | | U | | 200 | |
| | | | | U | | 210 | |
| | 34.0 | | 12.3 | | | | |
| Very dense, red, silty SAND (SM) | | | | R | 50 | | |
| | | | | R | 62 | | |
| | | | | | 50 for 150 mm | | Refusal |
| | 30.0 | | 16.3 | | | | Termination level of borehole 30.0 m |

U : Undisturbed R : Representative sample

**Fig. 19.14** Borehole log

usually in a tabular form showing (i) the soil profile with elevations of different strata (ii) ground water level, (iii) termination level of the borehole, (iv) the depths or ranges of depth at which samples were taken or at

(ii). Refer bore log dia from (Basic & Applied Soil Mechanics by Gopal Ranjan)

The salient features of the bore log report are.

(i) The soil profile with elevations of different strata are shown.

(ii) It shows the ground water table.

(iii) It shows the termination depth of the borehole.

(iv) Also shows the depths or ranges at which samples were taken or at which in situ tests were performed.

(iv) The type of soil at different depths.

(v) N value at the measured elevation.

(vi) It shows the method of boring.

(vii) Name of the project & location of the project.

(viii) The Borehole number of the specific site.

(ix) The starting & ending dates of the boring operation.

(x) The diameter of the bore hole drilled, in general 150 mm.

2. A strip footing 2m wide carries a load intensity of 560kN/m2 at a depth of 1.2m in sand. The saturated unit weight of sand is 18kN/m3 and unit weight have a water table at 16.8 kN/m3.

The shear strength parameters are C = 0 and angle of friction 35° determine the factor safety with respect to shear failure for the following cares of location of water table.

(a) Water table is 3m below GL
(b) Water table is at GL itself
(c)Water table is 4m below GL
(d)Water table is 0.5m below GL **(AU Nov / Dec 2015)**

**Solution.** For a strip footing, the bearing capacity is given by

$$q_f = cN_c + \bar{\sigma} N_q + \tfrac{1}{2} B \gamma N_\gamma$$

Taking into account the water reduction factor, we have, from Eq. 24.34

$$q_f = cN_c + \gamma D N_q R_{w_1} + \tfrac{1}{2} B\gamma N_\gamma . R_{w_2}$$

For the present case $c = 0$. $\therefore$ $q_f = \gamma D N_q . R_{w_1} + \tfrac{1}{2} B \gamma N_\gamma . R_{w_2}$

For $\phi = 35°$ assuming general shear failure, $N_q = 41.4$ and $N_\gamma = 42.4$

$$\therefore \quad q_f = 41.4 \times 1.2 \times \gamma R_{w_1} + \tfrac{1}{2} \times 2 \times 42.2 \gamma R_{w_2}$$

$$q_f = 49.68 \gamma R_{w_1} + 42.3 \gamma R_{w_2} \qquad ...(1)$$

***Case (a) Water table is 4 m below G.L.***

$Z_{w_2} = 4 - 1.2 = 2.8$ m ; $R_{w_1} = 1$

Since $Z_{w_2} > B$, $R_{w_2} = 1$.

Hence there will be no effect of water table. Also $\gamma = 16.8$.

$$\therefore \quad q_f = 49.68 \times 16.8 \times 1 + 42.4 \times 16.8 \times 1$$

$$= 1546.9 \text{ kN/m}^2$$

Now actual footing load $= q_a = 400$ kN/m²

$$\therefore \quad F.S = \frac{q_f}{q_c} = \frac{1546.9}{400} \approx 3.87$$

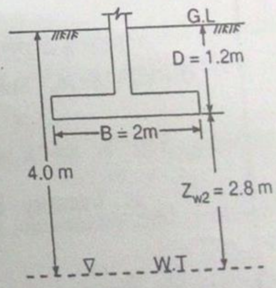



FIG. 24.16

***Case (b) Water table is just at the base of footing.***

$$\therefore \quad R_{w_1} = 0.5\left(1 + \frac{Z_{w_1}}{D}\right) = 0.5\,(1 + 1) = 1$$

$$R_{w_2} = 0.5\left(1 + \frac{Z_{w_2}}{B}\right) = 0.5\,(1 + 0) = 0.5$$

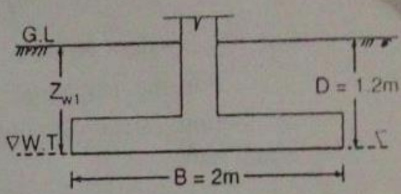



FIG. 24.17

$\therefore$ For the surcharge term, use $\gamma = 16.8$ kN/m$^2$, because the surcharge soil is situated above water table. For the 'wedge term', use $\gamma = \gamma_{sat} = 19.5$ kN/m$^3$, since the wedge soil is situated below water table.

$$\therefore \quad q_f = 49.68\,\gamma R_{w_1} + 42.4\,\gamma_{sat} \cdot R_{w_2}$$

or $$q_f = 49.68 \times 16.8 \times 1 + 42.4 \times 19.5 \times 0.5 = 1248 \text{ kN/m}^2$$

$$\therefore \quad \text{F.S.} = \frac{q_f}{q_a} = \frac{1248}{400} = 3.12.$$

***Case (c) Water table at 2.5 m below the G.L.*** (Fig. 24.18 *a*)

$$Z_{w_2} = 2.5 - 1.2 = 1.3 \text{ m} < B. \qquad \therefore \qquad R_{w_1} = 1$$

$$R_{w_2} = 0.5\left(1 + \frac{Z_{w_2}}{B}\right) = 0.5\left(1 + \frac{1.3}{2}\right) = 0.825.$$

For the surcharge term, $\gamma = 16.8$ kN/m$^3$

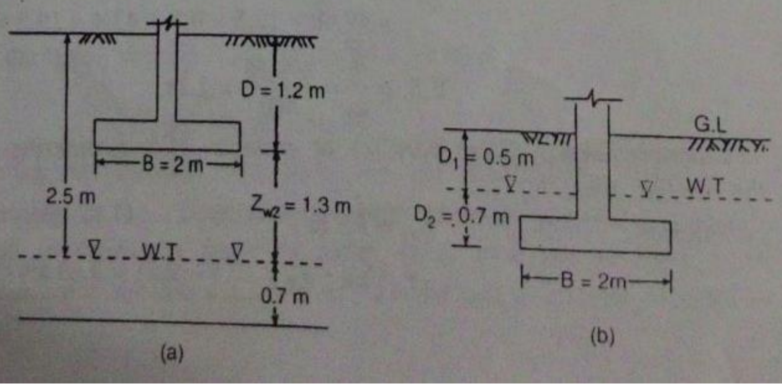
For the *wedge term,* $\gamma$ will be taken as *average unit weight* of soil situated below the footing level, since the soil upto depth $B$ below the footing is partly above water table and partly below the water table.

$$\gamma_{av} = \frac{(16.8 \times 1.3) + (19.5 \times 0.7)}{(1.3 + 0.7)} = 17.75 \text{ kN/m}^3$$

Hence from Eq. 1, we have $q_f = 49.68\,\gamma\,R_{w_1} + 42.4\,\gamma_{av}\,R_{w_2}$

$$= (49.68 \times 16.8 \times 1) + (42.4 \times 17.75 \times 0.825) = 1455.5 \text{ kN/m}^2$$

$$\therefore \quad \text{F.S.} = \frac{q_f}{q_a} = \frac{1455.5}{400} = 3.64$$



*Case (d) Water table is 0.5 m below G.L.* (Fig. 24.18 *b*)

$$Z_{w_1} = 0.5$$

$$\therefore \quad R_{w_1} = 0.5\left(1 + \frac{Z_{w_1}}{D}\right) = 0.5\left(1 + \frac{0.5}{1.2}\right) = 0.708$$

$R_{w_2} = 0.5$. Since water table is above footing.

For the wedge term, $\gamma = \gamma_{sat}$ 19.5 kN/m$^3$

For the surcharge term, take $\gamma$ = average unit weight of soil situated above the base of footing, since this soil is located partly above the water table and partly below the water table.

$$\therefore \quad \gamma_{av} = \frac{(16.8 \times 0.5) + (19.5 \times 0.7)}{(0.5 + 0.7)} = 18.38$$

Hence from Eq. 1. $q_f = 49.68\, \gamma_{av} R_{w_1} + 42.4\, \gamma_{sat} R_{w_2}$

$$= (49.68 \times 18.38 \times 0.708) + (42.4 \times 19.5 \times 0.5) = 1060 \text{ kN/m}^2$$

$$\therefore \quad F.S = \frac{q_f}{q_a} = \frac{1060}{400} = 2.65.$$

*Note.* Alternatively, $q_f$ can be calculated by taking $\bar{\sigma}$ in place of $\gamma D$ term, *without* considering reduction factor $R_{w_1}$ as recommended by IS code (see § 24.12)

$$q_f = \bar{\sigma} N_q + \tfrac{1}{2} B \gamma N_\gamma . R_{w_2}$$

or $$q_f = \bar{\sigma}(41.4) + (\tfrac{1}{2} \times 2 \times 42.4)\, \gamma_{sat} R_{w_2}$$

where $\bar{\sigma}$ = effective overburden pressure $= (\gamma_1 D_1 + \gamma_2 D_2) - \gamma_w D_2$ (Eq. 24.36 *a*)

$$= (16.8 \times 0.5) + (19.5 \times 0.7) - (9.81 \times 0.7) = 15.183$$

$$\therefore \quad q_f = 15.183 \times 41.4 + \tfrac{1}{2} \times 2 \times 42.4 \times 19.5 \times 0.5 = 1042 \text{ kN/m}^2$$

against a value of 1060 kN/m$^2$.

*Case (e) Water table at the ground level.*

When water table is at ground level,

$R_{w_1} = 0.5\,(1 + 0) = 0.5$; $\quad R_{w_2} = 0.5$

$\gamma = \gamma_{sat} = 19.5$ for both the surcharge soil as well as the wedge soil.

Hence from Eq.(1) $q_f = 49.68\, \gamma_{sat} R_{w_1} + 42.4\, \gamma_{sat} R_{w_2}$

$$= 49.68 \times 19.5 \times 0.5 + 42.4 \times 19.5 \times 0.5 = 897.78 \text{ kN/m}^2$$

$$\therefore \quad F.S. = \frac{q_f}{q_a} = \frac{897.78}{400} = 2.24.$$

**3.** Explain in detail about the various types of pile foundation with neat sketch and write their functions **(AU Nov / Dec 2015)**

26

# Pile Foundations

## 26.1. TYPES OF PILES

The use of piles as a foundation can be traced since olden times. The art of driving piles was well-established in Roman times and the details of such foundations were recorded by Vitruvious in 59 A.D. Today, pile foundation is much more common than any other types of deep foundation. Modern pile driving started with the first steam pile drivers, invented by Nasmyth in 1845. Piles may be classified as follows :

**(a) Classification based on the function.** Based on the function or the use, piles may be classified as : (1) end bearing pile (2) friction pile (3) compaction pile (4) tension pile or uplift pile (5) anchor pile (6) fender pile and dolphins (7) batter pile (8) sheet pile.

*End bearing piles* are used to transfer load through water or soft soil to a suitable bearing stratum.

*Friction piles* are used to transfer loads to a depth of a friction load carrying material by means of skin friction along the length of the piles.

*Compaction piles* are used to compact loose granular soil, thus increasing their bearing capacity. The compaction piles themselves do not carry any load. Hence they may be of weaker material–sometimes of sand only. The pile tube, driven to compact the soil, is gradu-

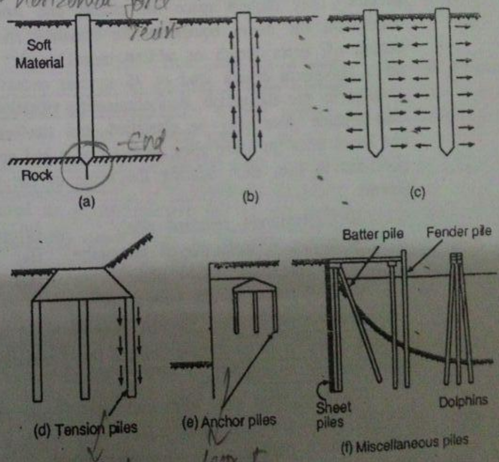



FIG. 26.1. CLASSIFICATION BASED ON FUNCTION.

ally taken out and sand is filled in its place thus forming a 'sand pile'.

*Tension or uplift piles* anchor down the structures subjected to uplift due to hydrostatic pressure or due to overturning moment.

*Anchor piles* provide anchorage against horizontal pull from sheet piling or other pulling forces.

*Fender piles and dolphins* are used to protect water front structures against the impact from ships or other floating objects. *Sheet piles* are commonly used as bulkheads, or as impervious cutoff to reduce seepage and uplift under hydraulic structures. The *batter piles* are used to resist large horizontal or inclined forces.

(*b*) **Classification based on materials and composition.**

1. *Concrete piles* :
   - (*a*) Precast
   - (*b*) Cast-in-situ
     - (*i*) Driven piles : Cased or uncased
     - (*ii*) Bored piles : Pressure piles and under-reamed piles.
2. *Timber piles*
3. *Steel piles* :
   - (*a*) H-piles (*b*) Pipe pile (*c*) Sheet pile.
4. *Composite piles* :
   - (*a*) Concrete and timber (*b*) Concrete and steel.

The *precast concrete piles* are generally used for a maximum design load of about 80 tonnes, except for large pre-stressed piles. They must be reinforced to withstand handling stresses. They require space for casting and storage, more time to set and cure before installation and heavy equipment for handling and driving. They also incur large cost in cutting off extra length or adding more length. The *cast-in-situ* piles are generally used for a maximum design load of 75 tonnes, except for compacted, pedestal piles. They are installed by pre-excavation, thus eliminating vibration due to driving and the handling stresses. Cast-in-place piles may be classified into two classes : driven piles (cased or uncased) and bored piles (pressure piles, pedestal piles and under-reamed piles). A variety of cast-in-situ piles are in use, each bearing the name of the manufacturer. The common types are as follows :

- (*i*) Raymond standard pile,
- (*ii*) Raymond step-taper pile,
- (*iii*) Union metal pile of monotube,
- (*iv*) MacArthur compressed uncased pile,
- (*v*) MacArthur cased pile,
- (*vi*) Franki standard pile,
- (*vii*) Western button bottom pile etc.

*Under-reamed pile* is special type of bored pile having an increased diameter or bulb at some point in its length, to anchor the foundation in expansive soil subjected to alternate expansion and contraction.

*Concrete filled steel piles* and steel *H-pile* sare used as long piles with high bearing capacity. They are rarely used unless they reach a stratum of exceptionally high supporting capacity, since their cost is very high. *Timber piles* have small bearing capacity, and are not permanent unless treated. They are prone to damage by hard driving, and should not



be driven through hard stratum or boulders. *Composite piles* are suitable where the upper part of a pile is to project above the water table. Such a pile consists of a lower portion of untreated timber and an upper portion of concrete. In the other type of composite piles, steel piles are attached to the lower end of cast-in-place concrete pile. This type is used in case where the required length of piles is greater than that available for the cast-in-place type.

**4.** Explain in detail about the culmann's graphical method for finding active pressure with a neat sketch. **(AU May / June 2016)**

## 20.10 . CULMANN'S GRAPHICAL METHOD FOR ACTIVE PRESSURE

Culmann (1886) also gave a graphical solution to evaluate the active earth pressure by the Coulomb's theory. His method is more general than Rebhann's method, and can be conveniently used for ground surface of any shape, for various types of surcharge loads, and for a layered backfill of different densities.

*Procedure:*

1. Draw the ground line, $\phi$-line and the $\psi$-line as usual.

2. Take a slip plane $BC_1$. Calculate the weight of the wedge $ABC_1$ and plot it as $BE_1$, to some scale, on the $\phi$-line.

3. Through $E_1$, draw $E_1F_1$ parallel to the $\psi$-line, to cut the slip plane $BC_2$ in $F_1$.

4. Similarly take another slip plane $BC_2$, calculate the weight of wedge $ABC_2$ and plot it as $BE_2$ on the $\phi$-line. Draw $E_2F_2$ parallel to the $\psi$-line to cut the slip plane $BC_2$ in $F_2$.

5. Take a number of such slip planes $BC_3$, $BC_4$ etc., plot the weight

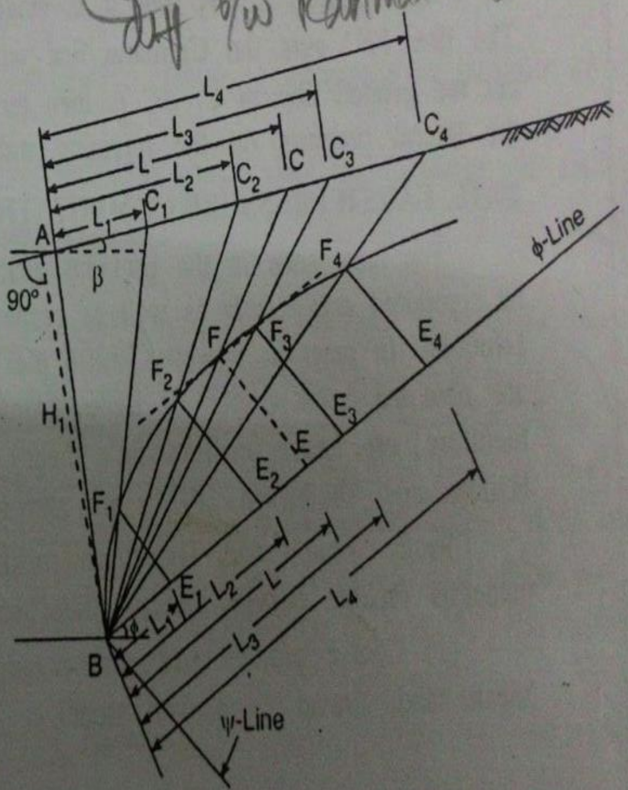



FIG. 20.28. CULMANN'S GRAPHICAL METHOD FOR ACTIVE PRESSURE.

of the corresponding wedges on the $\psi$-line and obtain points $F_3$, $F_4$, etc.

6. Draw a smooth curve through points $B$, $F_1$, $F_2$, $F_3$, $F_4$ etc. This curve is known as the Culmann's line.

7. Draw a tangent to the Culmann's line, parallel to the $\phi$-line. The maximum value of the earth pressure is represented by the intercept $EF$, on the adopted scale, $EF$ being drawn through the point of tangency parallel to the $\psi$-line. $BFC$ represents the critical slip plane.

8. To locate the point of application of the resultant pressure, draw a line (not shown) parallel to the cirtical slip plane $BC$, through the centre of gravity of the sliding wedge $ABC$ and obtain its intersection on the back $AB$.

When the ground line is a plane, the weights of the wedges $ABC_1$, $ABC_2$, $ABC_3$, $ABC$ etc. are proportional to the length $AC_1$ $(=L_1)$, $AC_2$ $(=L_2)$, $AC_3$ $(=L_3)$, $AC$ $(=L)$ etc., since the height of each soil wedge is constant being equal to $H_1$. Hence the weights of these wedges are plotted as their base lengths $L_1$, $L_2$, $L_3$, $L$ etc. on the $\phi$-line.

Let $L$ = base length of the critical wedge $= BE$

The total active pressure is calculated from the relation

$$\frac{P_a}{W} = \frac{EF}{BE} \quad \ldots(20.60)$$

$$\therefore \quad P_a = W \cdot \frac{EF}{BE} = \frac{1}{2}\gamma H_1 L \frac{EF}{BE}.$$

or

$$P_a = \frac{1}{2}\gamma H_1 (EF) \quad \ldots(20.61)$$

If the backill also carries a surcharge of intensity $q$, $\gamma_1$ given by Eq. 20.59 is used in Eq. 20.61 instead of $\gamma$.

**5.** A trapezoidal footing is to be provided to support two square columns of 30cm and 50cm sides respectively. Columns are 6m apart and the safe bearing capacity of the soil is 400kN/m2. The bigger column carries 5000kN and the smaller 3000kN. Design a suitable size of the footing so that it does not extend beyond the faces of the columns. **(AU May / June 2016)**

**Example 25.7.** *A trapezoidal footing is to be produced to support two square columns of 30 cm and 50 cm sides respectively. Columns are 6 metres apart and the safe bearing capacity of the soil is 400 kN/m². The bigger column carries 5000 kN and the smaller 3000 kN. Design a suitable size of the footing so that it does not extend beyond the faces of the columns.*

*(Civil Services Exam. 1993)*

Area $$A = \frac{a+b}{2} L = \frac{P_1 + P_2}{q_s}$$

$$\therefore \ a + b = \frac{2}{6.8} \times \frac{5000 + 3000}{400} = 5.882 \text{ m} \quad \ldots(1)$$

Also, $$\bar{x} = \frac{0.5}{2} + x' = 0.25 + \frac{3000 \times 6.4}{5000 + 3000} = 2.65 \text{ m}$$

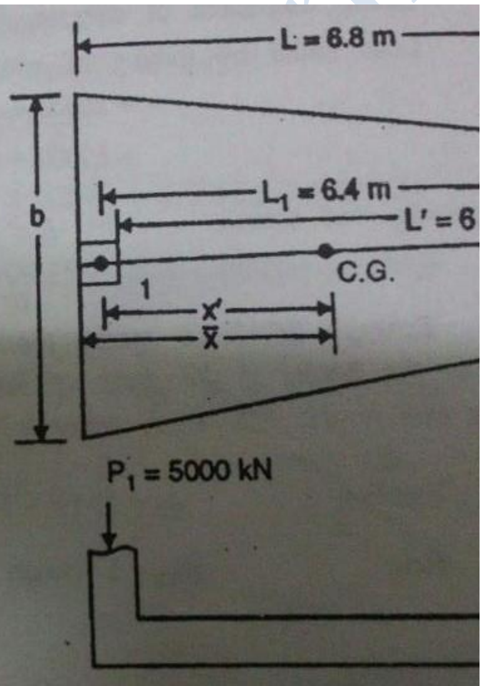



FIG. 25.13

6. What is meant by under-reamed pile. When and where they are used. Why? Discuss

At $\quad Z = 0, \; A_y = 2.435$ and $B_y = 1.623$

$$y = 0.0247(2.435 - 0.93 \times 1.623) = \mathbf{0.0228 \text{ cm}}$$

## 26.11. UNDER-REAMED PILE FOUNDATIONS

Under reamed piles are bored *cast-in situ* concrete piles having one or more *bulbs* formed by enlarging the bore hole for the pile stem by an under-reaming tool. These piles find applications in widely varying situations in different types of soils where foundations are required to be taken down to a certain depth to avoid the undesirable effect of seasonal moisture changes as in expansive soils or to reach strata or to obtain adequate capacity for downward, upward and lateral loads or to take the foundations below scour level and for moments.

Fig. 26.11 shows the details of the under reamed pile foundation. When the pile has only one bulb, it is known as *single under-reamed pile*, while the pile with more than one bulb is known as *multi-under-reamed* pile. Generally, the diameter of under-reamed bulbs is kept equal to 2.5 times the diameter of pile stem. However, it may vary from 2 to 3 times the stem diameter, if required, depending upon the design requirements and feasibility of construction.

**Details of pile and under-reamed bulb :** In deep layers of expansive soils, the minimum length of pile required is 3.5 m where the ground movements become negligible. In shallow depths of expansive soils and other poor soils depending upon the load requirements the length may be reduced and the piles may be taken upto at least 50 cm in stable zone (*i.e* the zone where there are no ground movements due to seasonal moisture changes). Pile length may be increased for higher loads.

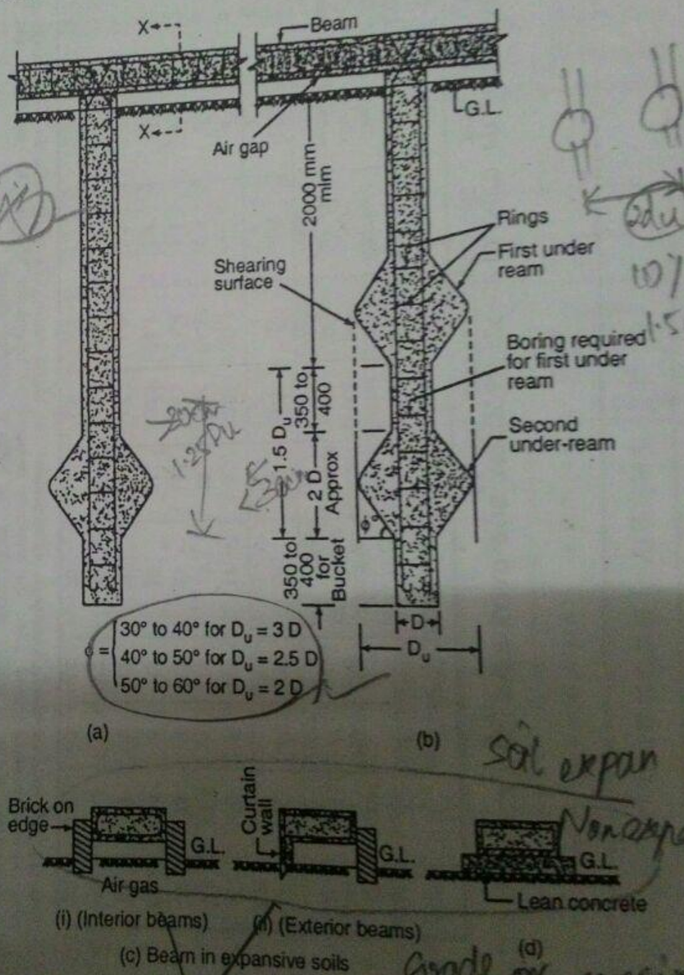



FIG. 26.11. DETAILS OF UNDER-REAMED PILE FOUNDATIONS.

The diameter of manually bored piles range from

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20 cm to 37.5 cm. The spacing of the piles shall be considered in relation to the nature of the ground, the types of piles and the manner in which the piles transfer the loads to the ground. Generally, the centre to centre spacing for under-reamed piles should not be less than $2\,D_u$ (where $D_u$ is the under-reamed diameter). It may be reduced to $1.5\,D_u$ when a reduction in load carrying capacity of 10 % should be allowed. For the spacing of $2\,D_u$ the bearing capacity of pile group may be taken equal to the number of piles multiplied by the bearing capacity of individual pile. If the adjacent piles are of different diameters, an averge value for spacing should be taken. The maximum spacing of the under-reamed pile should not normally exceed $2\frac{1}{2}$ metres so as to avoid heavy capping beams. In buildings, the piles should generally be provided under all wall junctions to avoid point loads on beams. Positions of intermediate piles are then decided trying to keep the door openings fall-in between two piles as far as possible.

In double and multi-under-reamed piles of size less than 30 cm dia, the centre-to-centre vertical spacing between the two under-reams may be kept equal to $1.5\,D_u$ while for piles of 30 cm and more this distance may be reduced to $1.25\,D_u$. The upper bulb should not be placed too close to the ground. The minimum desirable depth of the centre of the bulb is 1.5 m or $2\,D_u$ whichever is greater.

Under-reamed piles can be made at a batter also, for sustaining large lateral loads, thus making them suitable for tower footings, retaining walls and abutments. They have also been found useful for factory buildings, machine foundations and transmission line towers and poles. In black cotton soils and other expansive soils the under-reamed pile anchors the structures at a depth where the volumetric changes in soils due to seasonal and other variation is negligible.

The under-reamed pile is nominally reinforced with 10 to 12 mm dia. longitudinal bars, and 6 mm $\phi$ rings. The details of reinforcement are shown in Table 26.3. A clear cover of 4 cm is provided.

**Load carrying capacity from Soil Properties**

**Clayey soils.** In the case of clayey soils the ultimate load bearing capacity of an under-reamed pile may be worked out from the following expression :

$$Q_u = A_p\, N_c\, C_p + A_a \,.\, N_c . C_a' + C_a'\, A_s' + \alpha\, C_a\, A_s \quad \ldots (26.48)$$

where $Q_u$ = ultimate bearing capacity of the pile

$A_p$ = cross-sectional area of the pile stem at toe

$N_c$ = bearing capacity factor, usually taken as 1

$C_p$ = cohesion of the soil around the toe

$A_a = \frac{\pi}{4}(D_u^2 - D^2)$ where $D_u$ and $D$ are the under reamed bulb and stem diameter respectively

... cohesion of soil around the under-reamed bulbs

... circumscribing the under-reams

7. Determine the ultimate bearing capacity of a strip footing, 1.5m wide, with its base at a depth of 1m, resting on a dry sand stratum. Take $\gamma$ = 17kN/m3 ; $\phi$ = 38° ; use IS code method . for $N_q$ = 48.9 and $N_\gamma$ = 56.2 **(AU May / June 2013)**

... the one found in Example 24.5 (c).

**Example 24.7.** *Design a strip footing to carry a load of 750 kN/m*
*1.6 m in a c-φ soil having a unit weight of 18 kN/m³ and shear stre*
*as c = 20 kN/m² and φ = 25°. Determine the width of footing, using a fac*
*3 against shear failure. Use Terzaghi's equations.*

**Solution.** Assume general shear failure. From Eq. 24.12.

$$q_f = cN_c + \bar{\sigma} N_q + 0.5\,\gamma\, BN_\gamma$$

For $\phi = 25°$ we have $N_c = 25.1$, $N_q = 12.7$ and $N_\gamma = 9.7$ from Ta
$\bar{\sigma} = \gamma D = 18 \times 16$. Substituting the values, we get

$$q_f = (20 \times 25.1) + (18 \times 1.6) \times 12.7 + 0.5 \times 1$$

or
$$q_f = 502 + 365.8 + 87.3\,B = 867.8 + 87.3\,B$$

∴ Intensity of pressure, at F.S. of 3 at footing level

$$= \frac{q_f}{3} = \frac{867.8 + 87.3\,B}{3} \text{ kN/m}^2$$

$$\text{Applied load intensity} = \frac{750}{B \times 1} = \frac{750}{B} \text{ kN/m}^2 \qquad \ldots(3)$$

Equating the two, we get $\frac{750}{B} = \frac{867.8 + 87.3\,B}{3}$. Simplifying, we get

$$87.3\,B^2 + 867.8\,B - 2250 = 0$$

or

$$B^2 + 9.94B - 25.77 = 0$$

From which, we get $B =$ **2.134 m**