BCS

Foundation Engineering - 30.

preapard by

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38th. BCS.

P-92

Syllabus:

Engineering properties of soils, shear strength, permeability, consolidation, settlement and compaction. Analysis and design of spread footings pile foundations; Mat foundation, settlement Analysis, Large excavation underpinning etc.

Questions:

27th BCS

7

ⓐ Why pile foundation is recommended for a civil engeneering work? What are the different types of piles? Discuss their use. C-25. Arona

8

ⓑ Design a square footing to carry a vertical load of 600 kips F.S shall be 3. Base of the footing shall be placed 5' below the sorrounding grand level. The clay material below the footing has an unconfined compressive strength of 3000 lb/ft². Wate level/table is at great depth. Assume f'_c = 3000 psi, f_y = 60000 psi. Other data may be Assume

7

ⓒ Name the causes of soil sample disturbance in soil test what are the effects of soil sample disturbance on the engineering properties of soil.?

15

ⓓ Write short notes on any six of the followings:

a) Plastic limit
b) Plasticity index. 31st BCS.
c) Geotextile and its uses. (32nd BCS)
d) Co-efficient of permeability.
e) Coffer dam and its uses.
f) Cantiliver Retaining wall.
g) Compaction of soil
h) Mat fondation — 30th. BCS,
i) Quick sand condition.

30 BCS.

1.

ⓐ Write short notes on the followings: 7

i) Pile foundation 31st BCS.
ii) Liquefaction of soil. 31st BCS.
iii) Over-consolidation of clay.
iv) Pore water pressure.

ⓑ. The time required to reach 50% consolidation for a soil specimen of 3 cm thick tested in a consolidometer under single drainage condition is 30 minutes. Determine the time time required for the same speciment for double drainage condition. 8

2. ⓐ state the different methods for determining the co-efficient of permeability of soil. Explain the facto affecting the permeability of soil. (36th BCS.) 7

ⓑ Differentiate between primary consolidation and seconda consolidation. Explain different causes of preconsolidation of soil. 8

3ⓐ What is meant by S.P.T of soil? How is it carried out in fie Explain the relationship of SPT value with bearing capacity of soil. 34th BCS 7

ⓑ Define shear strength of soil. Explain the shear characterist of cohesive and cohesionless soil. 8

31st BCS.

1 (a) What do you mean by active and passive earth pressure? 4

(b) Draw a neat diagram showing variation of different co-efficient of earth pressure. 7

(c) A clay stratum 5 m thick has the initial void ratio of 1.5 and the effective overburden pressure of 120 kN/m². When the sample is subjected to an increased pressure of 120 kN/m². The void ratio reduces to 1.44. Determine the co-efficient of volume compressibility and final settlement of the stratum. (36th BCS) 5

2 (a) What are the principal objectives of soil exploration? Write down the most common type of in-situ-test. (36th BCS) 4

(b) Discuss the effect of water table on the bearing capacity of soil. (36th BCS) 6

(c) What are the different types of raft foundation? Explain the procedure for designing a raft foundation.

(a) Explain the various types of pile foundation. 4

(c) A square concrete pile (30 x 30 cm²) 10 m long is driven into coarse sand (γ = 18.5 kN/m³), N = 20. Determine the load capacity of pile. 5

32 BCS.

1.

(a) Define the following geotechnical terms: 5

- Flow index.
- Toughness index
- liquidity index.
- Density index.
- Sand drain.

(b) Mension the basic objective and specifications for sail compaction. 5

*** (c) A 27.50 lb sample has a volume of 0.220 cft. moisture content of 15.2% and specific gravity of soil solids 2.67. Compute the bulk density, dry density, degree of saturation and void ratio. 5

2. (a) What is meant by OCR? Defferentiate between OC clay and NC clay. How will you find the pre-consolidation pressure for clay? 6

(b) When and why raft foundation are used? 3×3

(c) When and why sheet pile are used?

(d) See 27th BCS.

3. (a) Draw and discuss different types of footings. 6

(b) Differentiate the following :-

i) Seepage and permeability. 6
ii) Effective stress and Total stress.
iii) Sand pile and sand drain.

ⓒ When and why pile foundation is more suitable than that of shallow foundation? 3

34th BCS.

1. ⓐ What is standard proctor test (SPT)? How is it conducted? Explain with its uses. 10

ⓑ Define disturbed and undisturbed sampling. Where they are used? 5

2. ⓐ What is soil improvement? Write down the various methods of soil improvements. 7

ⓑ An infinite slope without seepage having soil parameters, specific gravity of soil = 2.7, void ratio = 0.55, cohesion = 400 lb/ft, height = 15 ft. Find the factor of safety against sliding. 8

3. ⓐ Differentiate between friction pile and point bearing pile. 7

ⓑ Briefly explain the field procedure of pile load test. 8

35th BCS.

1\. (a) What are the principal objectives of soil exploration. Write down the most common types of in-situ test. 6

(b) A static cone penetration was performed in a cohesive soil at a depth of 7.0 m with a tip resistance of 1 MPa and friction ratio 3%. The soil is intensive and plasticity index of 15%. What is the undrained shear strength of the soil? 9

2\. (a) Show with diagram the different modes of slope failures. 6

(b) Find the centre of the critical circle for $\beta = 75°$, $H = 60'$ and $D = 18'$ and toe circle failure. 5

(c) Estimate F for a slope having $H = 20$ m, $D = 4.0$ m, $\beta = 25°$, $\gamma = 19$ kN/m³, $c_u = 50$ kPa. 4

3\. See 31st BCS Question. full common.!!

36th BCS.

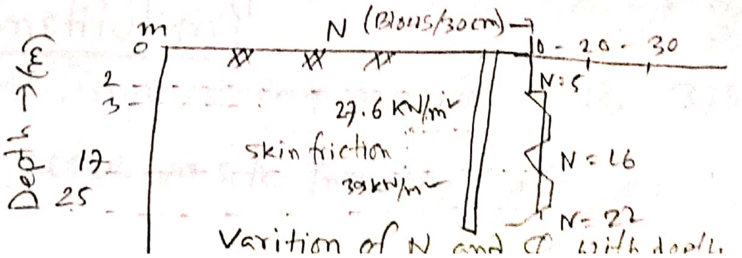
1. a) What are the principal objectives of soil exploration? (35th BCS)
What are the common safety measures that should be taken during soil excavation.

b) Find the centre of the critical circle for $\beta = 75^\circ$ $H = 60$ ft and $D = 18$ ft and toe circle failure. (35th BCS)

2. a) Show with diagrams the different modes of slope failure. (35th BCS.)

b) Estimate F for a slope having $H = 20$ m $D = 4$ m $\beta = 25^\circ$ $\gamma = 19\ kN/m^3$, $c_u = 50$ kPa. (35th BCS)

c) A closed ended steel pipe 30 cm dia and 20 m long is driven to a sand deposit with cutt-off at ground level. The depth wise variation of N and φ values is given in the following figure. Water table is 3 m below. G.L. Compute the ultimate load capacity of pile based on soil support using N value.



Varition of N and φ with depth

Q-1. What are the principal objectives site investigation/ sail exploration? Also define site investigation. [31, 36 BCS]

Site investigation: Site investigation / exploration is a technique composed of a number of activities to provide reliable, specific and detailed information about the sail and groundwater condition of the site for a safe and economic design of foundation.

Principal objectives of site investigations:

1. To determine the nature and sequence of strata.
2. Groundwater conditions at the site.
3. Engineering properties of sail underlying the site.
4. Location of groundwater and its variation.
5. To select the type and depth of foundation.
6. To determine the bearing capacity of the selected foundation
7. For the prediction of settlement.
8. To determine the remedial measures if the structure is unsaf.

*** In-situ Testing standards:

ASTM: 1) Field vane shear test in cohesive sail: D2573-72
ii) Soil investigation and sampling by Auger boring: D1452-65
iii) Penetration test and split-barrel sampling of sail: D1586-67
iv) Thin-Walled Tube sampling of sail: D1587-74

British Standards Institution:
i) Test for sails for civil Engineering purposes: BS 1377-1990
ii) British code of practice on site investigation: CP2001-1957

Q-2: Write down the most common dype of in-situ-tests. [35, 36, BCS]

Most common in-situ-tests are:

i) standard penetration test (SPT)
→ Best suited to sandy soil.
→ Qualitative evaluation of compactness and comparison of sub soil stratification can be determined.

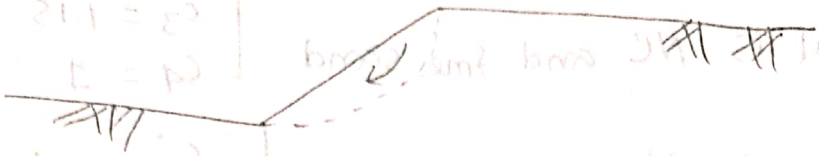
ii) Dynamic cone Test:
→ Best suited to sand and gravel.
→ compactness and comparison of sub soil can be determined

iii) field Vane Test:
→ Best suited to clay.
→ Undrained shear strength can be determined.

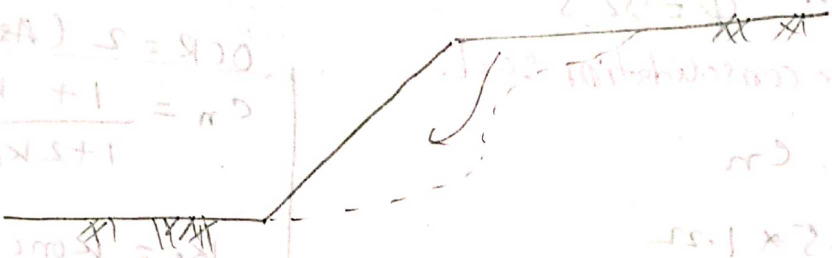
iv) Plate bearing test and Screw plate test:
→ Best suited to sand and clay.
→ Deformation modulus, modulus of subgrade, reaction, Bearing capacity are determined.

Slope stability.

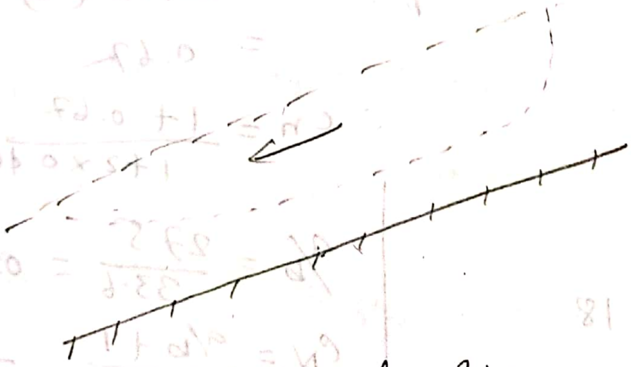
Q-3: Show with diagrams the different modes of slope failure.



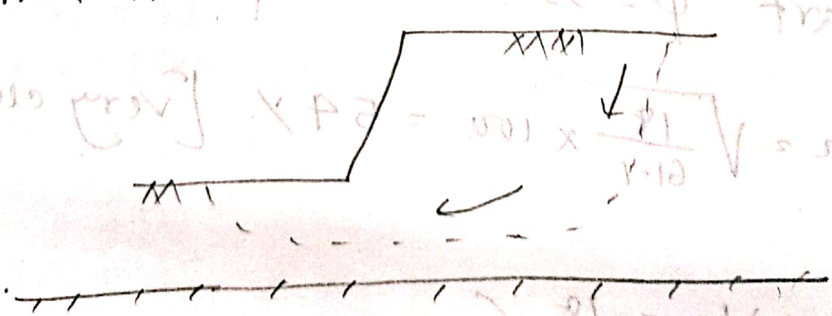
Circular ~~circitilate~~ slope failure
(Rotational slips)



Non-circular failure (Rotational slips)



Transitional slip.



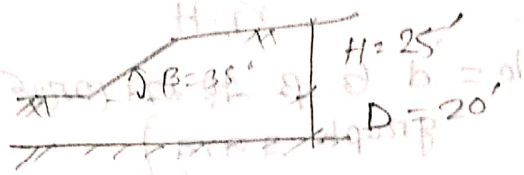
compound slip

—o—

Q-5: Estimate the factor of safety for a slope having $H = 25'$ $D = 20'$ $\beta = 35°$ and undrained shear shear strength $c_u = 600$ psf $\gamma_T = 115$ pcf.

Soln:

$D = 20'$ $H = 25'$



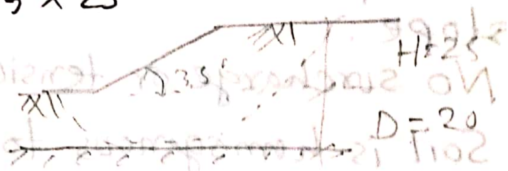
$\therefore d = \frac{D}{H} = \frac{20}{25} = 0.8$

Now, for $d = 0.8$ and $\beta = 35°$ from graph (P-70)

$N_o = 5.8$.

$\therefore$ Factor of safety $= N_o \frac{c}{\gamma_T H} = 5.8 \times \frac{600}{115 \times 25} = 1.21$

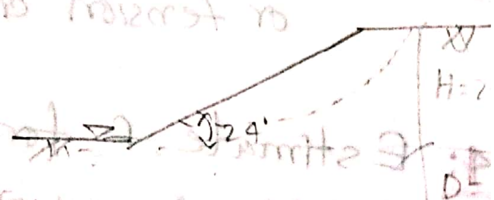
failure surface is base circle.



Q-6: Estimate the factor of safety for the slope shown in figure below. $H = 20m$ depth of hard stratum $D = 6m$. slope angle $\beta = 24°$ Undrained shear strength $C = 100$ kPa. $\gamma_T = 20$ kN/m
What is the type of failure for this slope? Show probable geometry of the failure surface.

Solution: $d = \frac{D}{H} = \frac{6}{20} = 0.3$

$\beta = 24°$

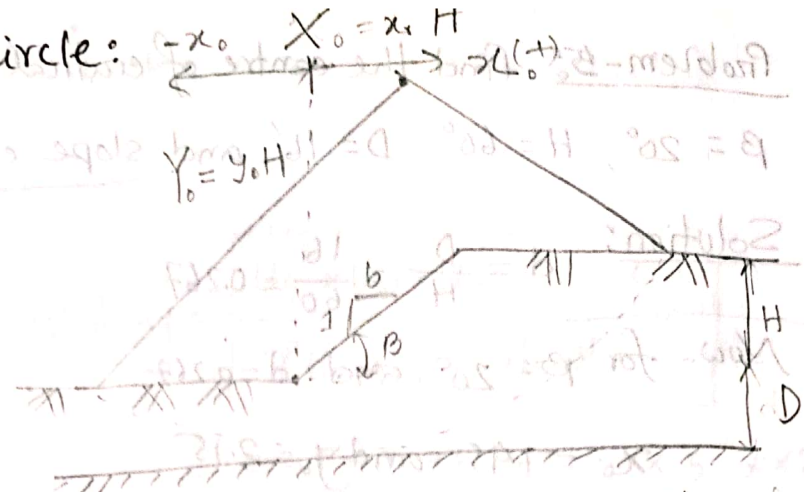


$\therefore$ from fig-2 $N_o = 6.8$

$\therefore F.S = N_o \frac{c_u}{\gamma_T H} = \frac{100 \times 6.8}{20 \times 25} = 1.36$

and failure surface is slope circle.

*** Centre of critical circle:



Centre of critical Circle, slope in cohesive soil.

Q-7: Find the centre of critical for $\beta = 75°$, $H = 60ft$ and $D = 18$ ft and toe circle failure.

Solution:

$\beta = 75°$

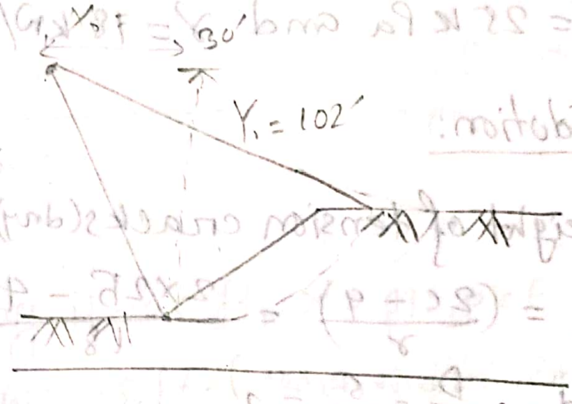
$d = \frac{D}{H} = \frac{18}{60} = 0.3$

from fig-3 $y_0 = 1.7$

$x_0 = -0.5$

$\therefore Y_0 = y_0 H = 1.7 * 60 = 102$

$X_0 = x_0 H = -0.5 \times 60 = -30$



$\therefore$ centre of critical surface, $(X_0, Y_0) = (-30, 102)$

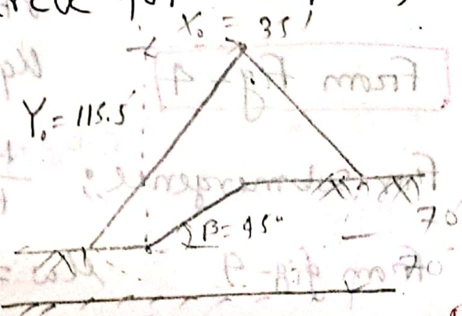
Problem-4: find the centre of critical circle for a slope of $\beta = 45°$, $H = 70'$ $D = 70'$. Base circle.

Soln: $d = \frac{D}{H} = \frac{70}{70} = 1$..

from fig-3. $x_0 = 0.5$ and $y_0 = 1.65$

$\therefore Y_0 = y_0 H = 1.65 \times 70 = 115.5'$

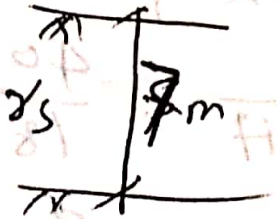
$X_0 = x_0 H = 0.5 \times 70 = 35'$



Q-8: A static cone penetration Test was performed in a cohesive soil at a depth of 7.0 m, with a tip resistance q_c of 1 MPa and friction ratio R_f of 3%. The soil is insensitive and has a plasticity index of 15%. What is the undrained shear strength of the soil?

Solution: Given, $q_c = 1$ MPa, $R_f = 3\%$, $I_p = 15\%$

$S_u = ?$



From fig-12: The soil is silts and silty clays.

Assume $\gamma_s = 19.65$ kN/m³

$\therefore$ Effective vertical stress $P'_o = \gamma_s h = 19.65 \times 7 = 137.55$ kPa.

$\therefore$ shear strength $S_u = \frac{q_c - P_o'}{N_k}$

$= \frac{1000 - 137.55}{15}$

$= 57.5$ kPa.

formula.

$N_k = 13 + \left(\frac{5.5}{50}\right) \times I_p \pm 2$

= Normally 12~16

$\therefore N_k = 13 + \frac{5.5}{50} \times 15 \pm 2$

$= 14.65$

Assume $= 15$.

$q_c = 1$ MPa $= 1000$ kPa.

Q-9: A square concrete pile (30×30 cm), 10 m long is driven into coarse sand ($\gamma = 18.5$ kN/m³, N = 20). Determine the allowable load.

Solution:

For square pile, End bearing $= q_p A_p$

$q_p = 40 N \left(\frac{D}{B}\right) \leq 400 N$

Here,

$400 N = 400 \times 20$

$= 8000$ kN/m²

and $40 N (D/B) = 40 \times 20 \times \frac{10}{0.3}$

$= 26666.67$ kN/m²

Adopt lower value of 8000 kN/m²

Skin friction $f_s = 2N = 2 \times 20 = 40$ kN/m²

$\therefore Q_u = q_p A_p + f_s A_s = 8000 \times 0.3^2 + 40 \times (4 \times 0.3 \times 10)$ ← perimeter. skin.

$= 1200$ kN.

Assume, F.S = 3.

$\therefore Q_{all} = \frac{Q_u}{F.S} = \frac{1200}{3} = 400$ kN.

36th: Q. What are common safety measures that should be taken during soil excavation. ??

Ans: Common safety measures are :

1. Eadges of excavation should be protected with substantial barrier where people are liable to fall into them.

2. Battening the excavation side to a safe angle of repose may also make excavation safer.

3. loose materials may fall from spoil heaps into the excavation. So edge protection should be done.

4. Check that excavation donot undermine scaffold footing, or fondation of nearby buildings or walls.

5. Don't park vehicles close to the sides of exeavation.

Q- what is permeability? what is co-efficient of permeability? what are the factors affecting co-efficient of permeability.

Permeability: It is the property of soil which permits flow of water through it. (m/s).

co-efficient of permeability: It is the average velocity of flow througth total cross-sectional area per unit hydraulic gradient ~~is called~~ (m/s).

Factors affecting co-efficient of permeability are:

1. Size of soil particles / grains.
2. Quality of pore water.
3. Arrangement of soil pore.
4. Degree of saturation.
5. The void ratio of soil.

Q- what is Sample disturbance? What is Disturb Sample and what is undisturbed Sample?

Ans Sample disturbance:

The change in field properties of soil when they are collected from field to laboratory is clled sample disturbance.

[P.T.O]

Disturbed sample:

When the natural arrangement of soil structure is partially or fully modified, then the soil sample is known as disturbed sample.

Samples collected from Auger sampler, spit spoon sampler and are disturbed samples.

Undisturbed samples:

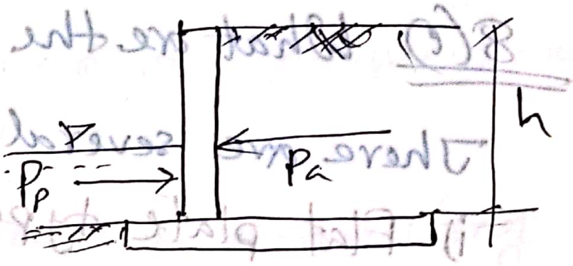
When the natural arrangement of soil particles remain same after collecting the sample, the sample is known as undisturbed sample.

Sample collected by shelby tube, piston sampler are undisturbed sample.

Q-1. What do you mean by active earth pressure and passive earth pressure.? P-2128. khurmi.

Active earth pressure: The lateral pressure exerted by the soil when the retaining wall tends to move away from the backfill due to excessive pressure of the retained soil, is called active earth pressure.

Passive earth pressure: The lateral pressure exerted by the soil when the retaining wall moves towards the backfill due to any natural cause, is called passive earth pressure.



active earth pressure.

$P_a = \frac{1}{2} K_a \gamma H$.

K_a = co-efficient of active earth pressure $= \frac{1-\sin\phi}{1+\sin\phi}$

Passive earth pressure; $P_p = \frac{1}{2} K_p . \gamma H$.

K_p = co-efficient of passive earth pressure

$= \frac{1+\sin\phi}{1-\sin\phi}$

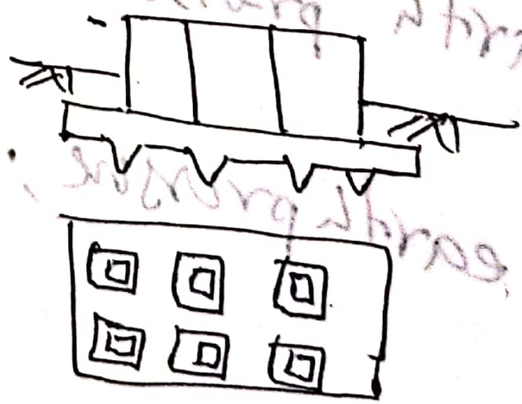
ϕ = angle of internal friction

8(i) What are the different types of raft fondation?

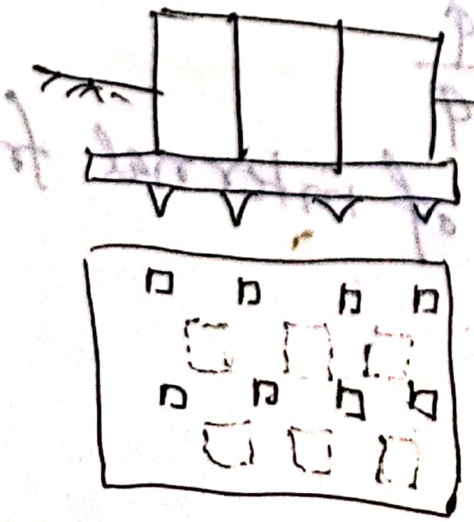
There are several types of raft fondation.

i) Flat plate type

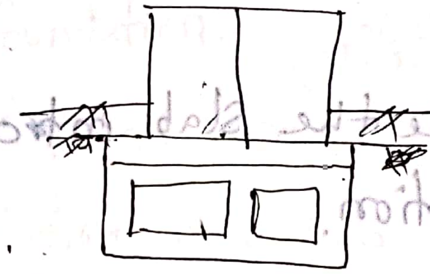
ii) Flat plate thickend under column



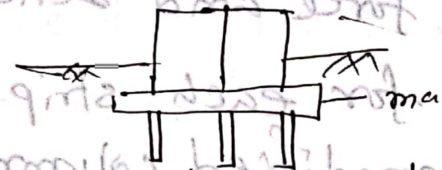
iii) Beam and slab construction.



4. Box structure:
- can resist very high bending stress.



5. Mats placed on piles.



Methods of Raft foundation:

1. Rigid Beam method.
2. Elastic method.
3. Simplified elastic method.
4. Non-linear elastic method.

Design procedure of Rigid Beam method / conventional method:

It consists of the following steps.

1. Determine the line of action of all the loads acting on the raft.
2. Determine the contact pressure distribution as under
3. If the resultant pressure passes through the centre of the raft, the contact pressure is given by

$$q = Q/A.$$

4. If the resultant has an ~~ecn~~ eccentricities of e_x and e_y the

$$q = \frac{Q}{A} \pm \frac{Q \cdot e_x}{I_{yy}} \pm \frac{Q \cdot e_y}{I_{xx}} \cdot y.$$

5. Devide the slab into strips in X and Y direction.

6. Draw the shear force and bending moment diagram for each strip.

7. Determine the modified column loads.

8. Bending moment and shear force diagram are drawn for the modified column loads and modified average soil pressure.

9. Design individual strips for the bending moments and shear force. The raft is designed as an inverted floor supported at column.

Deep foundation.

Lecture 22/05

When the depth of fondation is greater than the width of fondation is called deep foundation. There are two types of deep fondation.

i) Pile fondation.
ii) Well/caisson or pier foundation.

Pile fondation: A pile is a long vertical load transfering member composed of either steel, timber or concrete. In pile foundation a number of piles are driven in the base of the structure.

⇒ Selection of pile depends on the following parameters:

1. When the soil is highly compressible, made up type and water-logged.
2. Nature of structure.
3. Bearing capacity of soil.
4. Availability of fund
5. Availability of materials.
6. Type of loading.
7. Factors causing deterioration.

Uses of pile.

1. To transfer loads of the structure to hard strata.
2. To resist uplift pressure (transmission tower)
3. To resist horizontal forces in addition to resist the vertical loads.
4.

Types of piles:

Mainly two types i) Pre-cast or driven piles. may be timber, concrete or steel.

ii) Cast in situ or concrete piles.

⇒ Based on load Transfer.

→ End Bearing piles.
→ Skin/friction piles.
→ Combined friction and E.B. pile

⇒ Based on use

→ load bearing pile
→ Compaction pile
→ sheet pile
→ Fender piles.
→ Anchor piles.

[7] Pre-cast / Driven piles,

Advantages.

1. Piles of any size, shape and length can be made in advance.
2. Rapid progress of work.
3. Compact the adjacent soil and hence, increase the bearing capacity
4. The work is neat and clean.
5. less storage space required.
6. Material cost of pile is less.

Dis-advantages:

1. Extra-transportation cost required.
2. Advance planning is required for handling and driving
3. Requires heavy equipment for handling and driving.
4. It is not suitable in soils of poor drainage
5. It damages sometimes during driven.
6. It may damage or harm adjacent structure.
7. It makes huge sound pollution, which is harmful for near school, college or hospital

Bored pile / cast in situ pile.

Advantage:

1. Piles of any size, length and ~~shape~~ can be constructed at the site.
2. Suitable in soils of poor drainage.
3. No transportation cost required.
4. less possibility of damage to adjacent structure.
5. No sound pollution.
6. Piles are not damage as it has not required to handle or driving operation.
7. No need to curing.

Disadvantage:

1) It requires sufficient storage space
2) Requires carefull supervision and quality control of materials.
3. Material cost is high since bore dia can not maintain and top level of pile has to break.
4. Slower progress of work.

Scanned with CamScanner

Liquifaction

→ Liquifaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading.

→ liquifaction occurs in saturated soils in which the pore of the soil particles is completely fill with water. This water exerts a pressure on the soil particle that influences how tightly the particles themselves are pressed together.

→ During earthquake, shaking can cause to increase the water pressure to the point where the soil particle can readily move with respect to each other.

- → Avoid liquifaction succeptible soil.
- → Improve soil
- → Buil/construct liquifaction resistant structur

Normally Consolidated Soils.

→ It is a soil deposit that has ~~been~~ never subjected to a vertical effective stress greater than the present vertical stress.

Under Consolidated Soils:

A soil deposit that has not ~~deposit~~ consolidated under present overburden pressure is called under consolidated soil.

Over consolidated soil:

- It is a soil deposit that has been subjected to vertical effective stress greater than the present vertical effective stress.

Over consolidation Ratio (OCR)

It is defined as the ratio of preconsolidation pressure to the present effective vertical stress.

$$OCR = \frac{P_c}{P_0'}$$

= 1 Normally consolidated soils.

OCR > 1 are less compressible soil and show elastic behaviour to certain extent.

Total settlement.

$$S = S_e + S_c + S_s$$

S_e / Immediate settlement: Occurs immediately after the construction, or after load application. Calculation is based on the elasticity. (granular soil)

S_c / Primary consolidation: Expulsion of water from soil mass due to external load, hence volume change. (Inorganic clay).

S_s / Secondary consolidation: Plastic adjustment of soil particles. (organic soils)

Engineering properties of soil.

→ Unconfined compression strength (8 – 146 kPa)
→ Cohesion
→ Angle of internal friction
→ compressibility [compression index $e_c = 0.285 \sim 2.435$

Shallow foundation Settlement.

(1) The co-efficient of consolidation (c_v) for a clay found to be $0.955\ mm^2/min$. Final consolidation to be expected 280mm. for a 5m thick deposit of double drainage calculate time factor. for i) 90% consolidation.
ii) a settlement of 100 mm.

Solutions i) Given. $c_v = 0.955\ mm^2/min$

$U = 90\%$

$\therefore T_{90} = 0.848.$

$H = 5/2 = 2.5$

we know.

$$T_{90} = \frac{c_v t_{90}}{H^2}$$

$$t_{90} = \frac{H^2 \times T_{90}}{c_v}$$

$$= \frac{2.5^2 \times 0.848}{0.955} \quad \left| \frac{m^2}{mm^2/min} \right.$$

$= 5.5 \times 10^6$ min

~~= 64.23 days.~~

$= 10.55$ yrs.

ii) ~~H = 2.5~~ $U = \frac{100}{280} = 0.357$

$\therefore T_{90} = \pi/4 \times \left(\frac{U}{100}\right)^2 = 0.10$

Again, $T_{90} = \frac{c_v t_{90}}{H^2}$

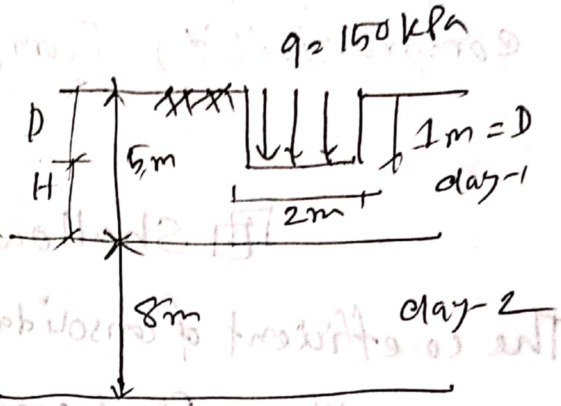
$t_{90} = \frac{H^2 \times T_{90}}{c_v} = \frac{2.5^2 \times 0.10 \times 10^6}{0.955}$

$= 6.5 \times 10^5$ min

$= 1.25$ yrs.

(2) A foundation 4m×2m carrying a uniform load net pressure of 150 kPa. is located at a depth of 1m. Young Modulus of soil $E_u = 40$ MPa. Determine the immediate settlement.

Solution:



i) For upper clay layer. $E_u = 40$ MPa

$H/B = \frac{5-1}{2} = 2$; $L/B = 4/2 = 2$

$D/B = 1/2 = 0.5$

$\therefore \mu_1 = 0.7$ and $\mu_0 = 0.9$ [from chart]

$\therefore S_{i_1} = \mu_0 \mu_1 \frac{qB}{E_u} = 0.90 \times 0.7 \times \frac{150 \times 2}{40 \times 10^3} = 4.73$ mm

ii) for two layers combined with $E_u = 75$ MPa

$H/B = 12/2 = 6$, $L/B = 2$, $D/B = 0.5$

$\therefore \mu_0 = 0.9$ $\mu_1 = 0.9$

$\therefore S_{i_2} = \mu_1 \mu_0 \frac{qB}{E_u} = 0.9 \times 0.9 \times \frac{150 \times 2}{75 \times 10^3} = 3.24$ mm

iii) For upper layer with $E_u = 75$ MPa.

$S_{i_3} = \mu_1 \mu_0 \frac{qB}{E_u} = 0.9 \times 0.7 \times \frac{150 \times 2}{75 \times 10^3} = 2.52$ mm

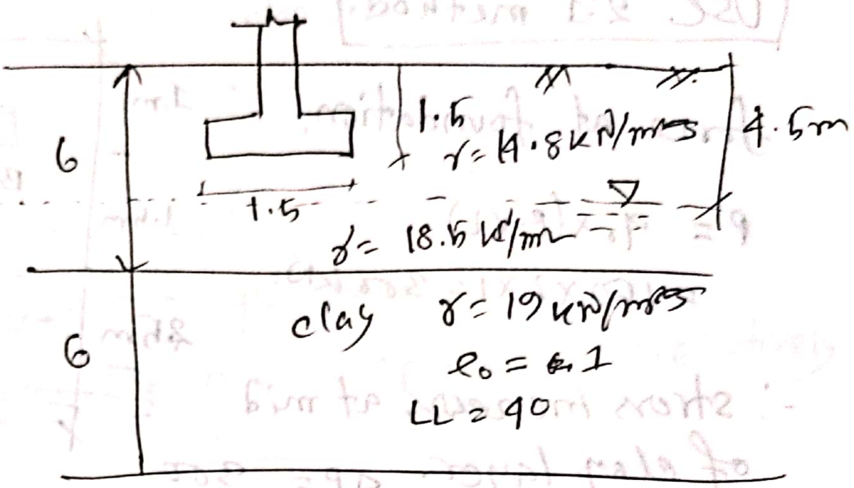
Using the principle of Superposition.

$S_i = S_{i_1} + S_{i_2} - S_{i_3} = 4.73 + 3.24 - 2.52 = 5.45$ mm.

A

(3) A rectangular footing measuring 3m × 1m (L × B) in plan carries a net load of 1100 kN at a depth of 1.5m in a sand deposit extending from the ground surface to a depth of 4.5m

Calculate consolidation settlement of clay layer for the specified load.



Solution:

Given, $Q = 1100\,kN$. $B = 1.5m$ and $L = 3m$.

consolidation settlement, $S = \frac{C_c H}{1+e_0} \log \frac{\Delta\sigma_0' + \sigma_0'}{\sigma_0'}$

effective vertical stress at mid of clay layer.

$\sigma_0' = 4.5 \times 14.8 + (18.5 - 9.81) \times 1.5 + (19 - 9.81) \times 3$ (layer thickness not from top.)

$= 107.205$ kPa.

$\Delta\sigma_0'$ at mid point of clay by 2:1 method.

$$\Delta\sigma_0' = \frac{1100}{(B+h)(L+h)} = \frac{1100}{(1.5+7.5)(3+7.5)} = 11.64 \text{ kPa}.$$

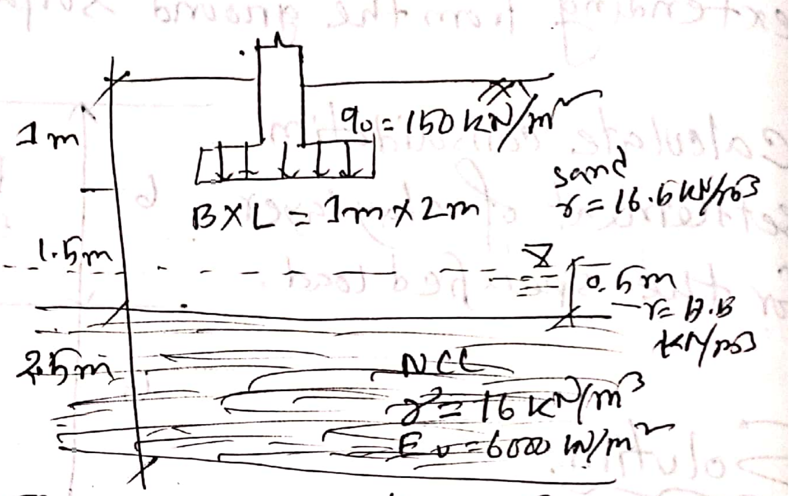
$\therefore$ and $C_c = 0.009(LL - 10) = 0.009(40 - 10) = 0.27$

$$\therefore S_c = \frac{C_c H}{1+e_0} \log \frac{\Delta\sigma_0' + \sigma_0'}{\sigma_0'} = \frac{0.27 \times 6}{1+1} \log \frac{11.64 + 107.205}{107.205}$$

$= 0.036\ m = 36\ mm$. (Ans)

8

④ A plan of a foundation 1m×2m is shown below. Estimate consolidation settlement of the foundation. **Use 2:1 method.**



$\mu_0 = 0.5$

$e_0 = 0.8$

$C_c = 0.32$

$C_s = 0.09$

force at foundation,

$P = q_0 \times (B \times L)$

$= 150 \times 2 \times 1 = 300$ kN.

∴ stress increase at mid of clay layer.

$\Delta P = \frac{300}{(B+h)(L+h)}$

$= \frac{300}{(2+2.75)(1+2.75)}$

$= \frac{300}{4.75 \times 3.75} = 22.96$ kN/m²

effective vertical stress at mid of clay layer.

$P_0' = \underset{\gamma H}{(2.5)} \times 16.5 + 0.5 \times (17.5 - 9.81) + 1.25(16 - 9.81)$

$= 52.83$ kN/m²

$\therefore S_c = \frac{C_c H}{1+e_0} \log \frac{P_0' + \Delta P}{P_0'} = \frac{0.32 \times 2.5}{1 + 0.8} \log \frac{52.83 + 22.96}{52.83}$

~~$= 0.0944$ m~~

~~$= 94.4$ mm Ans~~

$= 0.06196$ m

$= 69.6$ mm Ans

Shallow foundation.

when depth of foundation is less than width of it, then it is called shallow foundation.

Types of shallow foundation.

i) Isolated/spread/single footing.

→ These are used to support single columns.

→ Most economical when column are spaced at relatively long interval.

fig: spread footing

ii) strip footing/continuous footing/wall footing:

→ These are used to support structural walls, that carry loads for other structure or rows of columns.

→ Use a wide strip footing when bearing capacity is so low that is necessary to have transverse bending

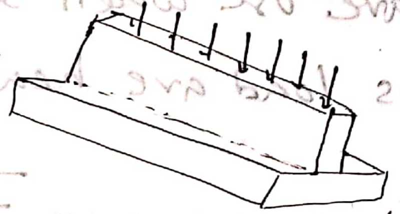


fig - strip footing

iii) Combined footing:

- They are used to support two columns or three columns not in a row.

→ They are used when two columns are so close that single ~~column~~ footings cannot be used.

Fig: combined footing.

iv) Cantiliver / strap footing:

- It consists of two single footings connected with a beam and support two single columns.
- It replaces a combined footing and is more economical.

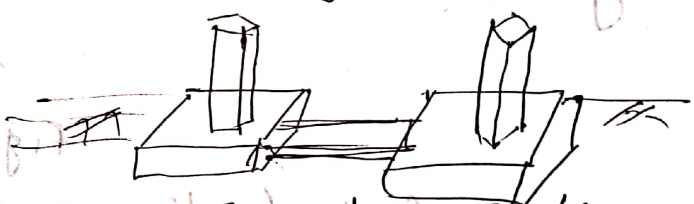


fig: strap footing

v) Raft or mat foundation:

→ It is consists of concrete slab covering the entire area of foundation.

→ They are use when soil bearing capacity is low, columns load are heavy, single footing cannot be used.

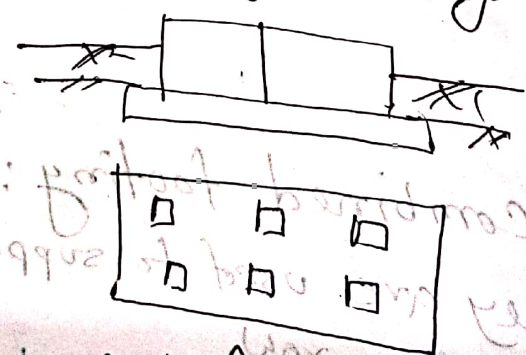
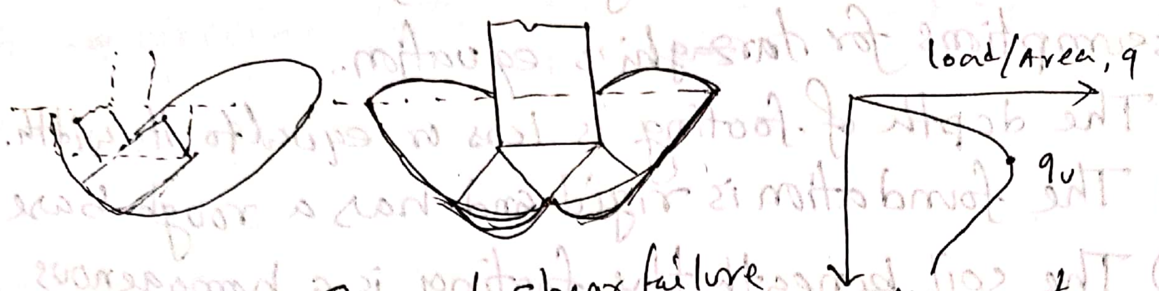
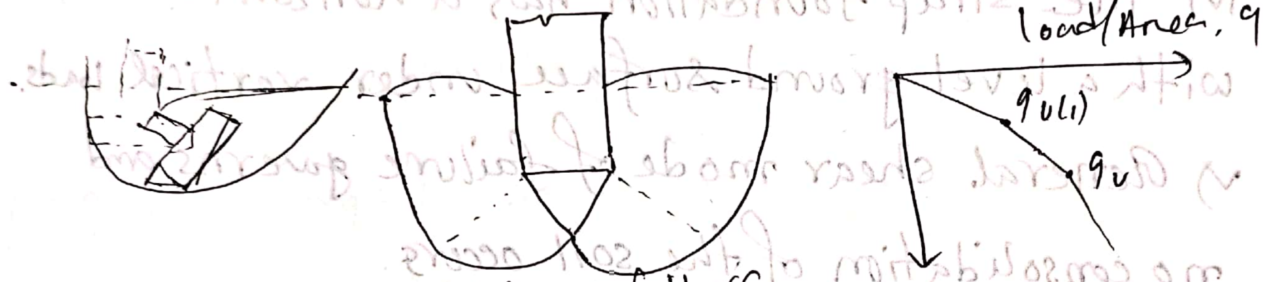


fig: Mat foundation.

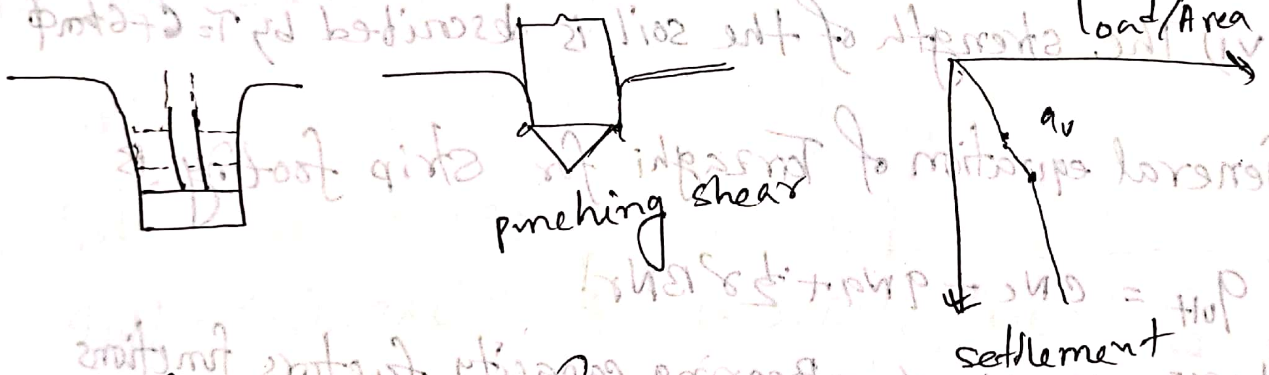
⊞ Bearing capacity failure modes



General shear failure



local shear failure



punching shear

Defination Arorar. এর C-24.

Tarzaghi's Bearing capacity equation.

~~Assumptions for tarzaghi's equation.~~

i) The depth of footing is less or equal to its width.

ii) The foundation is rigid and has a rough base.

iii) The soil beneath the footing is a homogenous semi-infinite mass.

iv) The strip foundation has a horizontal base with a level ground surface under vertical loads.

v) General shear mode of failure governs and no consolidation of the soil occurs.

vi) The strength of the soil is described by $\tau = c + \sigma \tan\phi$

General equation of Tarzaghi for strip footing is

$$q_{ult} = cN_c + qN_q + \frac{1}{2}\gamma BN_\gamma$$

Here; N_c, N_q, N_γ = Bearing capacity factors, functions of ϕ'.

c', ϕ', γ = effective cohesion, angle of internal friction, unit weight.

1st term = contribution from cohesive strength.

2nd term represents from surcharge above foundation.

3rd term = represent contribution from self ~~wt of soil~~ beneath the foundation.

→ for square footing $\boxed{q_{ult} = 1.3c'N_c + \gamma D \cdot N_q + 0.4\gamma B N_\gamma}$

→ for circular footing, $\boxed{q_{ult} = 1.3c'N_c + \gamma' D N_q + 0.3\gamma B N_\gamma}$

[2nd term represents the soil above the foundation level.]

$N_q = e^{\pi \tan\phi'} \cdot \tan^2(45 + \phi/2)$.

$N_c = (N_q - 1)\cot\phi'$

$N_\gamma = 1.5(N_q - 1)\tan(1.4\phi')$.

$\phi = 0$: হলে $N_q = 1$, $N_\gamma = 0$, $N_c = 5.70$.

for Local shear failure.

$q_{ult} = 2/3 \cdot c'N_c + qN_q' + \frac{1}{2}\gamma B N_\gamma'$ [strip footing]

$q_{ult} = 2/3 \times 1.3c'N_c + qN_q' + 0.4\gamma B N_\gamma$ [square]

$q_{ult} = 2/3 \times 1.3 \times c'N_c + qN_q + 0.3\gamma B N_\gamma$ [circular]

$\phi' = \tan^{-1}(2/3 \tan\phi)$

Example-3.1: A square footing of 1.5m x 1.5m in plan. Angle of internal friction is $\phi' = 20°$ and $c' = 15.2\ kN/m^2$. The unit weight of soil is $\gamma = 17.8\ kN/m^3$. Determine the allowable gross load on the foundation with factor of saftety 4. Assume depth of foundation is $1m = D_f$.

i) General shear failure.

ii) Local shear failure.

i) for $\phi = 20°$ $N_c = 17.69$

$N_q = 7.44$

$N_\gamma = 3.64$

$\therefore q_{ult} = 1.3\,cN_c + qN_q + 0.4\,\gamma B N_\gamma$

$= 1.3 \times 15.2 \times 17.69 + 17.8 \times 1 \times 7.44 + 0.4 \times 17.8 \times 1.5 \times 3.64$

$= 521\ kN/m^2$

$\therefore q_{all} = \frac{521}{4} = 130\ kN/m^2$

Totall allowable gross load $Q = 130 \times 1.5^2 = 292.5\ kN$.

Ans

ii) for Local shear failure,

$\phi' = 2/3\,\phi = 2/3 \times 20 = 13.3°$.

$\therefore N_c = 11.85$

$N_\gamma = 3.88$

$N_q = 1.12$

So, $q_{ult} = 0.86\,cN_c + qN_q + 0.4\,\gamma B N_\gamma$

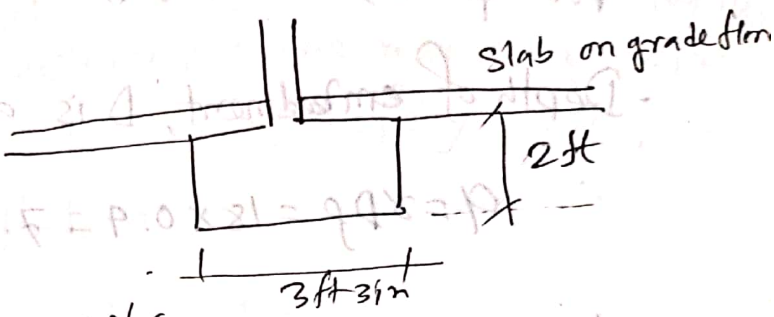
$= 0.86 \times 15.2 \times 11.85 + 17.8 \times 1 \times 1.12 + 0.4 \times 17.8 \times 1.5 \times 3.88$

$= 237.13\ kN$.

$q_{all} = 237.3/4 = 59.3\ kN/m^2$

$\therefore Q = 59.3 \times 1.5^2 = \boxed{133.4\ kN}$

Example-3.2: A square footing is to be constructed. The GWT is at 50 ft depth. Compute ultimate bearing capacity and column load required to produce a bering capacity failure. $c' = 150\ lb/ft^3$, $\phi' = 30°$, $\gamma' = 121\ lb/ft^3$ [ignore floor slab]



Soln: for $\phi = 30°$

$N_q = 22.8$, $N_c = 37.2$

$N_\gamma = 20.1$

$$\therefore q_{ult} = 1.3 c' N_c + q N_q + 0.4 \gamma B N_\gamma$$

$$= 1.3 \times 150 \times 37.2 + \underbrace{121 \times 22.8 \times 2}_{\gamma D_f} + 0.4 \times 121 \times 3.25 \times 20.1$$

$$= 15933.33\ lb/ft^3$$

Self weight of footing, $W_f = 3.25 \times 3.25 \times 2 \times 150\ lb$

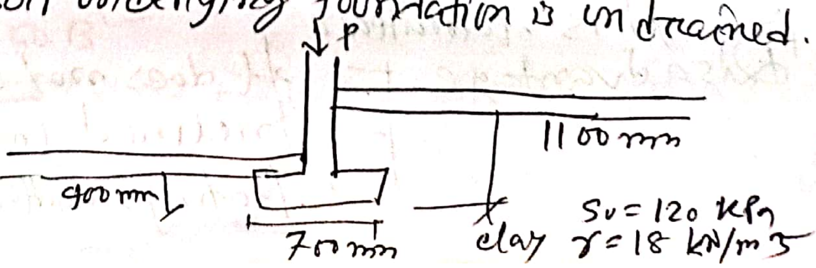
$$= 3168.75\ lb$$

$$\therefore q = \frac{P + W_f}{A} - u \ (\rightarrow 0)$$

Now. $15933.33 = \dfrac{P + 3168.75}{A} = \dfrac{P + 3168.75}{3.25^2}$

$\therefore P = 165127\ lb = $ **165 kip**

Example-3.3 Compute ultimate bearing capacity of the continuous footing. Compute the wall load to cause bearing capacity failure. Assume soil underlying foundation is undrained.



Solution: for undrained shear strength, $\varphi = 0$

$\therefore c_T = S_u = 120$ kPa.

for $\varphi = 0$; $N_c = 5.7$, $N_q = 1$ and $N_\gamma = 1$

- Depth of embedment, D is assumed lowest depth D=.4m

$\therefore q = \gamma D_f = 18 \times 0.4 = 7.2$ kPa.

$\therefore q_{ult} = cN_c + qN_q + \frac{1}{2}\gamma B N_\gamma$ [strip footing]

$= 120 \times 5.7 + 7.2 \times 1 + \frac{1}{2} \times 121 \times 0.7 \times 0$

$= 691$ kPa.

Assume average weight of footing and soil is 21 kN/m³

$\therefore W_f/b = 0.7 \times \left(\frac{0.4 + 1.1}{2}\right) \times 21 = 11$ kN/m

Now, $q_{ult} = q = \frac{P/b + W_f/b}{B} - u^{\nearrow 0}$

$\Rightarrow 691 = \frac{P/b + 11}{0.7}$

$\Rightarrow$ $P/b = 472.7$ kN/m. Ans

Advantage of Terzaghi equation is
→ It is easy and simple
→ It is familiar

Disadvantage.
→ It does not consider rectangular,
→ Inclined loads
→ footings width large depth width ratios.

Example-3.4: A column has the following vertical loads $P_D = 300k$, $P_L = 140k$, $P_W = 100k$. will support on a square footing located 3 ft below the ground. The underlying soil has an undrained shear strength of 2000 lb/ft³. and $\gamma = 109$ lb/ft³ GWT is at a depth of 4 ft. Determine the minimum width of the footing to maintain a factor of safety of 3. against bearing capacity failure.

Solution: ~~Design~~ design working loads.

$$P_D + P_L = 300 + 140 = 440k.$$

$$0.75(P_D + P_L + P_W) = 0.75(300 + 140 + 100) = 450k.$$

(controls)

Using Terzaghi's equation.

$$q_{ult} = 1.3cN_c + qN_q + 0.4\gamma BN_\gamma$$
$$= 1.3 \times 2000 \times 5.7 + 3 \times 109 \times 1$$
$$= 15147 \text{ lb/ft}^2$$

$\phi = 0$
$N_c = 5.7$
$N_\gamma = 0$
$N_q = 1$

$$\therefore q_{all} = \frac{15147}{F.S} = \frac{1547}{3} = 5049 \text{ lb/ft}^2$$

Self weight of foundation with surcharge.

$$W_f = 3 \times B \times B \times 150 = 450B^2 \text{ lb}$$

$$\therefore q_{all} = \frac{P + W_f}{B^2}$$

$$\Rightarrow 5049 = \frac{450000 + 450B^2}{B^2}$$

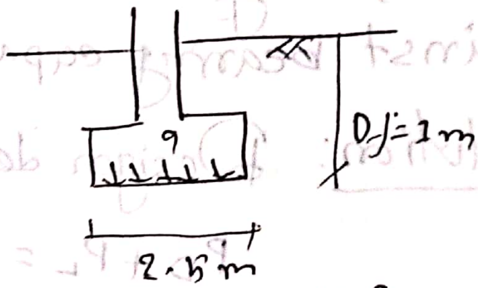
$$\Rightarrow B = 9.89 \text{ ft} \simeq 10 \text{ ft.}$$ Ans

Example 3.5 A square footing 2.5 m square carrying a pressure of 500 kN/m² at a depth of 1 m in sand. The saturated unit wt of sand is 20 kN/m³ and wt weight above the WTB is 17 kN/m³. The shear strength parameter is c = 0°, φ = 40°. Determine F.S with respect to shear failure:

i) GWT is 5 m below GL.

ii) GWT is 1 m below G.L.

iii) GWT is at GL. depth



Soln. For φ = 40° N_q = ~~85~~.81.27, N_γ = 115.31

γ_{sat} = 20 kN/m³, γ = 17 kN/m³, c = 0°, φ = 40°

(i) $D_f \leq B$; so GW has no effect in B.C.

$\therefore q_{ult} = 1.3\,cN_c + qN_q + 0.4\gamma B N_\gamma$ ($cN_c \to 0$)

$= \gamma D_f N_q + 0.4\gamma B N_\gamma$

$= 17 \times 1 \times 81.27 + 0.4 \times 17 \times 2.5 \times 115.31$

$= 3341.86$ kN/m²

$q_{all} = 500 + \gamma \to 0 = 500$ kN/m²

$\therefore F.S = \frac{3341.86}{500} = 6.688$

(ii) GWT is F.L ~~∴ q = 1 × (20 − 9.81) = 10.2 kN/m³~~

~~∴ q_{all} = 0 + 10.2 × 81.27 + 0.4 × 115.31 × 2.5 ×~~

(ii) GWT is at foundation level.

[$q = \gamma D_f$ no change, third term $\frac{1}{2} N_\gamma \gamma' B N$ γ' change হবে.]

$\therefore \gamma' = \gamma_{sat} - \gamma_w = 20 - 9.8 = 10.2$ kN/m³

$\therefore q_{ult} = 0 + 17 \times 1 \times 81.27 + 0.4 \times 10.2 \times 2.5 \times 115.31 = 2557.73$ kN/m²

$\therefore F.O.S = \dfrac{q_{ult} - \gamma D}{P - \gamma D} = \dfrac{2557.72 - 17 \times 1}{500 - 17 \times 1} = 5.26.$

(iii) G.W.T is located at G.L:

এখানে / $q = (\gamma_{sat} - \gamma_w) \times D_f$ হবে, $\gamma' = \gamma_{sat} - \gamma_w$. / দুইটাই পরিবর্তন হবে!!!!

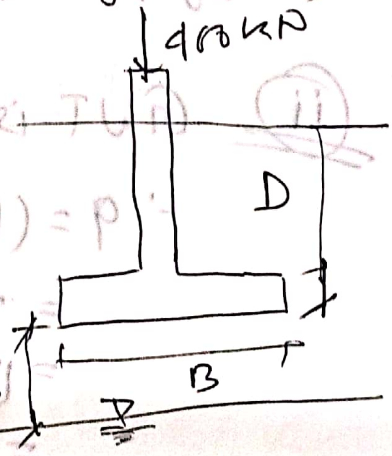
$\therefore q_{ult} = 0 + 10.2 \times 1 \times 81.27 + 0.4 \times 2.5 \times 115.31 = 2005.11$ kN/m²

$\therefore F.O.S = \dfrac{2005.11 - 17 \times 1}{500 - 17 \times 1} = 4.11$

Example-3.6: Design a suitable footing to carry a column load of 400 kN in a subsoil of homogeneous silty clay. $\gamma = 17$ kN/m³, $c = 20$ kPa, $\phi = 15°$.

i) Assume GWT is not in the vicinity.

ii) GWT is a 5m above the footing.



Solution: Assume a square footing of $B \times B$ m² and Depth of footing $D = B$.

Now for $\phi = 15°$, $N_c = 12.86$, $N_q = 4.45$, $N_\gamma = 1.52$

∴ Using Tarzaghi's Bearing capacity equation.

$q_{ul} = 1.3 c N_c + q N_q + 0.4 \gamma B N_\gamma$

$= 1.3 \times 20 \times 12.86 + 17 \times D \times 4.45 + 0.4 \times 17 \times B \times 1.52$

$= 334.36 + \cancel{17 \times 4.4}\ 75.65 B + 10.336 B$ [∵ B = D]

$= 334.36 + 85.99 B$

Assume F.O.S = 2.5

$\therefore q_{all} = \frac{85.99}{2.5} B + \frac{334.36}{2.5} = 34.39 B + 133.744.$

contact stress at the base level $= P/B^2 + \gamma D$

$= P/B^2 + 17B.$

$\therefore P/B^2 + 17B = 34.39 B + 133.744$

$\Rightarrow 400 + 17 B^3 = 34.39 B^3 + 133.744 B^2$

$\Rightarrow 17.39 B^3 + 133.744 B^2 - 400 = 0$

By trial and error, B = 1.57 m

(ii) GWT is 0.5 m above footing.

$\therefore q = (D - 0.5) \times \gamma + 0.5 (\gamma_{sat} - \gamma_w)$

$= \gamma D - 0.5 \gamma + 0.5 \times (17 - 9.8)$

$= 17 \times B - 0.5 \times 17 + 0.5 \times 7.2$

$= 17B - 4.9$

γ' in the last term will be replace by γ!

$\therefore q_{ult} = 1.3 \times 20 \times 12.86 + (17B - 4.9) \times 4.45 + 0.4 \times \underset{\gamma'}{\underline{(17 - 9.8)}}$

$1.5 \times B$

Scanned with CamScanner

$q_{uf} \Rightarrow 334.36 + 75.65B - 21.805 + 4.32B$

$q_{ul} = 79.97B + 312.55$

Now. $\frac{400}{B^2} + 17B = \frac{79.97B + 312.55}{2.5}$

$\Rightarrow 400 + 17B^3 = 31.988B^3 + 125B^2$

$\Rightarrow 14.988B^3 + 125B^2 - 400 = 0;$

$\therefore B = 1.635$

$\therefore \Rightarrow B = 1.64$ m. Ans

concrete unit wt
= 150 lb/ft3
= 23.6 kN/m3

☆ For undrained total stress Analysis $c_T = S_u$ and $\phi_T = 0$

$\therefore N_q = 1, N_c = 5.7, N_\gamma = 0.$

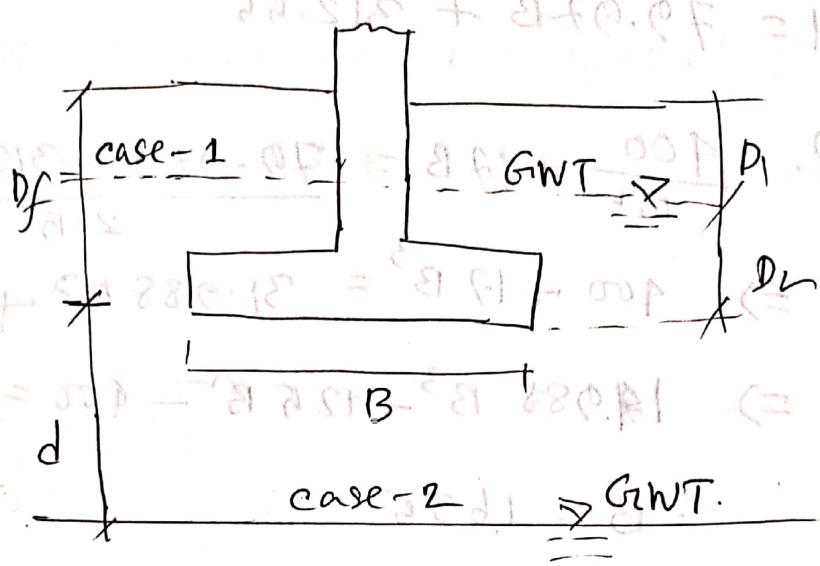
$N_q = e^{\pi \tan\phi} \cdot \tan^2(45 + \phi/2)$

$N_\gamma = 2(N_q + 1)\tan\phi$

$N_c = (N_q - 1)\cot\phi.$

According to Vesic's

Effect of Ground water table on Bearing capacity of foundation.



If the water table is close to the foundation, the bearing capacity is changes as follow.

case-1: If water table is located so that $0 \le D_1 \le D_2$, The factor q in the bearing capacity ~~factor~~ equation becomes,

$$q = \text{effective surcharge} = D_1\gamma + D_2(\gamma_{sat} - \gamma_w)$$

and $\gamma' = \gamma_{sat} - \gamma_w$.

γ_{sat} = saturated wt.
γ_w = unit wt of water.

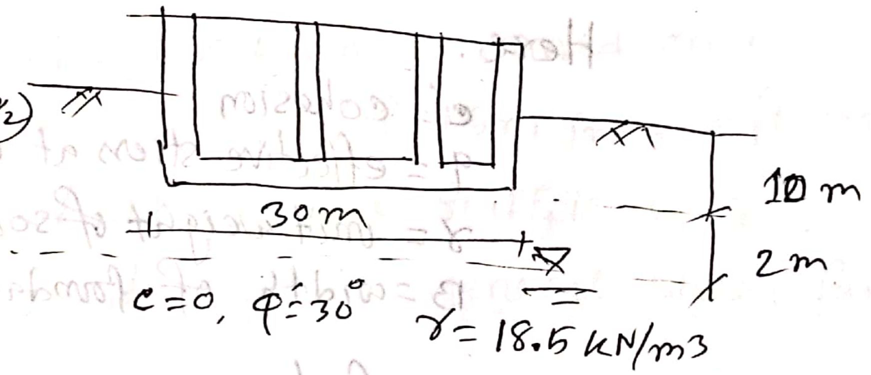
case-II: if $0 \le d \le B$ Then

$$q = \gamma D_f$$

In this case the factor in the last term of the bearing capacity equation must be ~~changed~~. replace by the factor. $\bar{\gamma} = \gamma' + \frac{d}{B}(\gamma - \gamma')$

case-ii) When the water table is located so that $d \geq B$. The water will have no effect on the ultimate bearing capacity.

Example-3.7: A 30m by 50m mat foundation is to be built as shown below. Compute the ultimate bearing capacity for $\phi = 30°$



$N_q = e^{\pi \tan 30°} \cdot \tan^2(45 + 30/2)$

$= 18.4$

$N_\gamma = 2(N_q + 1)\tan\phi$

$= 22.40$

Determin GW case. $0 \leq d \leq B \Rightarrow 0 \leq 2 \leq 30$

case - 2:

$\therefore q = \gamma D_f = 18.5 \times 10 = 185$ kN/m²

$\bar{\gamma} = \gamma' + \frac{d}{B}(\gamma - \gamma') \approx \gamma' + 0.06(\gamma - \gamma') \approx \gamma'$

$= (18.4 - 9.8) + 0.06 \times 9.8 = 9.22$ kN/m³

$\therefore q_{ult} = cN_c + qN_q + \frac{1}{2}\gamma B N_\gamma$ [for mat foundation]

$= 185 \times 18.4 + \frac{1}{2} \times 9.22 \times 30 \times 22.4 = 6501.9$ kN/m²

$\therefore q_{ult} = 6501.9$ kPa.

[4] Which equation to use.

i) Tarzaghi's equation $= cN_c + qN_q + \frac{1}{2}\gamma B N_\gamma$.

→ very suitable for cohesive soil where $D/B \leq 1$

→ well known, simple.

→ For a quick estimate of q_{ult} to compare with other method.

→ Dont use for the footing ~~of~~, with moments, horizontal forces, tilted bases or sloping ground.

ii) Hansen, Meyerhof, vesic equation.

$$q_{ult} = cN_c F_{ci} F_{cd} F_{cs} + qN_q F_{qi} F_{qs} F_{qd} + \frac{1}{2}\gamma B N_\gamma F_{\gamma i} F_{\gamma s} F_{\gamma d}.$$

→ Any situation that applies depending on user preferences. or familiarity with a particular metho

iii) Hansen, vesic (Brinch Hansen) equation.

$$q_{ult} = cN_c \, s_c D_c I_c + qN_q S_q D_q i_q + \frac{1}{2}\gamma B N_\gamma S_\gamma d_\gamma i_\gamma.$$

→ best suited when base is tilted.

→ footing is on a slope. when $D/B > 1$.

It is good practice to use at lest two method and compare the computed values of q_{ult}.

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Example-3-10 Design of footing in sand from SPT value:

Estimate the size of the square footing of a column carrying a load of 1500 kN in a sand deposit width average N value is 15. Assume allowable settlement of 25 mm. Depth of foundation is 2m and $\gamma = 18\ kN/m^3$.

Solⁿ: M-1

For 1 mm settlement $q_{net} = 1.385(N-3)\left(\frac{B+.3}{2B}\right)^2$

$\therefore q_{25} = 25 \times 1.385(15-3)\left(\frac{B+0.3}{2B}\right)^2$

$= 34.625 \times 12 \times \left(\frac{B+0.3}{2B}\right)^2$

$= 415.5\left(\frac{B+0.3}{2B}\right)^2$

Teng's equation $N \geq 15$

contact pressure at the bottom of foundation

$q_{all} = P/A = \frac{1500}{B^2}$

$\therefore \frac{1500}{B^2} = 415.5\frac{(B+0.3)^2}{4B^2}$

$\Rightarrow 4 \times 1500 = 415.5(B^2 + 0.6B + 0.09)$

$\Rightarrow B^2 + 0.6B - 14.35 = 0$;

$\therefore$ **B = 3.5 m**

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Method-2

from bearing capacity formula of parray.

$$q_u = 0.24 N_F \left(\frac{D + 0.73B}{D + 0.75B}\right)$$

if $D/B \leq 1$

$q_{ult} = 0.24 N_F$ (MPa)

$= 0.24 \times N_F = 0.24 \times 15$
$= 3.6$ MPa
$= 3600$ kPa.

contact stress $q_{all} = \frac{1500}{B^2} + \gamma D$

$= \frac{1500}{B^2} + 2 \times 18 = \frac{1500}{B^2} + 36$

Assuming. F.O.S $= 3$. and equalizing allowable bearing pressure

$\frac{3600}{3} = \frac{1500}{B^2} + 36$

$\Rightarrow 1200B^2 = 1500 + 36B^2$

$\Rightarrow 1164 B^2 = 1500$

$\therefore B = 1.14$ m.

$\therefore B = 1.14$ m

So settlement governs the design and provide $B = 3.50$ m.

Example-3.11 Design a square footing carrying a load of 500 kN in saturated deposit with SPT value of 20. The depth of foundation is 2m. Unit weight of soil is 20 kN/m³ F.S = 3.

Solⁿ:

Method-1:

We know unconfined compression strength from SPT(N)

$$q_u = N/8 \; kg/cm^2 = 12.5 N \; kN/m^2$$

$$\therefore q_u = 12.5 \times 20 \; kN/m^2 = 250 \; kN/m^2$$

$$\therefore c = \frac{250}{2} = 125 \; kN/m^2$$

For clay $\phi = 0$; $\therefore N_c = 5.7$, $N_q = 1$, $N_\gamma = 0$.

From Tarzaghi's bearing capacity equation

$$q_{ult} = 1.3 c N_c + q N_q + 0.4 \gamma B N_\gamma$$

$$= 1.3 \times 125 \times 5.7 + 20 \times 2 \times 1 + 0$$

$$= 966.25 \; kN/m^2$$

$$\therefore q_{all} = \frac{q_{ult}}{F.S} = 322. \; kN/m^2$$

Contact stress at the bottom of foundation

$$q_{all} = P/A + \gamma D = \frac{500}{B^2} + 20 \times 2 = \frac{500}{B^2} + 40$$

Now. $322 = \frac{500}{B^2} + 40$

$$\therefore B = 1.33 \; m$$

Method-2:

q_{all} from empirical equation

$$q_{all} = 12.5N + \gamma D = 12.5\times 20 + 20\times 2 = 250 + 40 = 290 \text{ kN/m}^2$$

$$\therefore \frac{500}{B^2} + 40 = 290$$

$$\Rightarrow B = 1.41 m.$$

So the safe width of footing is 1.41 m

Example-3.12 Design of footing in sand from SPT value.

A square footing is required to carry a net load of 1200 kN. Depth of footing is 2m. Tolerable settlement 40 mm. The soil is sandy with N = 12. F.S = 3. WT is very deep. Determine the size of footing. Use Teng's equation.

Soln: Method-1

Teng's bearing capacity equation for circular or square footing is

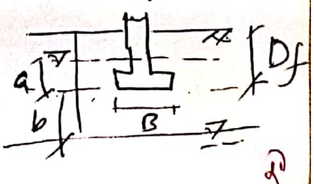
$$q_n = 0.33 N^2 B W_\gamma + (100 + N^2) D_f W_q$$

$$= 0.33 \times 12^2 \times B \times 1 + (100 + 12^2) \times 2 \times 1$$

$$= 488 + 47.52 B$$

$W_\gamma = 1 - 0.5 a/D_f \le 1$

$W_q = 0.5 + 0.5 b/B \le 1$



Total net load = 1200 kN

$\therefore 1200 = \frac{47.52B + 488}{B}$

$\therefore B = 8\ m$

method-2:

$q_{net} = 1.385(N-3)\left(\frac{B+0.3}{2B}\right)^2 W_r R_d S$

$R_d = 1 + \frac{0.2D_f}{B} \leq 1.2$

$S = 40mm$

$W_r = 1$

$q_{40} = 1.385(12-3)\left(\frac{B+0.3}{2B}\right)^2 * \left(1 + \frac{0.2\times2}{B}\right) * 40$

$= 124.6\left(\frac{B^2+0.6+0.09}{B^2}\right)\left(1+\frac{0.4}{B}\right)$

$P = 1200 = 124.6\left(\frac{B^2+0.6B+0.09}{B^2}\right)\cdot\left(1+\frac{0.4}{B}\right)\times B^2$

$\Rightarrow 9.63 = (B^2+0.6B+0.09)\left(\frac{B+0.4}{B}\right)$

$\Rightarrow 9.63B = B^3 + B^2 + 0.33B + 0.36$

$\Rightarrow B^3 + B^2 - 9.3B + 0.36 = 0$

$\boxed{B = 2.57\ m}$

consolidation settlement.

NCC

(i) $$S_c = \frac{C_c H}{1+e_0} \log \frac{P_0' + \Delta P}{P_0'}$$

(ii) OCC

$$P_c > \Delta P + P_0'$$

$$S_c = \frac{C_s H}{1+e} \log \frac{\Delta P + P_0'}{P_0}$$

if $P_c < \Delta P + P_0'$

$$S_c = \frac{C_s H}{1+e} \log \frac{P_c}{P_0} + \frac{C_c H}{1+e} \log \frac{\Delta P + P_0'}{P_c}.$$

$$C_s = \left(\frac{1}{5} \sim \frac{1}{10}\right) C_c.$$