Lecture No. 1 UNIT-I SITE INVESTIGATION AND SELECTION OF FOUNDATION

Topic(s) to be covered	Site investigation and selection of foundation

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Site investigation and selection of foundation	Understand

Teaching Learning Material	Student Activity
Chalk & Talk	Listen

Lecture Notes

Foundation Engineering:

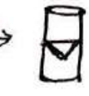
- The art of selecting, designing and constructing the elements that transfer the weight.
- (Weight may also include horizontal loads in addition to vertical loads) of a structure to the underlying soil or rock.
- A foundation is interfacing elements between the

Super structure and the underlying soil or rock.

• The loads transmitted by the foundation to the underlying soil must not cause soil shear failure or damaging settlement of the superstructure.

Definition of Structures:

• Assemblage of Load Bearing Elements such as Beams, Column.

Sub Structures — Super Structure — Special Structures (Towers, Silos) → 

• Design of retaining walls, bulkheads, Cofferdams, tunnels and earth dams, as well as the design of natural slopes, dewatering of soils and stabilization of soils mechanically and chemically.

• Geotechnical engineer

→ developing a soil exploration plan.

→ prepare primary Geotechnical Report (PGR) to assist in the selection of foundation type and to perform a preliminary seismic analysis/ evaluation.

→ Identifying the proposed boring locations and anticipated foundation type.

→ Assisting the Construction engineers by preparing pile driving criteria, reviewing pile installation plan and determining acceptance of as built piles.

→ Also assisting bridge designer in determining pile production lengths based on field load tests.

Objectives of soil exploration:

- Nature of deposits of soil
- depth & TK of various soil strata
- to locate ground water table and its fluctuations
- Obtain soil & Rock samples.
- Engineering properties of soil strata
- On - site properties.

Common problems in foundation:

- Cracks in building
- Tilting of towers, Concrete Chimneys, tall structures etc
- deflection of dams, pavements, pipe water supply or drainage line networks.
- Soil slope instability (Canals & embankments)
- Tilting or sinking of oil tanks (Resting on earth)

Objectives of site investigation:

- General stability of the site (for proposed work)
- To enable adequate and economical design of foundation
- To forsee construction difficulties.

Broad classification of soil exploration:

Direct: Trial pits, trenches and load tests.

Semi indirect: Boring and penetration tests (to reach deep layers)

Indirect: Seismic, Electric resistivity and dynamic methods

Main features:

Direct: UDS and DS samples shall be collected from verticle, inclined and horizontal directions 4m to 5m.

Semi direct: visual observations of soil profile is not possible. Hand boring - 10m, machine boring - even 100m.

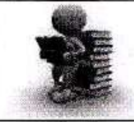
Indirect: No sample can be collected. Less cost and rapid test.

Choice of method for site exploration (IS)

depending on following factors:

1. Nature of ground
   a) Soils
   b) Gravel - boulder deposits
   c) Rocks
2. Topography - vertical opening, horizontal opening
3. Cost.

Suggested Questions / Assignments / Home works / any other
1. Define foundation engineering?



Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Text Book of Soil mechanics and foundation engineering	Murthy V.N.S	CBS publishers distributors Ltd new delhi

Any other suggested Materials

Lecture No. 2

Topic(s) to be covered	Method of Exploration

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Method of Exploration	Understand.

Teaching Learning Material	Student Activity
Chalk & Talk	Listen

Lecture Notes

Method of Exploration:

Direct Method	Semi direct / Boring method	Indirect / Geophysical Exploration
1. Trial pits	1. Boring methods	1. pressure meter test
2. plate load test	2. penetration tests	2. Seismic Refraction method.
		3. Electrical Resistivity method.

Semi Direct:

Boring method:

1. Displacement Boring
2. Wash Boring
3. Auger Boring
4. Rotary drilling
5. Peracussion drilling
6. Continuous Sampling

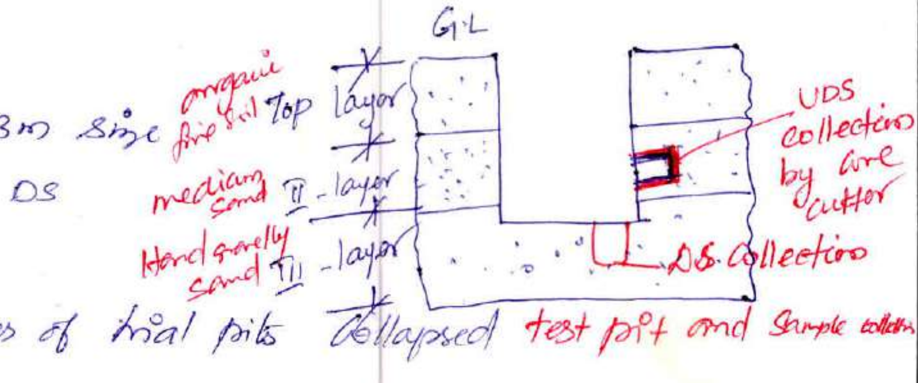
Penetration test:

1. Standard penetration test (SPT)
2. Dynamic Cone penetration test (DCPT)
3. Field Vane Shear test.
4. Soil Samples
   (i) Split Spoon sampler
   (ii) Thin Walled Sampler
   (iii) Piston Sampler

DIRECT METHOD:

Trial pits

* 1.25m x 1.25m x 3m size
* Both UDS and DS
* GWL
* Wheather sides of trial pits collapsed



test pit and sample collection

SEMI DIRECT METHOD:

Soil Sample is identified by outgoing slurry.

1. Displacement Boring: closed bottom Sampler - slit cup or piston type - Sampler bottom is opened - piston is released or withdraw - sample is collected.

* holes - 25mm to 75mm
* Soil character detected - penetration Resistance.

2. Wash Boring: Use of limited equipments, inexpensive and easily portable handling and drilling equipments depth of 8m - 10m Completely disturbed sample - not for very soft soil, fine to medium cohesionless soil & in cemented soil.

3. Auger Boring:

* Fast, Economical, light, flexible, inexpensive.
* Soft to Stiff cohesive soil suitable
* Ds but better than wash boring, percussion or rotary drilling.
* not suitable for very hard or cemented soils, no very soft soils.

4. Rotary drilling:

* Highly Resistant strata - quality of rocks from, Cracks, fissures and joints.
* heavy string of drill rod for chocking action.
  - broken rock is removed by circulating water or drilling mud.
* Drilling mud - slurry of bentonite in water - makes wall strong by forming mud cakes on sides.

cut pit, collect DS and UDS. Record visual identification of soil type, colour, nature (wet/dry) submerged loose, dense.

Plate Load test:

* excavated upto the expected foundation level.
* 300 to 750mm square steel plate (commonly 450mm)
* place plate over 5mm + R fine sand layer.
* Load increment - $1/5^{th}$ of estimated ultimate bearing capacity (or) 0.1 N/mm²
* Record settlement - 2 dial gauges - 0.01mm accuracy after 1, 2, 2.5, 4, 6.25, 9, 16 and 25 min after the application of load at every hr.
* For clayey soil - move to next stage when settlement has exceeded 70 to 80% of probable ultimate settlement or at the end of 24 hrs period.
* For soil other than clay - maintain each load increment for 1 hr or when settlement gets reduced to 0.02 mm/min.

procedure is carried out till settlement of 25mm under normal circumstances 50mm under special cases.

The elastic rebound of soil after release of load shall be measured for duration = that of action of load increment.

Suggested Questions / Assignments / Home works / any other

1. Explain the methods of Exploration in detail.

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil mechanics and foundations engineering	Arora. K.R	Standard publishers and distributors new delhi

Any other suggested Materials

Lecture No. 3

Topic(s) to be covered	Auger Boring

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Auger Boring	Understand

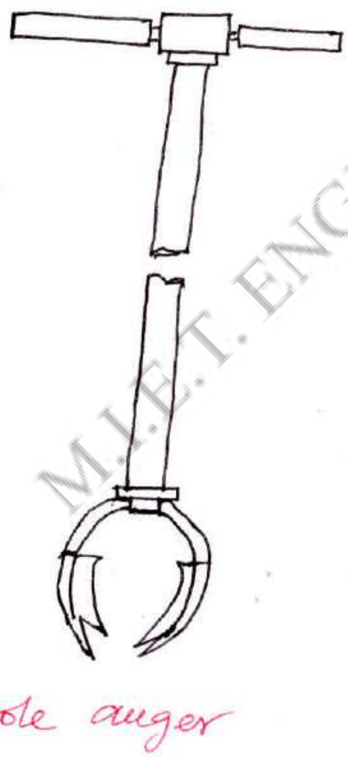
Teaching Learning Material	Student Activity
Chalk & Talk	Listen

Lecture Notes

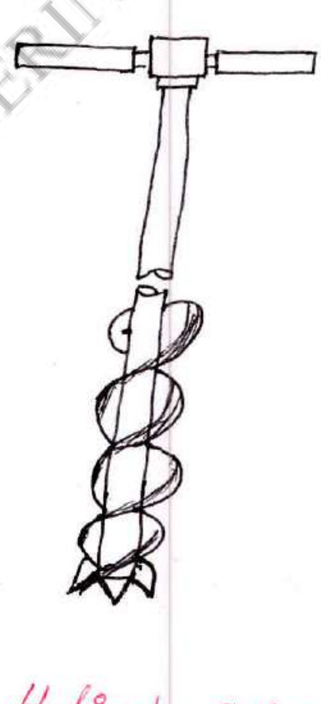
Auger Boring:

- It is the simplest method of making exploratory boreholes.
- Two types of hand auger: the posthole auger and the helical auger.
- Hand augers cannot be used for advancing holes to depths exceeding 3 to 5m.

- portable power driven helical augers (76 mm to 305 mm in diameter) are available for making deeper boreholes.
- The soil samples obtained from such borings are highly disturbed.
- In some non cohesive soils or soils having low cohesion, the walls of the boreholes will not stand unsupported.
- In such circumstances, a metal pipe is used as a casing to prevent the soil from caving in.



posthole auger



Helical auger

- When power is available, continuous - flight augers are probably the most common method used for advancing a borehole.

• The power for drilling is delivered by truck- or tractor- mounted drilling rigs.

• Boreholes up to about 60 to 70 m easily can be made by this method. Continuous - flight augers are available in sections of about 1 to 2 m with either a solid or hollow stem.

• Some of commonly used solid- stem augers have outside diameter of 67mm, 83mm, 102mm, and 114 mm.

• Common commercially available hollow-stem augers have dimensions of 63.5mm ID and 158.75 mm OD 69.85 mm ID and 177.8 OD, 76.2mm ID and 203.2 OD, and 82.55 mm ID and 228.6 mm OD.

• The driller can detect changes in the type of soil by noting changes in the speed and sound of drilling.

• When solid- stem augers are used the auger must be withdrawn at regular intervals to obtain soil samples and also to conduct other operations such as standard penetration tests.

• Hollow- stem augers have a distinct advantage over solid stem augers in that they do not have to be re-moved frequently for sampling or other tests.

The hollow-stem auger system include

Outer component: (a) hollow auger sections

(b) hollow auger cap

(c) drive cap

Inner Component:

(a) pilot assembly

(b) Center rod Column

(c) Rod-to-cap adapter

- The auger head contains replaceable Carbide teeth.

- During drilling, if soil samples are to be collected at a certain depth, the pilot assembly and the centre rod are removed.

- The soil sampler is then inserted through the hollow stem of the auger column.

Suggested Questions / Assignments / Home works / any other

1. Describe the auguring and boring?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil mechanics and foundation engineering	Arora. K.K	Standard publishers and distributors

Any other suggested Materials

Lecture No. 4

Topic(s) to be covered	Wash Boring and Rotary Drilling

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Wash Boring and Rotary Drilling	Understand

Teaching Learning Material	Student Activity
Chalk & Talk	Listen

Lecture Notes

Wash Boring:

- It is another method of advancing boreholes.
- In this method, a casing about 2 to 3m long is driven into the ground.
- The soil inside the casing is then removed by means of a chopping bit attached to a drilling rod.

• Water is forced through the drilling rod and exits at a very high velocity through the holes at the bottom of the chopping bit.

• The water and the chopped soil particles rise in the drill hole and overflow at the top of the casing through a T connectors.

• The wash water is collected in a container.

• The casing can be extended with additional pieces as the bore hole progresses, however that is not required if the borehole will stay open and not cave in.

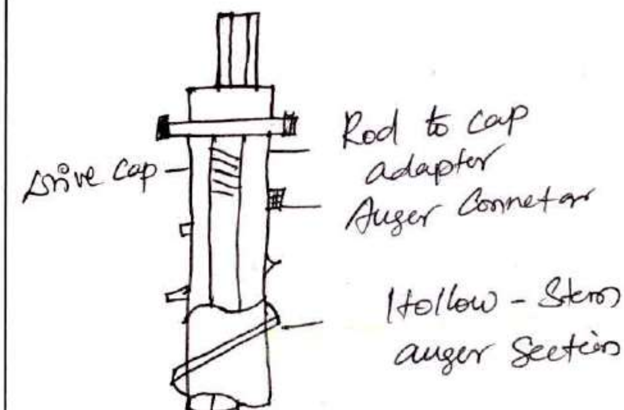
• Wash borings are rarely used now in the united states and other developed countries.

Rotary drilling:

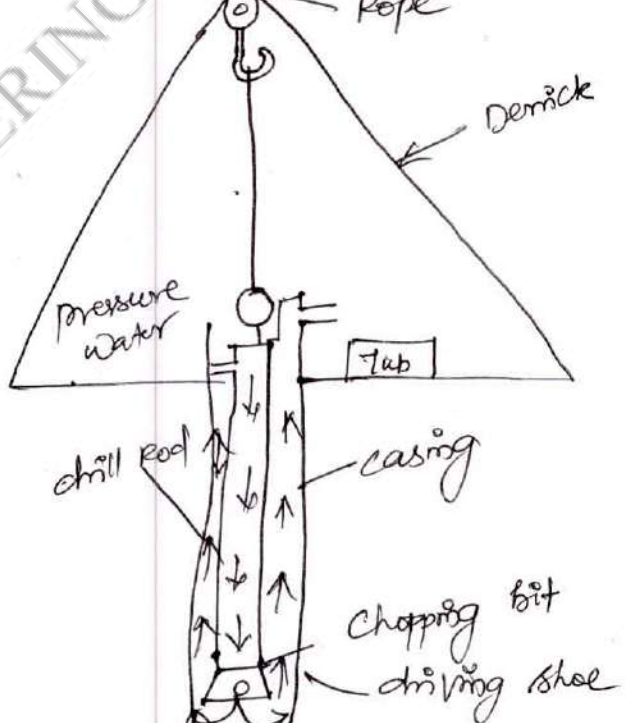
• It is a procedure by which rapidly rotating drilling bits attached to the bottom of drilling rods cut and grind the soil and advance the borehole.

• There are several types of drilling bit.

- Rotary drilling can be used in sand clay, and rocks (unless they are badly fissured).
- Water or drilling mud is forced down the drilling rods to the bits and the return flow forces the cuttings to the surface.
- Bore holes with diameters of 50 to 200mm easily can be made by this technique.
- The drilling mud is a slurry of water and bentonite.
- Generally, it is used when the soil that is encountered is likely to cave in.
- When soil samples are needed, the drilling rod is raised and the drilling bit is replaced by a sampler.
- With the environmental drilling applications, rotary drilling with air is becoming more common.



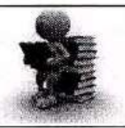
Hollow Stem auger Components (After ASTM; 2001)



Wash Boring.

Suggested Questions / Assignments / Home works / any other

1. Write short note on Wash Boring and Rotary drilling?



Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil mechanics and foundations	Punmia	Laxmi publications Pvt Ltd New delhi

Any other suggested Materials

Lecture No. 5

Topic(s) to be covered	Soil Samples

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Soil Samples	Understand Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen

Lecture Notes

- Two types of soil sample can be obtained during subsurface exploration: disturbed and undisturbed.
- Disturbed, but representative, samples can generally be used for the following types of laboratory test.

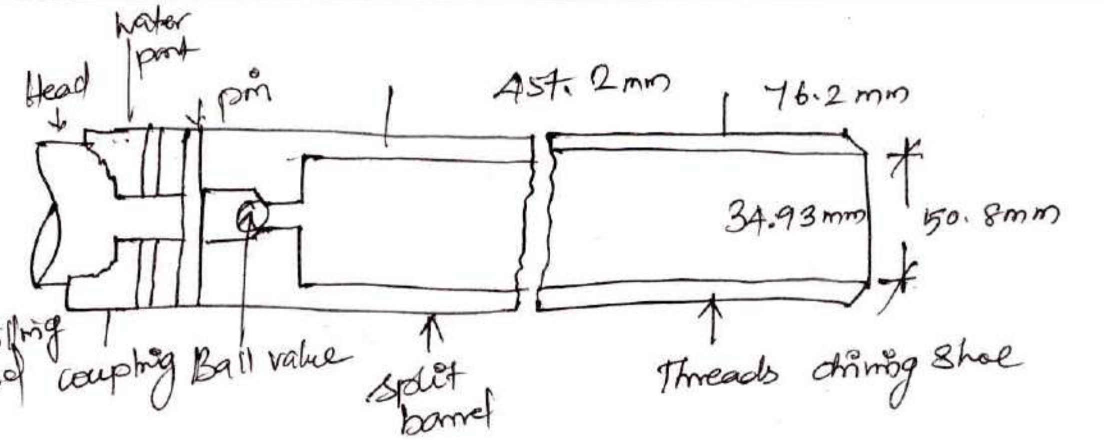
1. Grain-size analysis
2. Determination of liquid and plastic limits
3. Specific gravity of soil solids
4. Determination of organic content
5. Classification of soil.

Disturbed soil samples, however, cannot be used for consolidation, hydraulic conductivity, or shear strength tests.

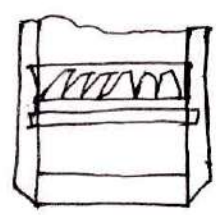
Undisturbed soil samples must be obtained for these types of laboratory tests.

Split-Spoon Sampling:

- Split-spoon samplers can be used in the field to obtain soil samples that are generally disturbed, but still representative.
- A section of a standard split-spoon sampler: The tool consists of a steel driving shoe, a steel tube that is split longitudinally in half, and a coupling at the top.
- The coupling connects the sampler to the drill rod.



Standard Split spoon Sampler.



Spring Core Catcher

- The standard split tube has an inside diameter of 34.93mm and an outside diameter of 50.8mm; however samplers having inside and outside diameters up to 63.5mm and 76.2mm respectively, are also available.

- When a borehole is extended to a predetermined depth, the drill tools are removed and the sampler is lowered to the bottom of the hole.
- The Sampler is driven into the soil by hammer

blows to the top of the drill rod.

• The sampler is then withdrawn, and the shoe and coupling are removed. Finally, the soil sample recovered from the tube is placed in a glass bottle and transported to the laboratory.

• This field test is called the standard penetration test (SPT).

$$A_R(\%) = \frac{D_o^2 - D_i^2}{D_i^2}(100)$$

Liao and Whitman's Relationship (1986):

$$C_N = \left[\frac{1}{\left(\frac{\sigma_o'}{p_a}\right)}\right]^{0.5}$$

Skempton's Relationship (1986):

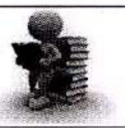
$$C_N = \frac{2}{1+\left(\frac{\sigma_o'}{p_a}\right)}$$

• An approximate relationship between the corrected standard penetration number and the relative density of sand.

• The values are approximate primarily because the effective overburden pressure and the stress.

Suggested Questions / Assignments / Home works / any other

1. Define Soil Samples?
2. What are the soil samples and its types?



Text Books / Reference Books

S.No	Title	Author	Publisher
1.	principles of foundation engineering	Braja. M.Das	Cengage Learning 2014

Any other suggested Materials

Lecture No. 6

Topic(s) to be covered	Thin walled tube (Sampler)

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Thin walled sampler	understand

Teaching Learning Material	Student Activity
Chalk & Talk	Listen

Lecture Notes

- Thin walled tubes are sometimes called as Shelby tubes.
- They are made of seamless steel and are frequently used to obtain undisturbed clayey soils.
- The most common thin-walled tube samplers have outside diameters of 50.8 mm and 76.2 mm.

- The bottom end of the tube is sharpened. The tubes can be attached to drill rods.
- The drill rod with the sampler attached is lowered to the bottom of the borehole, and the sampler is pushed into the soil.
- The soil sample inside the tube is then pulled out.
- The two ends are sealed, and the sampler is sent to the laboratory for testing.

Samples obtained in this manner may be used for consolidation or shear tests.

- A thin walled tube with a 50.8mm outside diameter has an inside diameter of about 47.63mm.

The area ratio is

$$A_R(\%) = \frac{D_o^2 - D_i^2}{D_i^2}(100) = \frac{(50.8)^2 - (47.63)^2}{(47.63)^2}(100)$$

$$= 13.75\%$$

Increasing the diameter of samples increases the cost of obtaining them.

Piston Sampler:

- When undisturbed soil samples are very soft or larger than 76.2mm in diameter, they tend to fall out of the sampler.

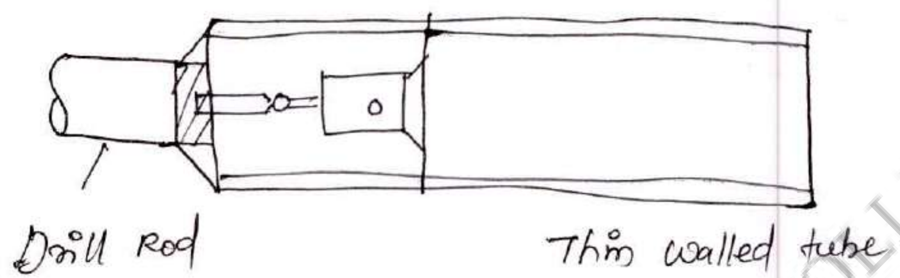
- Piston samplers are particularly useful under such conditions.

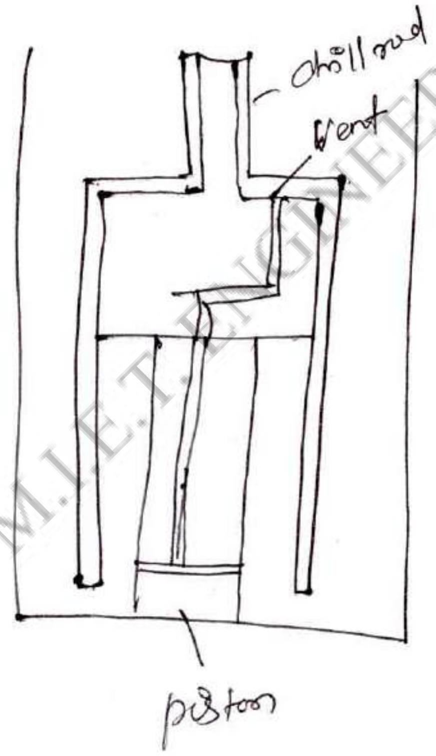
- Initially, the piston closes the end of the tube.
- The sampler is lowered to the bottom of the borehole and the tube is pushed into the soil hydraulically, past the piston.

- Then the pressure is realesed through a hole in the piston rod.

- To a large extent, the presence of the piston prevents distortion in the sample by not letting the soil squeeze into the sampling tube very fast and by not admitting excess soil.

- Consequently, samples obtained in this manner are less disturbed than those obtained by shelby tubes.





Suggested Questions / Assignments / Home works / any other

1. Explain in detail about thin walled samplers.

Text Books / Reference Books

S.No	Title	Author	Publisher

Any other suggested Materials

Lecture No. 7

Topic(s) to be covered	penetration test [Cone penetration test]

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Cone penetration test	Understand

Teaching Learning Material	Student Activity
Chalk & talk	Listen

Lecture Notes

- The Cone Penetration test (CPT), originally known as dutch cone penetration test, is a versatile sounding method that can be used to determine the materials in a soil profile and estimate their engineering properties.

• The test is also called as static penetration test and no bore holes are necessary to perform it. In the original version, a 60° cone with a base area of 10cm² was pushed into the ground at a steady rate of about 20 mm/sec. and the resistance to penetration (called the point Resistance) was measured.

• The cone penetrometers in use at present measure (a) the cone resistance (q_c) to penetration developed by the cone which is equal to vertical force applied to the cone, divided by its horizontally projected area. (b) the frictional resistance (f_c), which is the resistance measured by a sleeve located above the cone with the local soil surrounding it. The frictional resistance is equal to vertical force applied to the sleeve, divided by its surface area actually, the sum of friction and adhesion.

Generally two types of penetrometers are used to measure q_c and f_c.

1. Mechanical friction - Cone penetrometer: The tip of the penetrometer

is connected to an inner set of rods.

- The tip is first advanced about 40mm, giving the cone resistance.
- With further thrusting, the tip engages, the friction sleeve.
- As the inner rod advances, the rod force is equal to the sum of the vertical force on the cone and sleeve.
- Subtracting the force on the cone gives the side resistance.

2. Electric friction - cone penetrometer

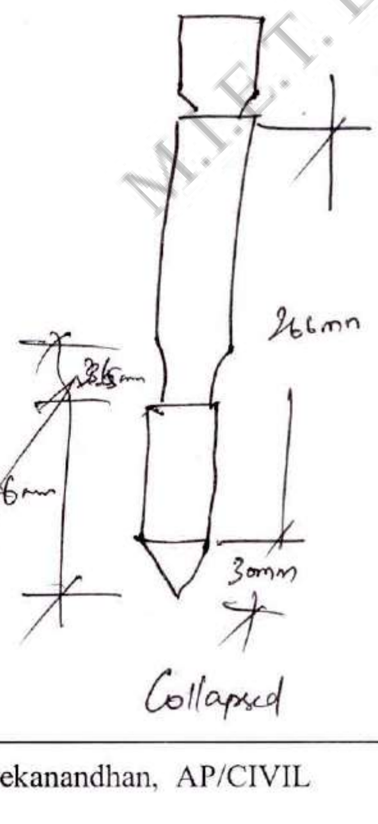
- The tip of this penetrometer is attached to a string of steel rods.
- The tip is pushed into the ground at the rate of 20mm/sec.
- Wires from the transducers are threaded through the centre of the rods and continuously measure the cone and side resistances.

- Several correlations that are useful in estimating the properties of soils encountered during an exploration program have been developed for the point resistance (q_c) and friction ratio (F_r) obtained from the cone penetration test. The friction ratio is defined as.

$$F_r = \frac{\text{Frictional resistance}}{\text{Cone resistance}} = \frac{f_c}{q_c}$$

- As in the case of standard penetration tests, several correlations have been developed between q_c and other soil properties.

- Some of these correlations are presented next.



Collapsed

Suggested Questions / Assignments / Home works / any other

1. Describe Cone penetration test?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Foundation analysis and design	Joseph E Bowles	McGraw Hill Education -2015

Any other suggested Materials

Lecture No. 8.

Topic(s) to be covered	Preparation of Boring Logs

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Preparation of Boring logs	Understand.

Teaching Learning Material	Student Activity
Chalk & Talk	Listen

Lecture Notes

- The detailed information gathered from each borehole is presented in a graphical form called the boring log.

- As a borehole is advanced downward the driller generally should record the following information in a standard log.

1. Name and address of drilling Company
2. Driller's Name
3. Job description and number
4. Number, type and location of boring
5. Date of boring
6. Subsurface stratification, which can be obtained by visual observation of the soil brought out by auger, split spoon sampler, and thin walled Shelby tube sampler.
7. Elevation of water table and date observed use of casing and mud losses, and so on
8. Standard penetration resistance and the depth of SPT
9. Number, type and depth of soil sample Collected.
10. In case of rock coring, type of core barrel used and, for each run, the actual length of coring, length of core recovery and RQD

. This information should never be left to memory, because doing so often results in erroneous boring logs.

. After completion of the necessary laboratory tests, the geotechnical engineer prepares a finished log that includes notes from the drillers field log and the results of test conducted in the lab.

Suggested Questions / Assignments / Home works / any other

1. Explain about the preparation of Boring log?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil mechanics and foundation	Punmia B.C	Laxmi publications pvt new delhi

Any other suggested Materials

Lecture No.9

Topic(s) to be covered	Bore log Report and Selection of foundation

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Bore log Report	Understand

Teaching Learning Material	Student Activity
Chalk & talk	Listen

Lecture Notes

- At the end of all soil exploration programs, the soil and rock specimens collected in the field are subjected to visual observation and appropriate lab. testing.
- The required information has for reference during future construction work.

Although the details and sequence of information in such reports may vary to some degree, depending on the structure under consideration and the person compiling the report, each report should include the following items.

1. A description of the scope of investigation
2. A description of the proposed structure for which the subsoil exploration has been conducted
3. A description of the location of the site, including any structures nearby, drainage conditions, the nature of vegetation on the site and surrounding it, and any other features unique to the site
4. A description of geological setting of the site.
5. Details of the field exploration - that is number of borings, depth of borings types of borings involved and so on.

6. A general description of subsoil conditions, as determined from soil specimens and from related lab tests, Standard penetration resistance and cone penetration resistance and so on.

7. A description of the water-table conditions

8. Recommendations regarding the foundation, including the type of foundation recommended, the allowable bearing pressure, and any special construction procedure that may be needed, alternative foundation design procedures should also be discussed in this portion of the report.

9. Conclusions and limitations of the investigations.

The following graphical presentations should be attached to the report:

1. A site location map
2. A plan view of location of borings with respect to proposed structure and those nearby

3. Boring logs

4. Lab test Results

5. Other special graphical presentations

The explorations reports should be well planned and documented as they will help in answering questions and solving foundation problems that may arise later during design and construction.

Suggested Questions / Assignments / Home works / any other

1. Describe in detail about Bore log Report

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil mechanics and foundation engineering	Arora K.R	Standard Publishers and distributors new delhi

Any other suggested Materials

Lecture No. 10 UNIT-II BEARING CAPACITY OF SHALLOW FOUNDATION

Topic(s) to be covered	Location and depth of foundation

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Location and depth of foundation Depth of foundation Width of foundation Procedure for construction of foundation	Understand and apply

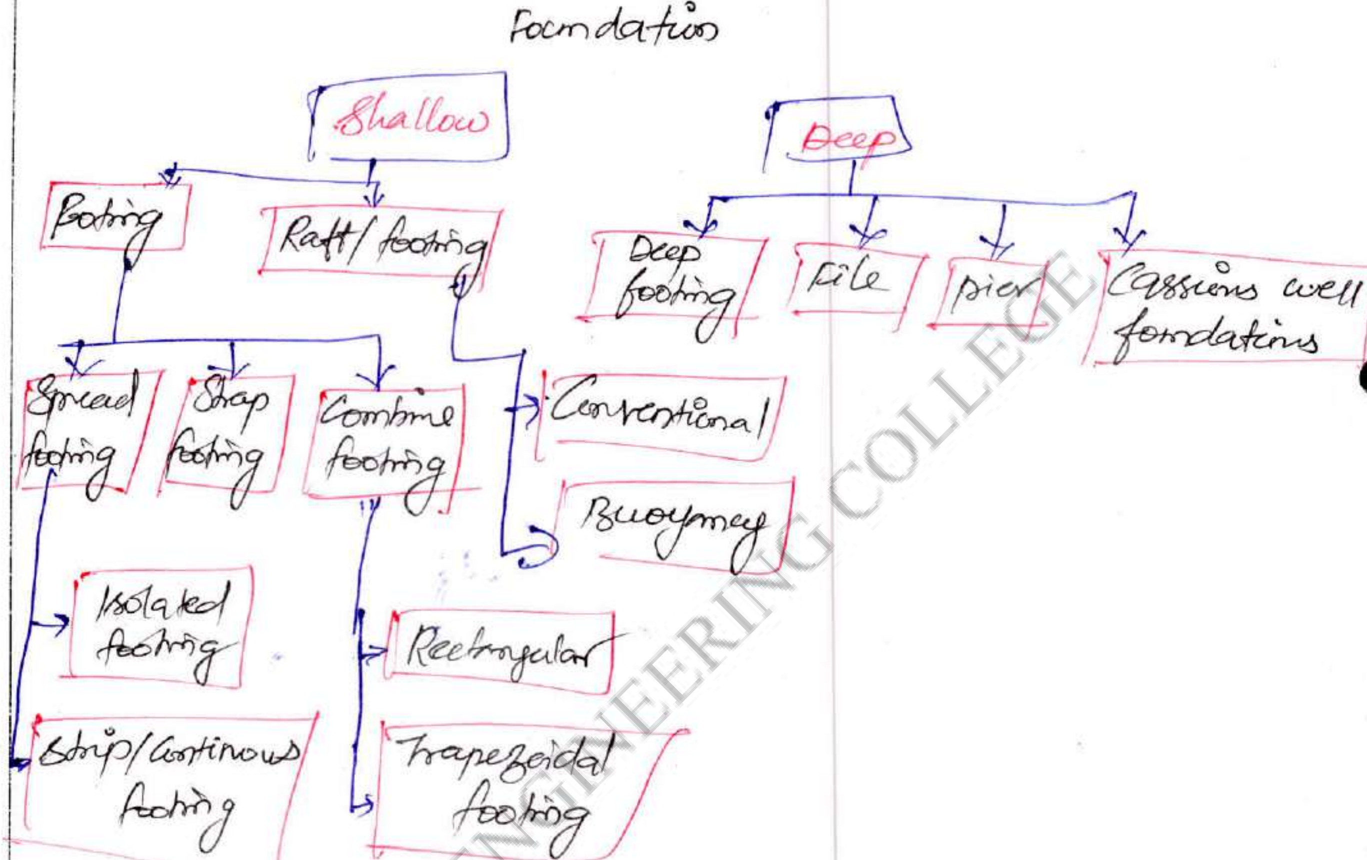
Teaching Learning Material	Student Activity
Chalk & Talk	Listen / apply

Lecture Notes

- A foundation is a integral part of the structure which transfer the load of the superstructure to the soil.
- A foundation is that member which provides support for the structure and its load.
- It includes the soil and rock of earth's crust and any special part of structure that

serves to transmit the load into the rock or soil.

Types of footings:



Depth of foundation:

1. Availability of adequate bearing capacity.
2. Depth of Shrinkage and Swelling in case of clayey soils due to seasonal changes, which may cause considerable movements.
3. Depth of frost penetration in case of fine sand and silt.

- possibility of Excavation nearby
- Depth of groundwater table
- The minimum practical depth of foundation should not be less than 50 cm. To allow removal of top soil and variations in ground level.

Hence the best recommended depth of foundation is from 1.00 meter to 1.5 meter from the original ground level.

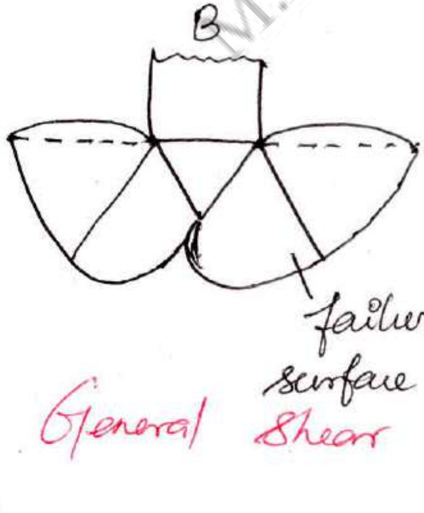
Width of foundation

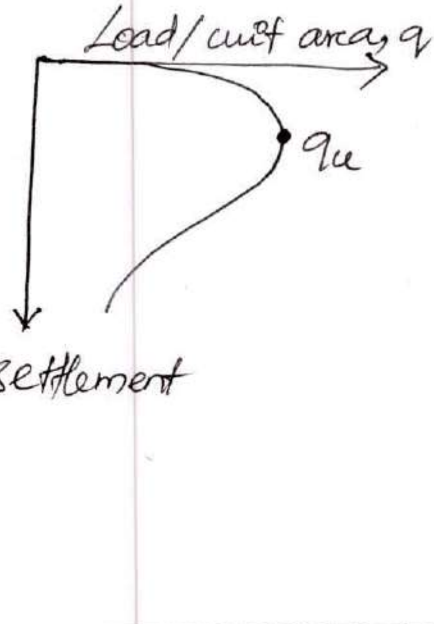
- The width of footings should be laid according to structural design.
- For light loaded building such as houses flats, school buildings, etc. have not more than two storeys, the width of the foundation

1. The width of the footing should not be less than 75 cm for one brick thick wall.
2. The width of footing should not less than 1 meter for one and a half brick wall.

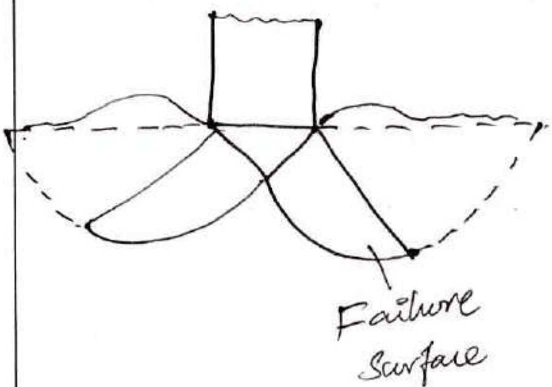
Procedure for Construction of Foundation:

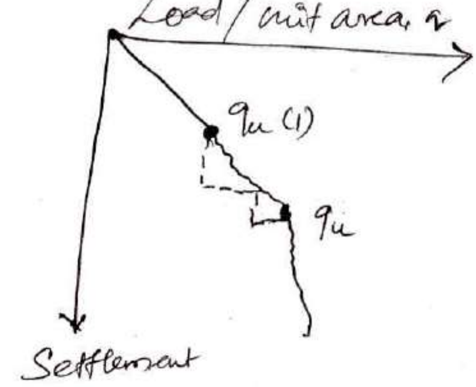
1. Excavation of earthwork in trenches for foundation.
2. Layout Cement Concrete
3. Lay of the footing in case of raft or column Construction.
4. Lay anti termite treatment
5. Lay Brickwork up to the plinth level.
6. Lay damp proof Course on the walls.
7. Refilling of earth around the walls
8. Refilling of earth in the building portion up to the required height according to the plinth level.



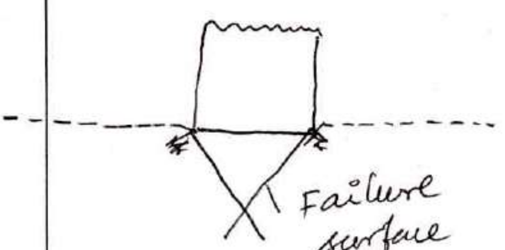


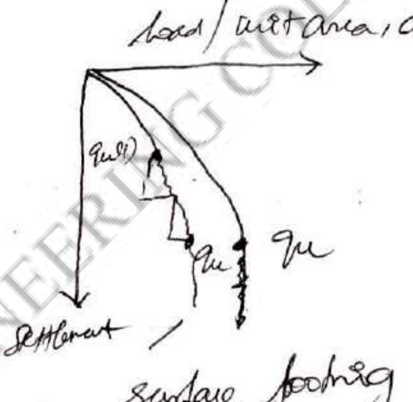
General Shear failure





Local shear failure





- When the load per unit area on the foundation equals $q_{u(1)}$, movement of the foundation will be accompanied by sudden jerks.
- The load per unit area at which this happens is the ultimate Bearing capacity, q_u.
- Beyond that point, an increase in load will be accompanied by a large increase in foundation settlement.
- The load per unit area of the foundation $q_{u(1)}$ is referred to as the first failure load.

Suggested Questions / Assignments / Home works / any other
1. Explain about the location and depth of foundation? 2. Describe the procedure for Construction

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundation Engineering	Arora. K.R	Standard publishers and distributors (Newdelhi)

Any other suggested Materials

Lecture No. 11

Topic(s) to be covered	Codal provisions and Bearing capacity

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Codal provisions and Bearing capacity Ultimate Bearing capacity Net ultimate Bearing capacity Safe Bearing Capacity	Understand and apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen / Apply

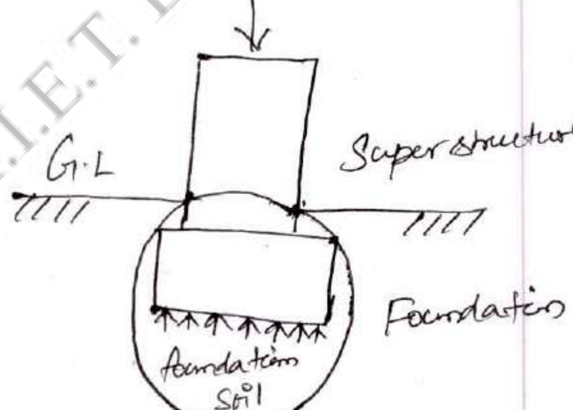
Lecture Notes

- The effect of settlement depends on its magnitude, its uniformity, length of time over which it take place the nature of structure.
- Maximum settlement of any individual foundation is 25m
- Office buildings, flats – 18mm
- National Building.

- allowable pressure should be such that the difference of settlement does not exceed 1/300
  - Sand - limited to 50mm
  - Clay - limited to 75mm

Bearing Capacity of Soil:

- It is the power of foundation soil to hold the forces from the superstructure without undergoing shear failure or excessive settlement.
- Foundation soil is that portion of ground which is subjected to additional stresses when foundation and superstructure are constructed on the ground.



Ultimate Bearing Capacity (q_f):

- It is the maximum pressure that a foundation soil can withstand without undergoing shear failure.

Net Ultimate Bearing Capacity (q_n):

- It is the maximum extra pressure (in addition to initial overburden pressure) that a foundation soil can withstand without undergoing shear failure

$$q_n = q_f - q_o$$

Here, q_o represents the overburden pressure at foundation level and is equal to D for level ground without surcharge where the unit weight of soil is and D is the depth to foundation bottom from Ground level.

Safe Bearing Capacity (q_s):

- It is the safe extra load the foundation soil is subjected to in addition to initial overburden pressure.

Allowable Bearing pressure (q_a):

- It is the maximum pressure the foundation soil is subjected to considering both shear failure and settlement.

Foundation:

It is that part of the structure which is in direct contact with soil.

- Foundation transfers the forces and moments from the super structure to the soil below such that the stresses in soil are within permissible limits and it provides stability against sliding and overturning to the super structure.
- It is a transition between the super structure and the foundation soil.
- The Job of a geotechnical engineer is to ensure that both foundation and soil below are safe against failure and to not experience excessive settlement.

Skempton's Relationship (1986)

$$C_N = \frac{2}{1+\left(\frac{\sigma'_0}{P_a}\right)}$$

An approximate relationship between the corrected standard penetration number and the relative density of sand

Standard Penetration number $(N_1)_{60}$	Approximate relative density D_r (%)
0-5	0-5
5-10	5-30
10-30	30-60
30-50	60-95

The values are approximate primarily because the effective overburden pressure and the results stress history of the soil significantly influence the N_{60} values of sand.

- An extensive study conducted by Marcuson and Bieganousky (1977) produced empirical relationship

$$D_r(\%) = 11.7 + 0.76\,(222 N_{60} + 1600 - 7.68\,\sigma'_o - 50\,C_u^2)^{0.5}$$

Where, D_r - Relative density

N_{60} - Standard penetration number in field

σ'_o - Effective Overburden pressure (kN/m^2)

C_u - Uniformity Co-efficient of the sand.

Cubrinovski and Ishihara (1999) also proposed a correlation between N_{60} and the relative density of sand (D_r) that can be expressed as

$$D_r(\%) = \left[\frac{N_{60}\left(0.23 + \frac{0.06}{D_{50}}\right)^{1.7}}{9}\left(\frac{1}{\frac{\sigma'_o}{P_a}}\right)\right]^{0.5} \times (100)$$

Where,

P_a = atmospheric pressure ($100\,kN/m^2$)

D_{50} = Sieve size through which 50% of soil will pass (mm)

The peak friction angle, ϕ', of granular soil has also been correlated with N_{60} or $(N_1)_{60}$ by several investigators

Suggested Questions / Assignments / Home works / any other

1. Define Bearing Capacity?
2. What are all the factors involved in Bearing Capacity.
3. Explain in detail about the Bearing capacity?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundation	B.C. Punmia	Standard publication & Distributors newdelhi

Any other suggested Materials

Lecture No. 12.

Topic(s) to be covered	Terzaghi's Bearing capacity theory

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 & LO2	Terzaghi's Bearing capacity theory Square foundation Circular foundation	understand & apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & apply

Lecture Notes

- He was the first to propose a comprehensive theory for evaluating the safe bearing capacity of shallow foundations with rough base.

Assumptions:

1. Soil is homogeneous and Isotropic
2. The shear strength of soil is represented by Mohr Coulombs Criteria.

3. The footing is of strip footing type with rough base. It is essentially a two dimensional plane strain problem.

4. Elastic zone has straight boundaries inclined at an angle equal to horizontal.

5. Method of superposition is valid.

6. passive pressure force has three components (P_{pc} produced by cohesion, P_{pq} produced by surcharge and P_p produced by weight of shear zone.

7. Effect of water table is neglected.

Footing carries concentric and vertical loads.

1. Footing and ground are horizontal.

2. Limit equilibrium is reached simultaneously at all points. Complete shear failure is mobilised at all points at the same time.

3. The properties of foundation soil do not change during the shear failure.

A strip footing of width B gradually compresses the foundation soil underneath due to the vertical load from superstructure.

. Let q_f be the final load at which the foundation soil experiences failure due to mobilization of plastic foundation

Ultimate bearing capacity:

$$q_u = c'N_c + qN_q + 0.5\gamma BN_\gamma \text{ (Continuous foundation)}$$

$$q_u = 1.3c'N_c + qN_q + 0.4\gamma BN_\gamma \text{ (Square foundation)}$$

$$q_u = 1.3c'N_c + qN_q + 0.3\gamma BN_\gamma \text{ (Circular foundation)}$$

B - equals the dimension of each side of the foundation /

B - equals the diameter of the foundation.

For foundations that exhibit local shear failure mode in soils.

$$q_u = \tfrac{2}{3}c'N'_c + qN'_q + \tfrac{1}{2}\gamma BN'_\gamma \text{ (Strip foundation)}$$

$$q_u = 0.867c'N'_c + qN'_q + 0.4\gamma BN'_\gamma \text{ (Square foundation)}$$

$$q_u = 0.867c'N'_c + qN'_q + 0.3\gamma BN'_\gamma \text{ (Circular foundation)}$$

Factor of Safety:

- calculating the gross allowable load bearing capacity of shallow foundation requires the application of a factor of safety (FS) to the gross ultimate bearing capacity.

$$\boxed{q_{all} = \frac{q_u}{FS}} \quad \& \quad q = \gamma D_f$$

Problem 1:

- A square foundation is 1.5m x 1.5m in plan. The soil supporting the foundation has a friction angle $\phi' = 20°$ and $c' = 15.2\ kN/m^2$. The unit weight of soil, γ, is $17.8\ kN/m^3$. Determine the allowable gross load on the foundation with a factor of safety (FS) of 4. Assume that the depth of foundation (D_f) is 1 meter and that general shear failure occurs in soil.

$$q_u = 1.3\, c' N_c + q N_q + 0.4\, \gamma B N_\gamma$$

$$\phi' = 20°,\ N_c = 17.69,\ N_q = 7.44,\ N_\gamma = 3.64$$

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

$$= 520.85 \approx 521\ kN/m^2$$

q = Depth of foundation $\times$ unit wt. of soil.

$$q_{all} = \frac{q_u}{FS} = \frac{521}{4} = 130.25\ kN/m^3 \approx 130\ kN/m^2$$

$$Q = (130) B^2 = 130(1.5 \times 1.5) = 292.5\ kN$$

Terzaghi's Bearing Capacity Factors:

ϕ'	N_c	N_q	N_γ^a	ϕ'	N_c	N_q	N_γ^a
0	5.70	1.00	0.00	26	27.09	14.21	9.84
1	6.00	1.10	0.01	27	29.24	15.90	11.60
2	6.30	1.22	0.04	28	31.61	17.81	13.70
3	6.62	1.35	0.06	29	34.24	19.98	16.18
4	6.97	1.49	0.10	30	37.16	22.46	19.13
5	7.34	1.64	0.14	31	40.41	25.28	22.65
6	7.73	1.81	0.20	32	44.04	28.52	26.87
7	8.15	2.00	0.27	33	48.09	32.23	31.94
8	8.60	2.21	0.35	34	52.64	36.50	38.04
9	9.09	2.44	0.44	35	57.75	41.44	45.41
10	9.61	2.69	0.50	36	63.53	47.16	54.36
11	10.61	2.98	0.69	37	70.01	53.80	65.27
12	10.76	3.29	0.85	38	77.50	61.55	78.61
13	11.41	3.63	1.04	39	85.97	70.61	95.03
14	12.11	4.02	1.26	40	95.66	81.27	115.31
15	12.86	4.45	1.52	41	106.81	93.85	140.51
16	13.68	4.92	1.82	42	119.67	108.75	171.99
17	14.60	5.45	2.18	43	134.58	126.50	211.56
18	15.12	6.04	2.59	44	151.95	147.74	261.60
19	16.56	6.70	3.07	45	172.28	173.28	325.34
20	17.69	7.44	3.64	46	196.22	204.19	407.11
21	18.92	8.26	4.31	47	224.55	241.80	512.84
22	20.27	9.19	5.09	48	258.28	287.85	650.67
23	21.75	10.23	6.00	49	298.71	344.63	831.99
24	23.36	11.40	7.08	50	347.50	415.14	1072.80
25	25.13	12.72	8.34				

2. Assuming that local shear failure occurs in soil supporting the foundation.

$$q_u = 0.867c'N'_c + qN'_q + 0.4\gamma B N'_\gamma$$

$\phi' = 20°$, $N'_c = 11.85$, $N'_q = 3.88$, $N'_\gamma = 1.12$

$$q_u = (0.867)(15.2)(11.85) + (1 \times 17.8)(3.88) + (0.4)(17.8)(1.5)(1.12)$$

$$= 156.2 + 69.1 + 12.0 = 237.3\ kN/m^2$$

$$q_{all} = \frac{231.3}{4} = 59.3\ kN/m^2$$

Allowable gross load $= Q = q_{all}(B^2) = (59.3)(1.5^2) = 133.4\ kN$.

Suggested Questions / Assignments / Home works / any other

1. Explain the Terzhagis safe bearing capacity for square foundation.

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Text book of soil mechanics and foundation Engineering	Murthy VNS	CBS Publisher distributors Ltd, New Delhi

Any other suggested Materials

Lecture No. 13

Topic(s) to be covered	Factors affecting bearing capacity

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Factors affecting Bearing capacity Soil strength, Foundation width, Foundation depth, Soil weight and surcharge, Spacing between foundations	understand

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & participate

Lecture Notes

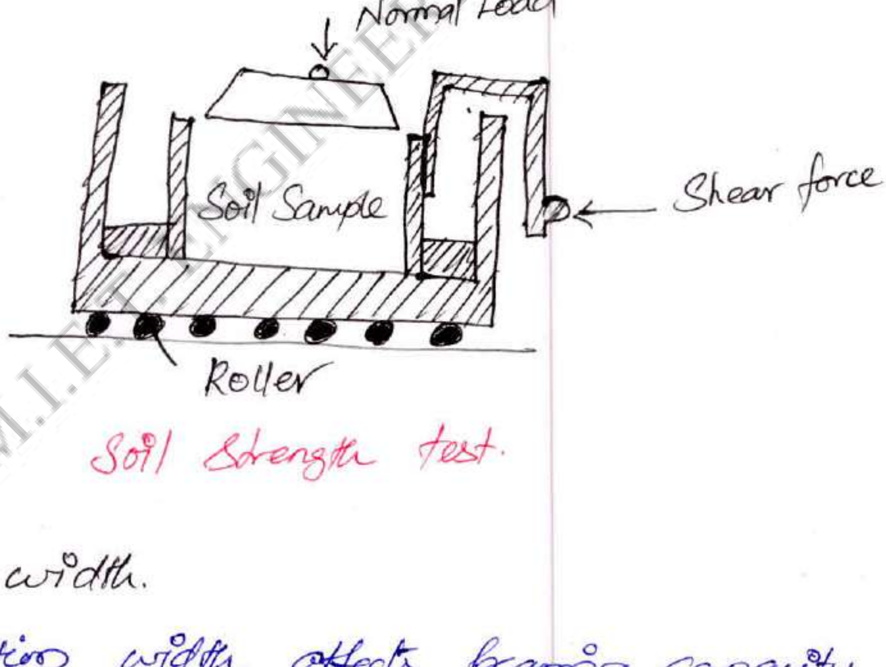
- The Bearing capacity of soil is influenced by many factors for instance soil strength, foundation width and depth, soil weight and surcharge, and spacing between foundations.

- These factors are related to the loads exerted on the soil and considerably affect the bearing capacity.

- Bearing capacity is the ability of soil to safely carry the pressure placed on the soil from any engineered structure without undergoing a shear failure with accompanying large settlements.

Soil Strength:

- Bearing capacity of cohesionless soil and mixed soil increases unproportionally with the increase of in the effective friction angle.
- However, bearing capacity of cohesion soil varies linearly with the soil cohesion provided that the effective friction angle is zero.



Soil Strength test.

Foundation width.

- Foundation width affects bearing capacity of cohesionless soil.
- The bearing capacity of a footing placed at the surface of cohesionless soil, where the soil shear strength is considerably dependent on internal friction,

is proportional to the width of foundation.

- Bearing capacity of Cohesive soil of Constant shear strength and infinite depth is independent of foundation width.

Foundation depth:

- The greater the bearing capacity the deeper the foundation. This is specifically obvious in a uniform cohesionless soil. In contrary, if the foundation is carried down to a weak soil layer, then bearing capacity is declined.

Soil Weight and Surcharge:

- The contribution of subsurface and surcharge soil which are influenced by water table, to the bearing capacity cannot be ignored.
- The water table should not be above the base of the foundation to avoid construction, seepage, and uplift problems.

Spacing between foundations:

- It is recommended to consider minimum spacing between footings which 1.5 times foundation width, during the design of foundation in order to avoid reduction in Bearing capacity

Earthquake and Dynamic Motion:

- Repeated movements could increase pore pressure in foundation soil and consequently bearing capacity is decreased.
- Sources of cyclic movements are earthquakes, vibrating machinery, and other sources like vehicular traffic, blasting and pile driving.

Subsurface Voids:

- Bearing capacity of soil decreases due to subsurface voids which are within a critical depth beneath the foundation.
- The critical depth is that depth below which the influence of pressure in the soil from the foundation is negligible.

Soil erosion and Seepage:

- Erosion of soil around and under foundations and seepage can reduce bearing capacity and can cause foundation failure.

Suggested Questions / Assignments / Home works / any other

1. Define Bearing capacity?
2. What are all the factors affecting the Bearing capacity of soil?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundations	Punmia, B.C	Laxmi publication pvt ltd, new delhi

Any other suggested Materials

Lecture No. 14

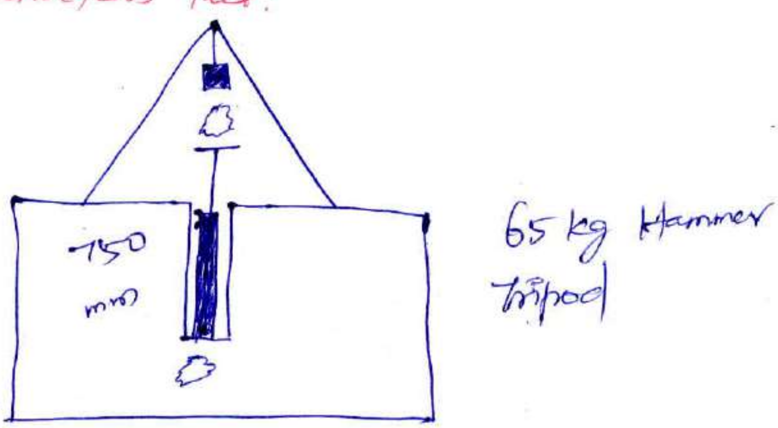
Topic(s) to be covered	Bearing capacity of in-site tests (SPT, SCPT, and plate Load)

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Bearing capacity of in-site tests (SPT, SCPT, and plate Load) Advantages, disadvantages of Standard penetration test Standard cone penetration test, plate load test	Understand

Teaching Learning Material	Student Activity
Chalk & Talk	Listen.

Lecture Notes

Standard penetration test:



- It is a field test to estimate the penetration resistance of soil.
- It consists of a split spoon sampler 50.8mm OD, 35mm ID min 600mm long and 63.5kg hammer freely dropped from a height of 750mm
- Test is performed on a clean hole 50mm to 150mm dia.

Advantages of Standard penetration test:

- Relatively quick & simple to perform
- Equipment & expertise for test is widely available
- provides representative soil sample.
- provides useful index for relative strength & compressibility of soil.

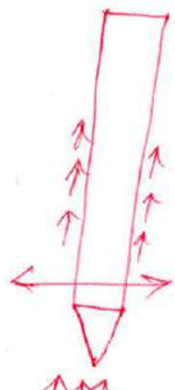
Disadvantages of SPT:

- Requires the preparation of bore hole.
- Dynamic effort is related to mostly static performance
- SPT is abused, standards regarding energy are not uniform
- Not possible to obtain properties continuously with depth.

Standard Cone penetration test:

- Cone penetration test can either be static cone penetration test (or) dynamic cone penetration test.
- Continuous record of penetration resistance with depth is achieved.

- Consists of a cone 36mm dia (1000mm²) and 60° vertex angle.
- Either the cone, or the tube or both can be forced in to the soil by jacks.



- Correction for overburden pressure is applied. approximately, N = 10qc (kPa)

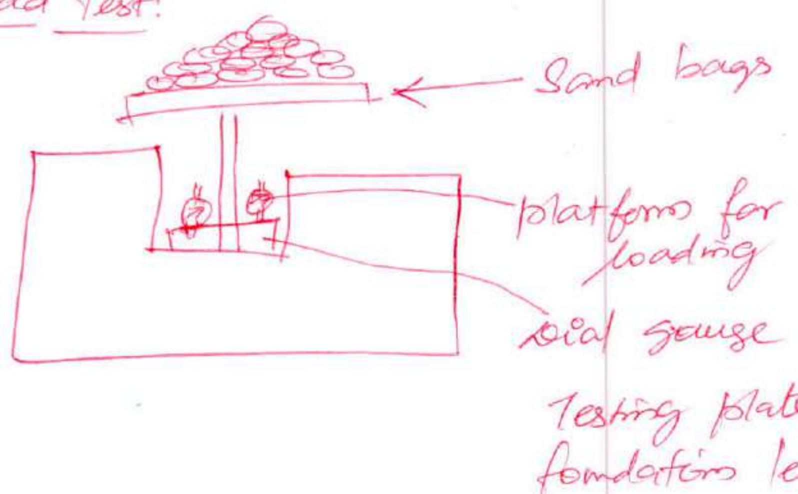
Advantages of SCPT are:

- Continuous resistance with depth is recorded.
- Static resistance is more appropriate to determine static properties of soil.
- Can be correlated with most properties of soil

Disadvantages of SCPT are:

- Not very popular in india
- If a small rock piece is encountered, resistance shown is erratic & incorrect.
- Involves handling heavy equipment.

Plate load test:



- It is a field test for the determination of bearing capacity and settlement characteristics of ground in field at the foundation level.
- The test involves preparing a test pit up to the desired foundation level.
- A rigid steel plate, round or square in shape, 300mm to 750mm in size, 25mm thick acts as model footing.
- Dial gauges, at least 2, of required accuracy (0.002mm) are placed on plate on plate at corners to measure the vertical deflection
- Load Vs settlement graph is plotted. Load (P) is plotted on the horizontal scale and settlement is plotted on the vertical scale.
- Red curve indicates the general shear failure & the blue one indicates the local or punching shear failure

- The ultimate Bearing capacity of a foundation, as well as the allowable bearing capacity based on tolerable settlement considerations can be effectively determined from the field load test, generally referred as plate load test.

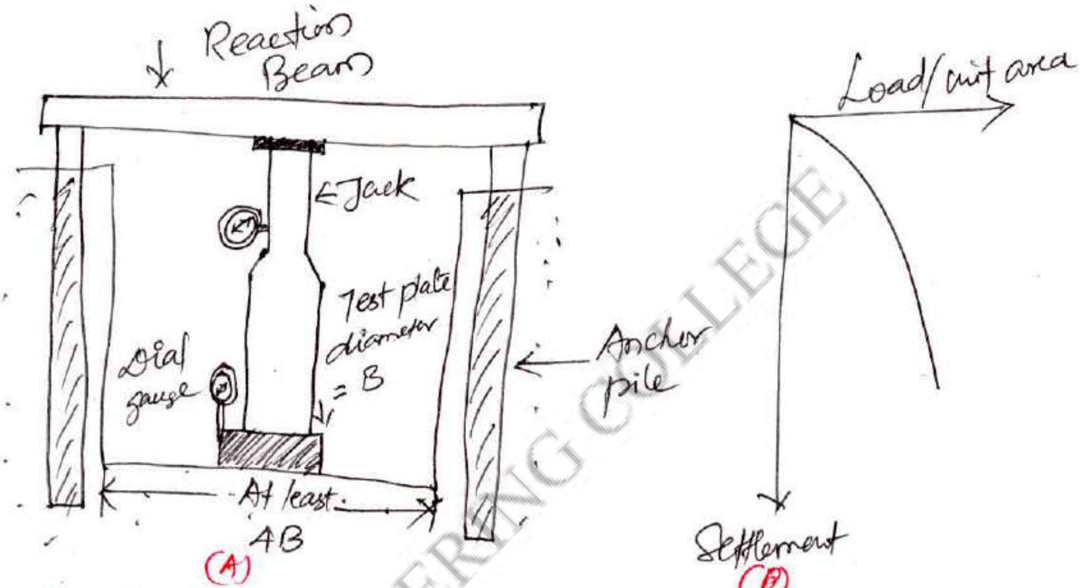


Plate load test (A) test arrangement, (B) Nature of load Settlement curve.

For test in clay

$$q_{u(F)} = q_{u(P)}$$

$q_{u(F)}$ = Ultimate Bearing capacity of proposed foundation.
$q_{u(P)}$ = Ultimate Bearing capacity of the test plate.

For test in Sandy Soils:

$$q_{u(F)} = q_{u(P)} \frac{B_F}{B_P}$$

B_F = width of foundation
B_P = width of test plate

The allowable Bearing capacity of a foundation, based on settlement consideration and for a given intensity of load q_0 is

$S_F = S_P \frac{B_F}{B_P}$ (clay), $S_F = S_P \left(\frac{2B_F}{B_F + B_P}\right)^2$ (Sand) / Relation Tertiary as per.

Suggested Questions / Assignments / Home works / any other

1. Write short note on Standard penetration test and advantages?
2. Describe the ~~test~~ SPT, SCPT and plate load test?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil mechanics and foundation engineering	Arora K.R	Standard publisher and distributors new delhi

Any other suggested Material

Lecture No. 15

Topic(s) to be covered	Seismic Considerations in bearing capacity evaluation.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Seismic Consideration in bearing Capacity evaluation Seismic method operations Applications	Understand and apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen/participate/Apply

Lecture Notes

Seismic Method:

· Seismic refraction is a geophysical method used for investigating subsurface ground conditions utilizing surface - sourced seismic waves.

· The method depend on the fact that seismic waves have differing velocities in different types of soil (or rock): in addition, the waves are refracted when they cross the boundary between different types (or conditions) of soil or rock. The methods enable the general soil type and the approximate depth to strata boundaries, or to bedrock, to be determined.

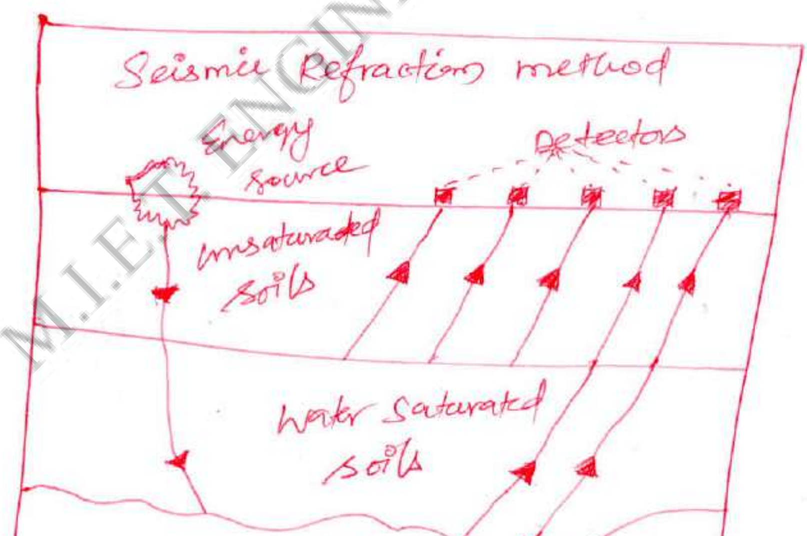
Operations

- pulses of low frequency seismic energy are emitted by a seismic source such as a hammer-plate weight drop or buffalo gun.
- The type of source is dependent on local ground conditions and required depth penetration.
- Explosives are best for deeper applications but are constrained by environmental regulations.
- The seismic waves propagated downward through the ground until they are reflected or refracted off subsurface layers.
- Refracted waves are detected by arrays of 24 or 48 geophones spaced at regular intervals of 1-10 meters, depending on the desired depth penetration of the survey.
- Sources are positioned at each end of the geophone array to produce forward and reverse wave arrivals along the array.

- Additional sources may be used at intermediate or off-line positions for full coverage at all geophone positions

- A Geophone is a device that converts ground movement (velocity) into voltage, which may be recorded at a recording station.

- The deviation of this measured voltage from the base line is called the seismic response and is analysed for structure of the earth.

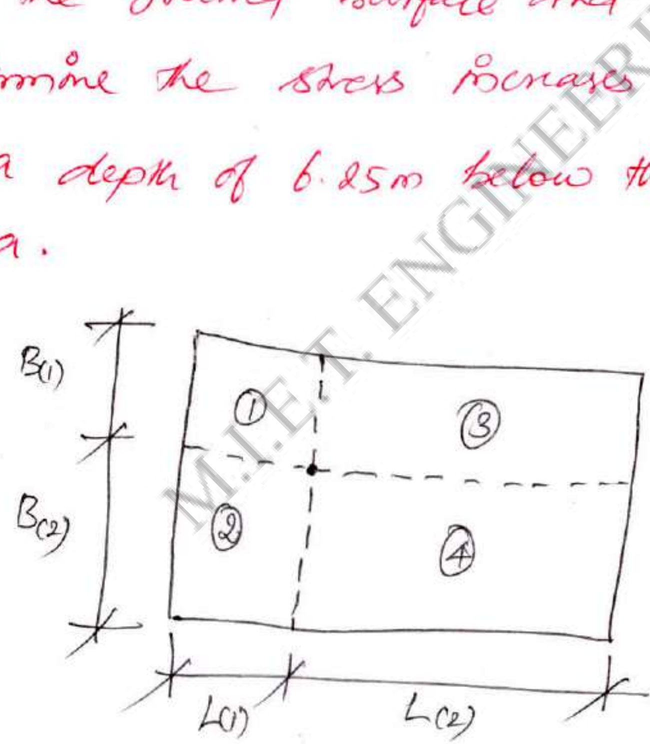


Seismic Refraction method.

Applications:

- Measure bedrock depth & overburden thickness
- Determines Rip ability parameters
- Investigates pipeline routes
- Locates Geological structures.
- Evaluates Sand & Gravel deposist
- Define ancient landfill sites.

A flexible rectangular area 2.5 m x 5m is located on the ground surface and loaded with $q_0 = 145 kN/m^2$. Determine the stress increase caused by this loading at a depth of 6.25m below the centre of rectangular area.



$$B_1 = \frac{2.5m}{2} = 1.25m$$

$$L_1 = \frac{5}{2}m = 2.5m$$

$m = \frac{B_1}{z} = \frac{1.25}{6.25} = 0.2$

$n = \frac{L_1}{z} = \frac{2.5}{6.25} = 0.4$

$m = 0.20$

$n = 0.4$

then the value of $I_1 = 0.0328$ from the variation of influence value

- Also note that $I_1 = I_2 = I_3 = I_4$.

$\Delta\sigma = q_0 (4 I_1) = (145)(4)(0.0328)$

$= 19 \text{ kN/m}^2$

Suggested Questions / Assignments / Home works / any other

1. What is Seismic Consideration?
2. Explain Seismic consideration in bearing capacity evaluation?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil mechanics and foundations	B.C. Punmia	Laxmi publication pvt Ltd. newdelhi (2011)

Any other suggested Materials

Lecture No. 16

Topic(s) to be covered	Determination of settlement of foundations on granular and clay deposits.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Settlement of foundations Appearance of structure Utility of structure Damage to the structure Immediate settlement, Consolidation	understand and apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen / Apply

Lecture Notes

- The vertical downward movement of the base of a structure is called settlement and its effect upon the structure depends on its magnitude, its uniformity, the length of the time over which it takes place, and the nature of the structure itself.

1. Appearance of structures
2. Utility of structures

3. Damage to the Structures

Appearance of Structures:

· Settlement affects the appearance of structures. If a structure settles excessively, its aesthetic is impaired. It causes doors and windows to distort, walls and plasters to crack and the structure to tilt.

Utility of Structures:

· Settlement interfere the utility of structures in many ways. If settlement is excessive overhead cranes do not operate correctly, machinery may go out of plumb and tracking units such as radar become inaccurate.

Damage to the structure:

If the settlement is severe, it may lead to the complete collapse of the structure even though the factor of safety against shear failure is high.

· Where foundation settlement occurs at roughly the same rate throughout all portions of a building, it is termed uniform settlement.

· Settlement that occurs at differing rates b/w different portions of a building is termed differential settlement.

1. Total settlement: It is Combination of initial and Consolidation settlement elastic settlement / initial settlement. Initial / elastic settlement is the settlement caused due to elastic properties of the soil due to applied load. Consolidation settlement - primary Consolidation - is the Consolidation occurs due to expulsion of air from the voids.

Secondary / creep:- is the Consolidation due to expulsion of water from the voids.

2. Differential settlement / angular distortion:

• It is the difference in settlement between two points below the footings.

3. Time dependent settlement: for sands, settlement is called imediate settlement as it is the major settlement, there being no or very less Consolidation settlement. For clays, we talk about initial or elastic settlements and not immediate settlements.

Immediate settlement:

Immediate settlement concerns the initial pressure on the soil under and surrounding the foundation. It is "immediate" because it occurs during and right after construction. It has nothing to do with water displacement, but is merely caused by the wt. of structure

Consolidation:

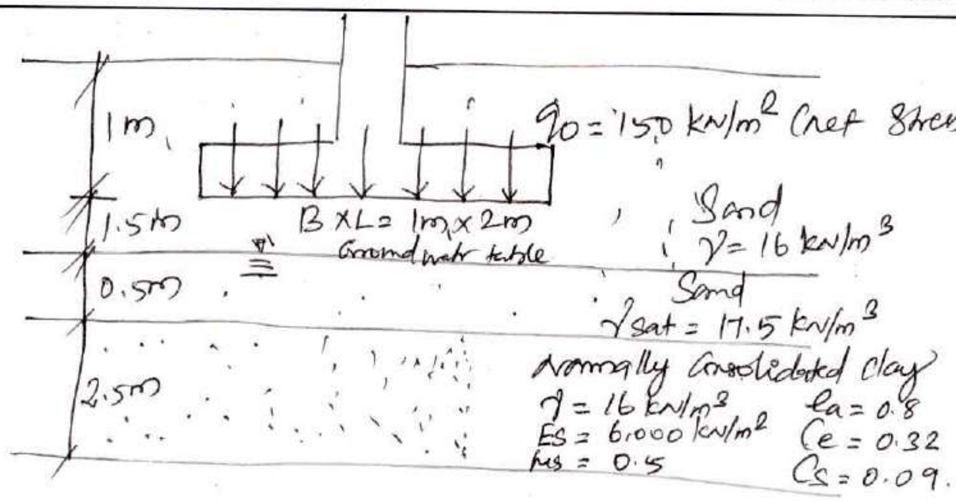
- Consolidation settlement is distinguised from immediate settlement both by the duration of the settlement and by displacement of water.
- Consolidation is the more worrisome form of settlement because it is difficult to predict over months or years.
- Consolidation settlement is the settling of a foundation over time, due to pressure exerted by the structure and squeezes out the water content of the soil, thus compressing it.

Primary and Secondary Consolidation:

- Consolidation settlement has two components, primary and secondary. The former deals explicity with the settlement caused by soil moisture displacement, and the latter deals with the elastic settlement after all movable water has been squeezed out of the soil.

A plan of a foundation 1m x 2m is shown in figure . Estimate the Consolidation settlement of the foundation

Calculation of primary consolidation settlement for a foundation.



The clay is normally consolidated.

$$S_c = \frac{C_c H_c}{1+e_0} \log \frac{\sigma_0' + \Delta\sigma'_{av}}{\sigma_0'}$$

$$\sigma_0' = (2.5)(16.5) + (0.5)(17.5 - 9.81) + (1.25)(16 - 9.81)$$

$$= 41.25 + 3.85 + 7.74 = 52.84\ kN/m^2$$

$$\Delta\sigma'_{av} = \frac{1}{6}(\Delta\sigma_t' + 4\Delta\sigma_m' + \Delta\sigma_b')$$

Using 2:1 method.

$$\Delta\sigma = \frac{q_0 \times B \times L}{(B+z)(L+z)}$$

For top of the clay layer, z = 2m, so

$$\Delta\sigma_t' = \frac{(150)(1)(2)}{(1+2)(2+2)} = 25\ kN/m^2$$

Similarly,

$$\Delta\sigma_m' = \frac{(150)(1)(2)}{(1+3.25)(2+3.25)} = 13.45\ kN/m^2$$

and

$$\Delta\sigma_b' = \frac{(150)(1)(2)}{(1+4.5)(2+4.5)} = 8.39\ kN/m^2.$$

Thus,

$$\Delta\sigma'_{av} = \frac{1}{6}[25 + 4(13.45) + 8.39] = 14.53\ kN/m^2$$

So,

$$S_c = \frac{(0.32)(2.5)}{1+0.8} \log\left(\frac{52.84 + 14.53}{52.84}\right) = 0.0469\ m = \boxed{46.70\ mm}$$

Suggested Questions / Assignments / Home works / any other

1. Explain the settlements of foundation in detail?
2. What is settlement foundation?

Text Books / Reference Books

S.No	Title	Author	
1.	Soil mechanics and foundation Engineering	Arora K.R	Standard publishers and Distributors and edition

Any other suggested Materials

Lecture No. 17.

Topic(s) to be covered	Total and differential settlement

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Total and differential settlement what is differential settlement and definitions of differential settlement in soil	understand and Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen / Apply

Lecture Notes

- Differential settlement occurs when the soil beneath the structure expands, contracts or shifts away.
- This can be caused by drought conditions; the root systems of maturing trees, flooding, poor drainage frost, broken water lines, vibrations from nearby construction or poorly compacted fill soil.

- Differential settlement can cause cracks in a structure's foundations and interior walls, as well as uneven setting of doors and windows.
- Other signs of differential settlement include tilting chimneys, exterior stairs that tilt or sink, bulging walls, leaking through openings and sunken slabs.
- Since soil settlements tends to be gradual, cracks due to differential settlement tend to be larger at the top diminishing to nearly nothing at the bottom.
- The best way to prevent differential settlement is to analyze the soil you are planning to build on as well as the surrounding environment.

Aspects of settlement:

(i) Uniform settlement

(ii) Differential settlement

Uniform settlement does not cause harm to the structural stability of the structure.

Differential Settlement:

- Different magnitude of settlement at different points underneath a structure.

- Supplementary stress and cause harmful effects cracking: permanent; irreparable damage, ultimate yield; failure of structure.

Definition of Differential settlement:

Differential settlement refers to the unequal settling of a building's piers or foundation that can result in damage to the structure. The damage occurs when the foundation sinks in different areas at different times.

Causes:

- Differential settlement is primarily due to the condition of the soil upon which the structure sits.
- Soils has the capacity to expand or contract based upon the temperature or weather conditions. It can also shift or wash away due to poor drainage, heavy rainfall, soil drying unevenly, or changes in water table.

Effects:

- The settlement cause cracks in a structures foundation, slab or supporting piers. These cracks lead to cracks in the building's interior walls and uneven settling of the building's doors window and trim

Prevention and solutions:

- The best way to prevent damage from differential settlement is to thoroughly analyse the soil and make necessary amendments before construction begins.

- It may be necessary to reinforce the structures piers or foundations if a problem occurs after the building has been constructed.

Methods of minimizing settlement:-

- Tightening loose sand, consolidating soft clays, grouting and freezing or solidifying soil mass with chemicals - distribute the pressure evenly to avoid differential settlement.

Total settlement:

Total foundation settlement can be divided into three different components, namely immediate or elastic settlement, consolidation settlement and secondary or creep settlement as

$$S = S_i + S_c + S_s$$

Assume from previous problem, that the pore water pressure parameter A = 0.6. Taking into account the three dimensional effect, estimate the primary consolidation settlement.

Sol: Assuming that the 2:1 method of stress increase holds good the area of distribution of stress at the top of the clay layer will have dimensions

$$B' = \text{Width} = B + Z = 1 + (1.5 + 1.5) = 3\,m$$

$$L' = \text{Width} = L + Z = 2 + (1.5 + 1.5) = 4\,m$$

The diameter of an equivalent circular area, B_{eq} can be given as

$$\frac{\pi}{4} B_{eq}^2 = B'L'$$

So that

$$B_{eq} = \sqrt{\frac{4B'L'}{\pi}} = \sqrt{\frac{(4)(3)(4)}{\pi}} = 3.91\,m$$

Also,

$$\frac{H_c}{B_{eq}} = \frac{2.5}{3.91} = 0.64$$

From previous figure, $A = 0.6$ and $H_c/B_{eq} = 0.64$ the magnitude of $K_{cr} = 0.78$

Hence,

$$S_e = K_{cr} S_{e\text{-}oed} = (0.78)(46.9) = 37\,mm$$

$$S_e = 37\,mm$$

Suggested Questions / Assignments / Home works / any oth

1. What is settlement in foundation?
2. Explain in detail about the total settlement and differential settlement?
3. Define differential settlements?

Text Books / Reference Books

S.No	Title	Author
1.	Soil mechanics and foundations	B.C. Punmia Laxmi publication new delhi 2014

Any other suggested Materia

Lecture No. 18

Topic(s) to be covered	The Codal provisions

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	The Codal provisions, the minimum shear reinforcement in the form of stirrups in the beams	understand & apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen / apply

Lecture Notes

Immediate settlements:

- Immediate settlement takes place as the load is applied or within a time period of about 7 days.
- predominates in cohesion less soils and unsaturated clay.
- Immediate settlement analysis are used for all fine-grained soils including silts and clays with a degree of saturation < 90%, and for all

coarse grained soils with large co-efficient of permeability (say above 10.2 m/s)

Consolidation settlement (ΔH_c)

- Consolidation settlements are time dependent and take months to years to develop.
- The leaning tower of pisa in italy has been undergoing consolidation settlement for over 700 years
- Dominates in saturated/ nearly saturated fine grained soils where consolidation theory applies

Secondary settlement / creep (ΔH_s)

- Occurs under constant effective stress due to continuous rearrangement of clay particles into a more stable configuration.
- predominates in highly plastic clays and organic clays.

Immediate settlement of cohesive soils:

Immediate settlement in cohesive soil may be estimated using elastic theory, particularly for saturated clays, clay shales, and most rocks. The linear theory of elasticity is used to determine the elastic settlement of the footing on saturated clay

$$S_i = qB \frac{1-\mu^2}{E_S} I_w$$

Consolidation Settlement Computation:

primary settlement also known as primary consolidation settlement (Sc), is the reduction in volume of a soil mass caused by the application of a sustained load to the mass and due principally to a squeezing out of water from the void spaces of the mass and accompanied by a transfer of the load from the soil water to the soil solids.

Secondary settlements: (Ss)

Secondary settlement, also known as creep, is the reduction in volume of a soil mass caused by the application of a sustained load to the mass and due principally to the adjustment of the internal structure of the soil mass after most of the load has been transferred from the soil water to the soil solids.

- Due to the absence of pore water pressure; the solid particles are being rearranged and further compressed as point to point contact is experienced.

Codal provisions - settlement:

- The effect of settlement depends on its magnitude its uniformity, length of time over which it take place the nature of structure.
- Maximum settlement of any individual foundation is 25 mm.
- Office buildings, flats - 18mm
- National building code of india (SP : 7: 1970)
  - Allowable pressure should be such that the different of settlement does not exceed 1/300.
- Sand limited to 50mm
- clay - limited to 75 mm

Types of structure	Allowable maximum settlement
Commercial & industrial buildings	25
Industrial building	38
Ware house	50

Special machinery foundations   offen less than 0.5 mm

Vertical settlement under a uniformly distributed flexible area:

$$S_i = qB \frac{1-\mu^2}{E_s} I_w$$

q = intensity of contact pressure in units (E_s)
B = least lateral dimension of contributing base area
E_s = modulus of elasticity of soil.
μ = poisson's Ratio of soil (0.5 for saturated clay)
I_w = influence factor.

Shape	Flexible footing Center	Flexible footing Corner	Flexible footing Average	Rigid footing
1. Circle	1	0.64	0.85	0.79
2. Square	1.12	0.56	0.95	0.82
3. Rectangle L/B=1.5	1.36	0.68	1.20	1.06
L/B = 2.0	1.53	0.77	1.31	1.20
L/B=2.0	1.78	0.89	1.52	1.42
L/B = 5.0	2.10	1.05	1.83	1.70
L/B = 10	2.52	1.26	2.25	2.10
L/B = 100	3.38	1.69	2.96	3.40

Value of influence factor

Suggested Questions / Assignments / Home works / any oth

1. Define types of settlements?
2. What is immediate settlements?
3. What is Consolidation settlements

Text Books / Reference Books

S.No	Title	Author	publishes
1.	Soil mechanics and foundation Engineering	Arora. K.R	Standard publishers 2014

Any other suggested Materi

Lecture No. 19 UNIT-IV FOOTINGS AND RAFTS

Topic(s) to be covered	Types of Isolated footing

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	What is isolated footing, its types, shapes, designs, advantages and disadvantages.	Understand and Apply

Teaching Learning Material	Student Activity
chalk / Talk / Solve	Listen / Apply

Lecture Notes

What is Isolated footing:

→ Individual Columns are supported by the Isolated footing.

→ They might be stepped or have projections in the Concrete foundation, steel reinforcement is given in both directions in a Concrete bed for heavily loaded Columns.

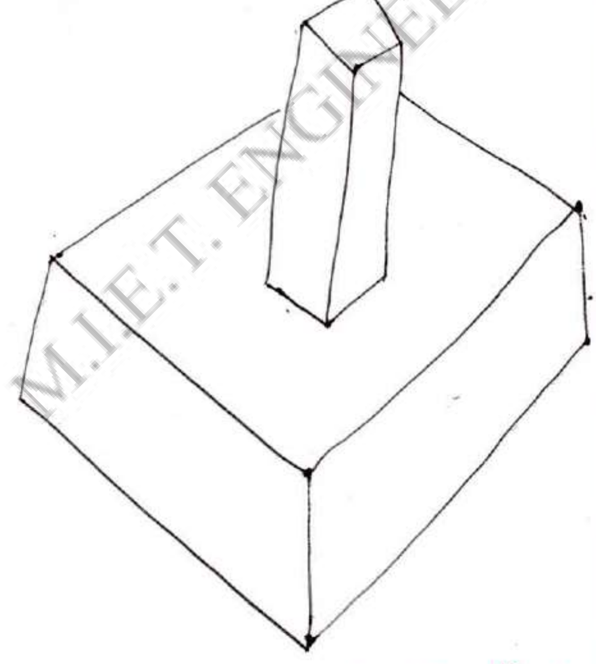
* On all sides of the Concrete bed, a 15cm offset is usually supplied. In the case of brick

masonry columns, a 5cm offset is likewise provided in regular layers on all four sides. When it comes to concrete column footings, they might be slabbed, stepped or sloped.

→ It comes in variety of shapes and sizes, including spread, stepped, and sloped footing.

→ The most common shapes are square, rectangular, and round.

→ The soil condition and the pattern of exerted loads determine which type of footing is used. When columns are placed at relatively long distances, isolated footings are one of the most cost-effective types of footings.



Isolated Footing

Types of Isolated footings:

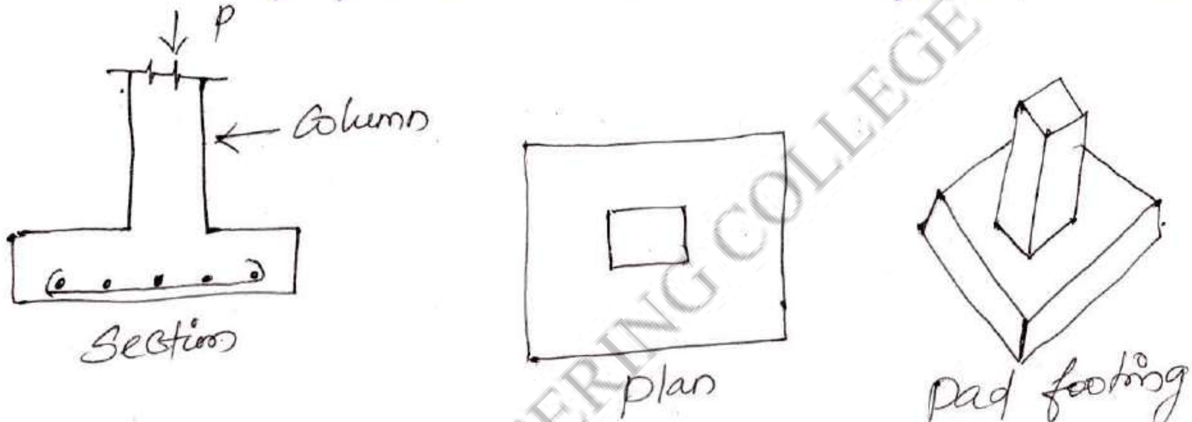
Isolated footings are generally three types:

1. Flat, pad, plain or Reinforced Isolated footing:

• It is commonly square, rectangular, or circular in shape and is built separately under each column.

• Flat isolated footing has a consistent thickness. It's included to help lessen bending moments and shear forces at important points.

• To boost the final weight carrying capability, it can be made of plain concrete or reinforced concrete.

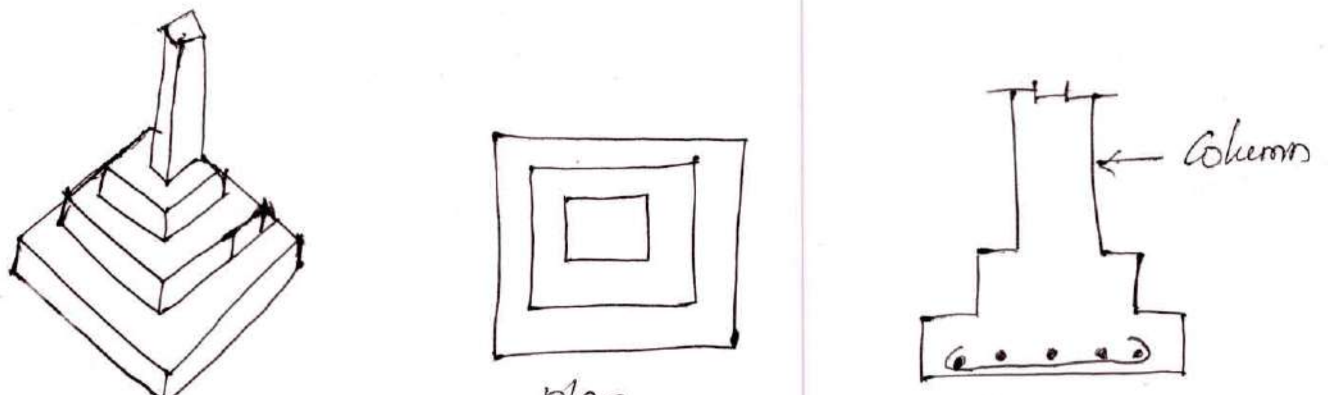


pad Isolated Footing

• A pad foundation is built to sustain concentrated loads from a single point load, such as a structural column. Another name for this is a simple spread footing.

Stepped Isolated Footing:

• Construction of this form of isolated footing was once common, but its use has waned in recent years. It is primarily used in the construction of Residential buildings.

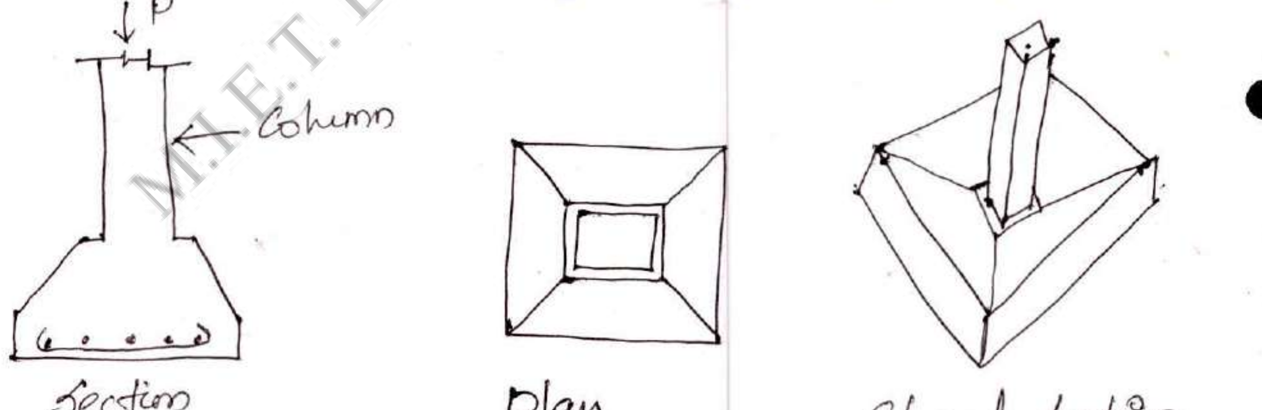


Stepped footing plan Section

- The stepped footing are stacked on top of each other. To make steps, three concrete cross-sections are typically piled on top of each other.

Sloped isolated footing:

- Sloped or trapezoidal footings are meticulously designed and built to maintain a 45-degree top slope on all sides. In the construction of a sloped footing less

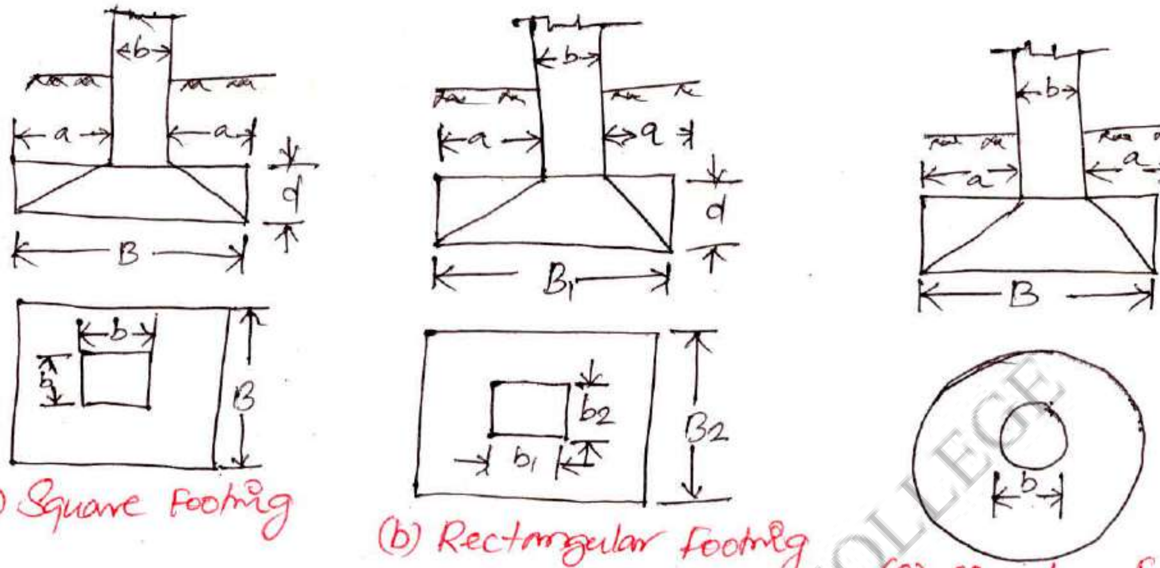


Section Plan Sloped footing

reinforcing and concrete is utilized than in the construction of a plain isolated footing. As a result, there is less need for concrete and reinforcement.

Different shapes of isolated footings:

1. Square, 2. Rectangular, 3. Circular



(a) Square Footing (b) Rectangular Footing (C) Circular Footing

Advantages of Isolated footing:

- Isolated footing are cost-effective.
- The independent footings are simple to build.
- Even unskilled workers can construct it.
- It necessitates minimal excavation of the earth.

Disadvantages of Isolated Footing:

- The earth must be stable all the way around the structure's base.
- It may be very huge in size to cope with the heavy load.
- Because of the separate foundations, this design is vulnerable to differential settlement that could harm the structure.

Suggested Questions / Assignments / Home works / any other

1. Explain about the types of isolated footing?
2. Define Isolated footing?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundation	B.C. Punmia	Laxmi Publication pvt. Ltd

Any other suggested Materials

Lecture No. 20

Topic(s) to be covered	Combined footing.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Introduction of combined footing types of combined footing, and	Understand & Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen and Apply.

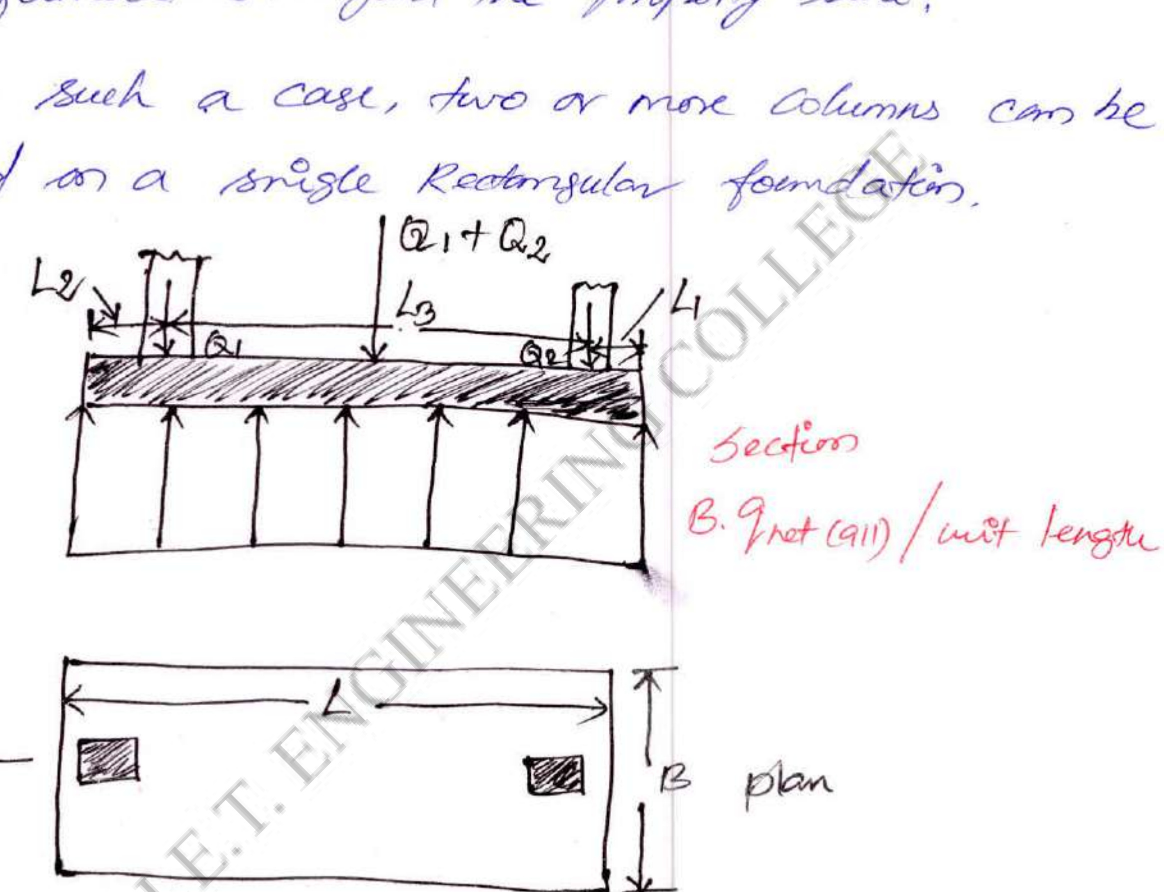
Lecture Notes

Introduction:

- Under certain circumstances, it may be desirable to construct a footing that support a line of two or more columns.
- These footings are refered to as combined footings.
- Rectangular, Trapezoidal, strap footing

Combined Footings:

- The load to be carried by a column and the soil bearing capacity are such that the standard spread footing design will require extension of the column foundation beyond the property line.
- In such a case, two or more columns can be supported on a single rectangular foundation.



Rectangular Combined Footing

Step 1: Determine the area of the foundation

$$A = \frac{Q_1 + Q_2}{q_{net(all)}}$$

Q_1, Q_2 = Column loads

$q_{net(all)}$ = net allowable soil bearing capacity.

Step 2: Determine the location of the resultant of the column loads

$$x = \frac{Q_2 L_3}{Q_1 + Q_2}$$

Step 3: For a uniform distribution of soil pressure under the foundation, the resultant of the column loads should pass through the centroid of the foundation

$L = 2(L_2 + X)$; where L = length of the foundation

Step 4: Once the length L is determined, the value of L_1 can be obtained as

$$L_1 = L - L_2 - L_3$$

Note that the magnitude of L_2 will be known and depends on the location of the property line.

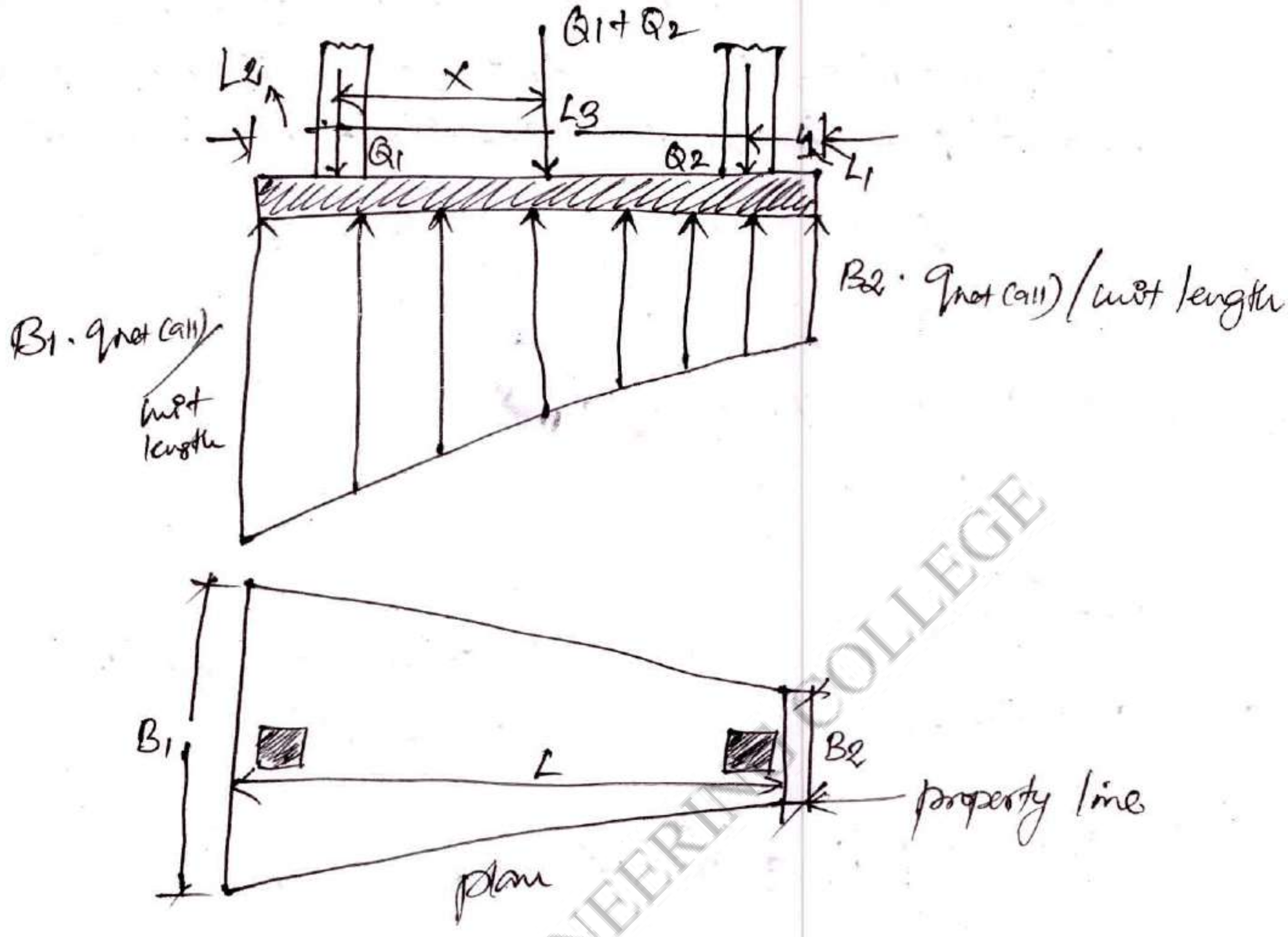
Step 5: The width of the foundation is then

$$B = \frac{A}{L}$$

Trapezoidal Combined footing:

- Trapezoidal Combined footing is sometimes used as an isolated spread foundation of Column carrying large loads where space is tight.
- The size of the foundation that will uniformly distribute pressure on the soil can be obtained in the following manner:

Step 1: If the net allowable soil pressure is known, determine the area of the foundation



Trapezoidal Combined footing

$$A = \frac{Q_1 + Q_2}{q_{net(all)}}, \quad A = \frac{B_1 + B_2}{2} L$$

Step 2: Determine the location of the Resultant for the Column loads

$$X = \frac{Q_2 L_3}{Q_1 + Q_2}$$

Step 3: From the property of a trapezoid.

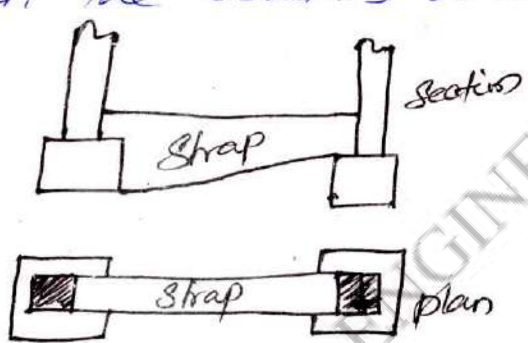
$$X + L_2 = \left(\frac{B_1 + 2B_2}{B_1 + B_2}\right)\frac{L}{3}$$

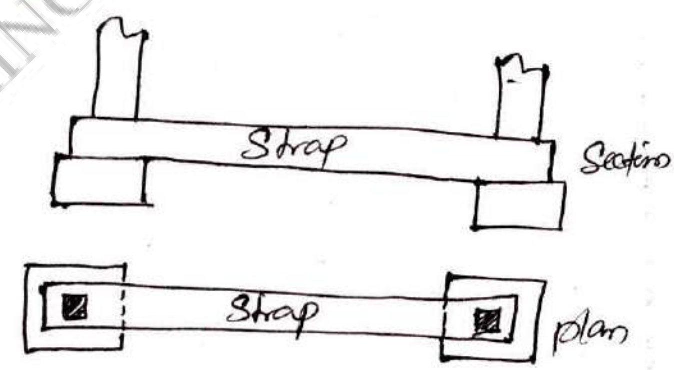
With known values of A, L, X and L_2, (step 2, step 3) to obtain B_1 and B_2. Note that, for a trapezoid

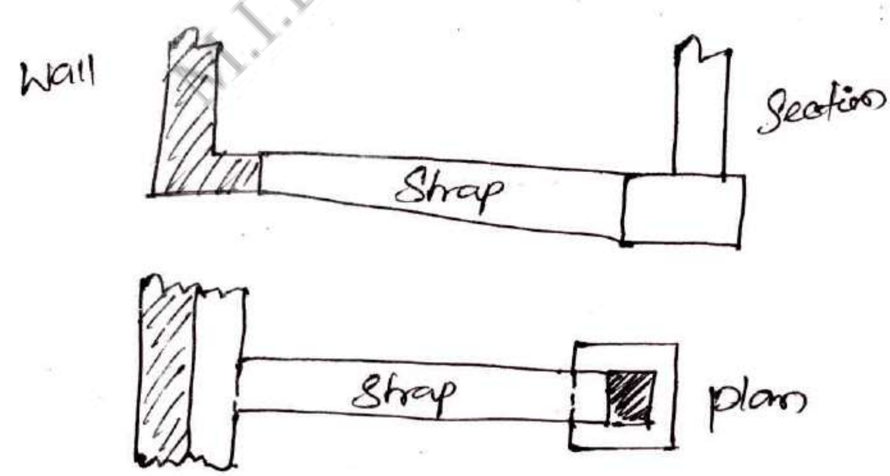
$$\frac{L}{3} < x + L_2 < \frac{L}{2}$$

Cantilever footing:

- Cantilever footing construction uses a strap beam to connect an eccentrically loaded column foundation to the foundation of an interior column.
- Cantilever footing may be used in place of trapezoidal or rectangular combined footings when the allowable soil bearing capacity is high and the distances between the columns are large.







Suggested Questions / Assignments / Home works / any other
1. Define Combine footing? 2. Describe types of footings)

	**Text Books / Reference Books**		
S.No	**Title**	**Author**	**Publisher**
1.	Text book of soil mechanics and foundation engineering	Murthy. V.N.S	CBS publishers Distributors Ltd New delhi

Any other suggested Materials

Lecture No. 21

Topic(s) to be covered	Mat Foundation

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
Lo1 Lo2	Mat fondation, Common types of mat fondation, Bearing capacity of mat foundations	Understand and Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen

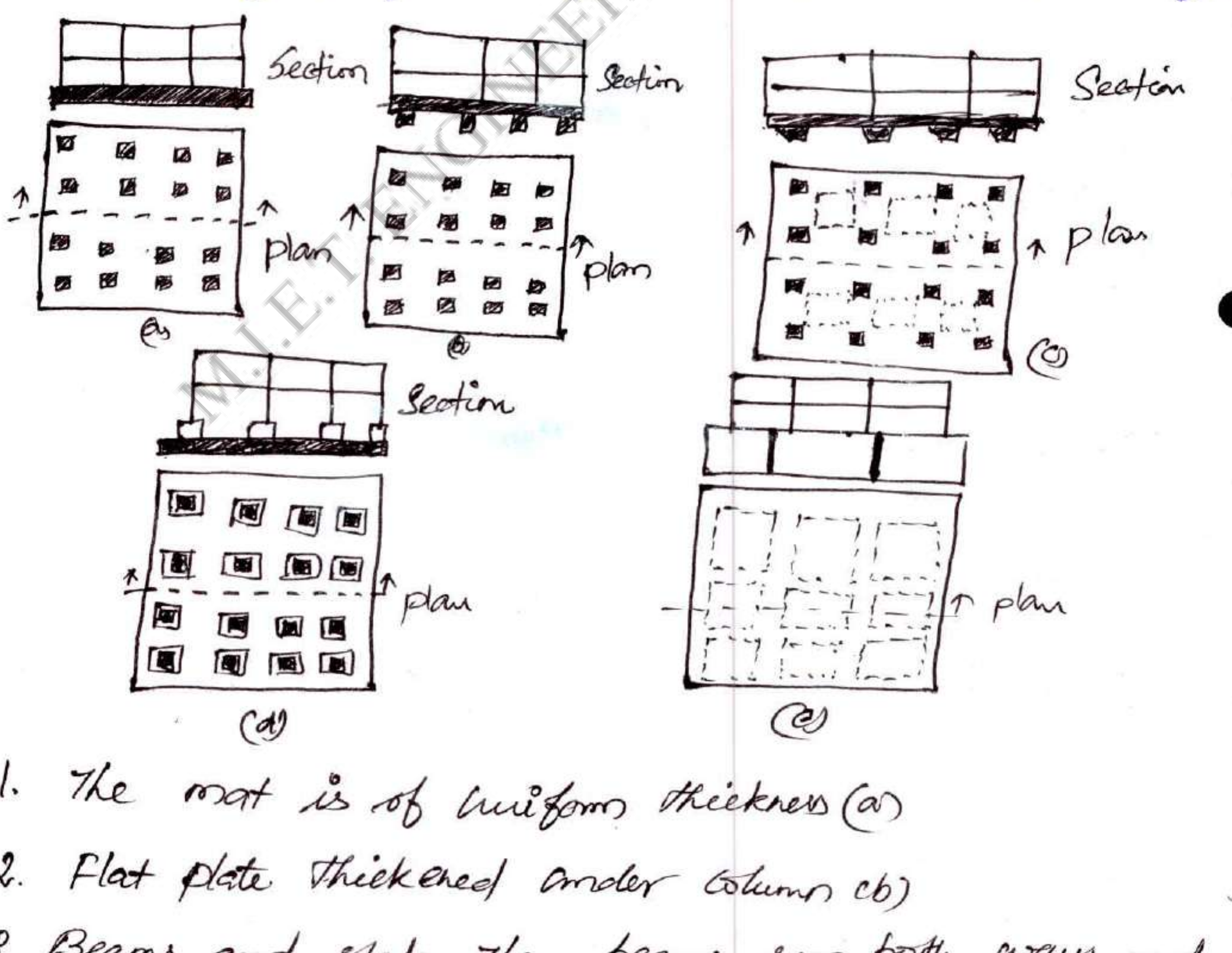
Lecture Notes

Mat Foundations:

- When more than one line of Column is supported by a Concrete slab, it is called a mat foundation.
- Mat foundation are generally used with soil that has a low bearing capacity.

Common types of mat foundation: The mat foundation, which is referred to as a raft foundation, is a combined footing that may cover the entire area under a structure supporting several columns and walls.

- Mat foundation are sometimes preferred for soils that have low load-bearing capacities, but that will have to support high column or wall loads.
- Under some conditions, spread footings would have to cover more than half the building area, and mat foundation might be more economical.
- Several types of mat foundations are used currently.



1. The mat is of uniform thickness (a)
2. Flat plate thickened under column (b)
3. Beams and slab, The beams run both ways, and the columns are located at the intersection of the beams

4. Flat plates with pedestals (d).

5. Slab with basement walls as a part of the mat. The walls act as stiffeners for the mat. (e)

Problem:

- Determine the net ultimate bearing capacity of a mat foundation measuring 15m × 10m on a saturated clay with $c_u = 95\ kN/m^2$, $\phi = 0$, and $D_f = 2m$.

Sol:

$$q_{net(u)} = 5.14\, c_u \left[1 + \left(\frac{0.195 B}{L}\right)\right]\left[1 + 0.4\frac{D_f}{B}\right]$$

$$= (5.14)(95)\left[1 + \left(\frac{0.195 \times 10}{15}\right)\right]\left[1 + 0.4 \times \frac{2}{10}\right]$$

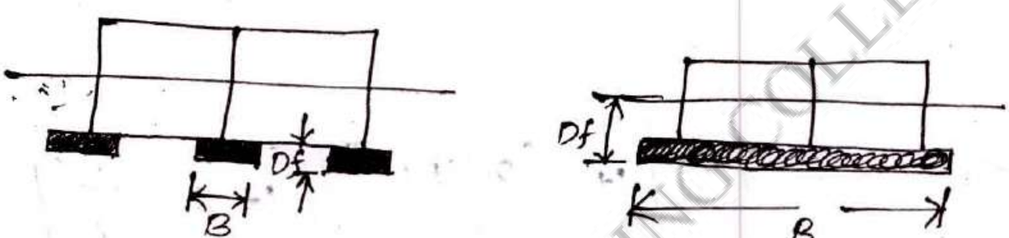
$$q_{net(u)} = 595.9\ kN/m^2$$

2. What will be the net allowable bearing capacity of a mat foundation with dimensions of 15m × 10m constructed over a sand deposit? Here $D_f = 2m$, the allowable settlement is 25mm, and the corrected average penetration number $N_{60} = 10$.

$$q_{net(all)} = 11.98\, N_{60}\left[1 + 0.33\left(\frac{D_f}{B}\right)\right]\left(\frac{S_e}{25}\right) \le 15.93\, N_{60}\left(\frac{S_e}{25}\right)$$

$$= 11.98 \times (10)\left[1 + \frac{0.33 \times 2}{10}\right]\left(\frac{25}{25}\right) = 127.7\ kN/m^2$$

- Mats may be supported by piles, which help reduce the settlement of a structure built over highly compressible soil.
- Where the water table is high, mat are often placed over piles to control buoyancy.
- The difference between the depth D_f and the width B of isolated foundations and mat foundations.



Bearing Capacity of Mat foundation:

- The gross ultimate bearing capacity of a mat foundation can be determined by the same equation used for shallow foundations.

$$q_u = c' N_c F_{cs} F_{cd} F_{ci} + q N_q F_{qs} F_{qd} F_{qi} + \frac{1}{2} \gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

B - is the smallest dimension of the mat.

The net ultimate capacity of a mat foundation is

$$q_{net(u)} = q_u - q$$

- The suitable factor of safety should be used to calculate the net allowable bearing capacity.
- For mats on clay, the factor of safety should not be less than 3 under dead loads or maximum live load.

- However, under the most extreme conditions, the factor of safety should be at least 1.75 to 2.
- For mats constructed over sand, a factor of safety of 3 should normally be used. Under most working conditions, the factor of safety against bearing capacity failure of mats on sand is very large.

$$q_u = C_u N_c F_{cs} F_{cd} + q$$

C_u = undrained cohesion (Note $N_c = 5.14$; $N_q = 1$, $N_\gamma = 0$)

$$F_{cs} = 1 + \frac{B}{L}\left(\frac{N_q}{N_c}\right) = 1 + \left(\frac{B}{L}\right)\left(\frac{1}{5.14}\right) = 1 + \frac{0.195B}{L}$$

$$F_{cd} = 1 + 0.4\left(\frac{D_f}{B}\right)$$

Substitution of the preceding shape and depth factors

$$q_u = 5.14c_u\left(1 + \frac{0.195B}{L}\right)\left(1 + 0.4\frac{D_f}{B}\right) + q$$

Hence, the net ultimate bearing capacity is

$$q_{net(u)} = q_u - q = 5.14c_u\left(1 + \frac{0.195B}{L}\right)\left(1 + 0.4\frac{D_f}{B}\right)$$

FS = 3, then net allowable soil bearing capacity

$$q_{net(all)} = \frac{q_{u(net)}}{FS} = 1.713c_u\left(1 + \frac{0.195B}{L}\right)\left(1 + 0.4\frac{D_f}{B}\right)$$

- The net allowable bearing capacity for rafts constructed over granular soil deposits can be adequately determined from the standard penetration resistance numbers.

$$q_{net(all)}\,(kN/m^2) = 11.98 N_{60}\left(\frac{3.28B + 1}{3.28B}\right)^2 F_d\left(\frac{S_e}{25}\right)$$

N_{60} = SP resistance, B = width (m), $F_d = 1 + 0.33(D_f/B) \le 1.33$,
S_e = Settlement, in mm

$$q_{net(all)}\,kN/m^2 = 11.98 N_{60} F_d\left(\frac{S_e}{25}\right)$$
$$= 11.98 N_{60}\left(1 + 0.33\left(\frac{D_f}{B}\right)\right)\left(\frac{S_e}{25}\right)$$
$$\le 15.93 N_{60}\left(\frac{S_e}{25}\right)$$

$q_{net(all)}\,(kN/m^2) = 23.96 N_{60}$

The net pressure applied on a foundation Q = dead wt of st. LL

$q = \frac{Q}{A} - \gamma D_f$ A = area of raft

q is less than or equal to $q_{net(all)}$

Suggested Questions / Assignments / Home works / any other
1. Explain about the features of bearing capacity of ~~soil~~ Mat foundation?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil mechanics and Foundation Engineering	K.R. Arora	Standard publishers and distributors new delhi

Any other suggested Materials

Lecture No. 22.

Topic(s) to be covered	Contact pressure and settlement distribution

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	~~What~~ is foundation Contact pressure, Contact pressure distribution under footings, factors affecting Contact pressure distribution. General assumptions of contact pressure distribution.	Understand & Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen

Lecture Notes

What is foundation Contact pressure:

- Generally loads from the structure are transferred to the soil through footings.
- A reaction to this load, soil exerts an upward pressure on the bottom surface of the footing which is termed as contact pressure.

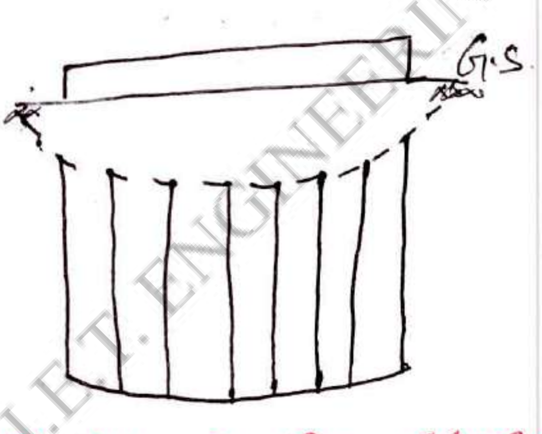
Contact pressure distribution under footings:

- The distribution of contact pressure under different types of footings on different types of soils are explained below.

1. Under Flexible Footing
2. Under Rigid Footing.

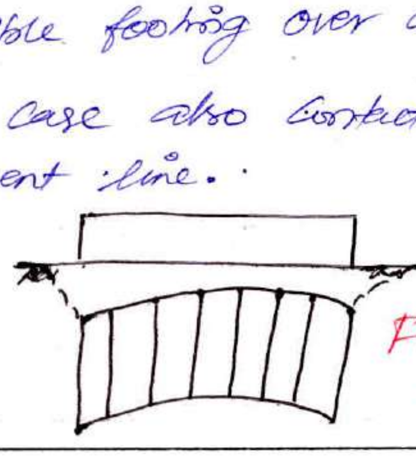
Contact pressure distribution under flexible footing:

- For flexible footing on cohesive soil, settlement is maximum at center of footing and minimum at the edges which bowl like shape..
- But the contact pressure is distributed uniformly along the settlement line or deflected line.



Flexible Footing- Cohesive Soil.

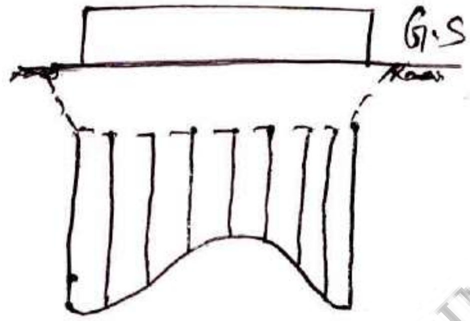
- When a flexible footing is laid on the cohesionless soil, settlement at center becomes minimum while at edges it is maximum which exact opposite case of the settlement of flexible footing over cohesive soil.
- But in this case also contact pressure is uniform along the settlement line..



Flexible footing - Cohesionless soil.

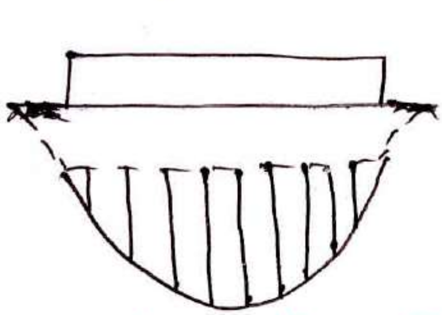
Contact pressure distribution under Rigid footing:

- For rigid footings resting on cohesive soils, settlement is uniform but contact pressure varies.
- At edges contact pressure is maximum and at center it is minimum which forms inverted bowl shape.
- The values of stresses at edges becomes finite when plastic flow occurs in real soils.



Rigid footing - Cohesive soil.

- If the footing is resting on cohesionless soils, contact pressure is maximum at center and gradually reduces to zero towards edges. settlement is uniform in this case also.
- If the footing is embedded, then there may be some amount of contact pressure at the edges of rigid footing.



Rigid footing - Cohesionless soil

Factors effecting contact pressure distribution:

1. Stiffness of footing, 2. Compressibility of soil.
3. Type of loading.

Stiffness of footing:

- Contact pressure is uniform in case of flexible footings such as earth embankments.
- Contact pressure varies in case of rigid foundations such as R.C.C. pad foundations etc.
- If the footing is partly flexible and partly rigid like raft foundation, contact pressure slightly varies.

Compressibility of soil:

- Compressibility or stiffness of soil also plays a role in contact pressure distribution.
- If the soil is coarse grained, contact pressure is more at the center of foundation than edges where as in case of clayey soils contact pressure is uniform.

Types of loading:

Concentrated Loading:

- If concentrated loading is applied at the center of foundation resting on cohesive soil, contact pressure is not uniform irrespective a stiffness of foundation.
- For flexible foundations, contact pressure is maximum exactly under the load application.
- For rigid foundations, contact pressure is maximum at edges. So, application of point load on rigid foundations can be comparable to the application of uniform loading on rigid foundations resting on cohesive soil.

Uniform loading

Already explained in contact distribution under uniform loading and deformed patterns of flexible and rigid foundations.

• Determine the net ultimate bearing capacity of a mat foundation measuring 15m x 10m on a saturated clay with $c_u = 95\ kN/m^2$, $\phi = 0$, and $D_f = 2m$.

Sol:

$$q_u - q = $$

$$q_{net(u)} = 5.14\, c_u \left(1 + \frac{0.195B}{L}\right)\left(1 + 0.4\frac{D_f}{B}\right)$$

$$= (5.14)(95)\left(1 + \frac{0.195 \times 10}{15}\right)\left(1 + \left(\frac{0.4 \times 2}{10}\right)\right)$$

$$= 595.9\ kN/m^2$$

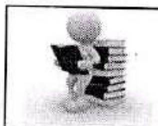
• What will be the net allowable bearing capacity of a mat foundation with dimensions of 15m x 10m constructed over a sand deposit? Here, $D_f = 2m$, the allowable settlement is 25mm, and the corrected average penetration number $N_{60} = 10$

$$q_{net(all)} = 11.98 N_{60}\left[1 + 0.33\left(\frac{D_f}{B}\right)\right]\left(\frac{S_e}{25}\right) \le 15.93 N_{60}\left(\frac{S_e}{25}\right)$$

$$= (11.98)(10)\left[1 + \frac{0.33 \times 2}{10}\right]\left(\frac{25}{25}\right)$$

$$= 127.7\ kN/m^2$$

Suggested Questions / Assignments / Home works / any other
1. What are all the factors to affecting the Contact pressure distribution?

	Text Books / Reference Books		
S.No	Title	Author	Publisher
1.	Text book of Soil Mechanics and Foundation Engineering	V.N.S. Murthy	CBS publishers Distribution Ltd, New delhi

Any other suggested Materials

Lecture No. 23.

Topic(s) to be covered	proportion of foundations for Conventional Rigid Behaviour.

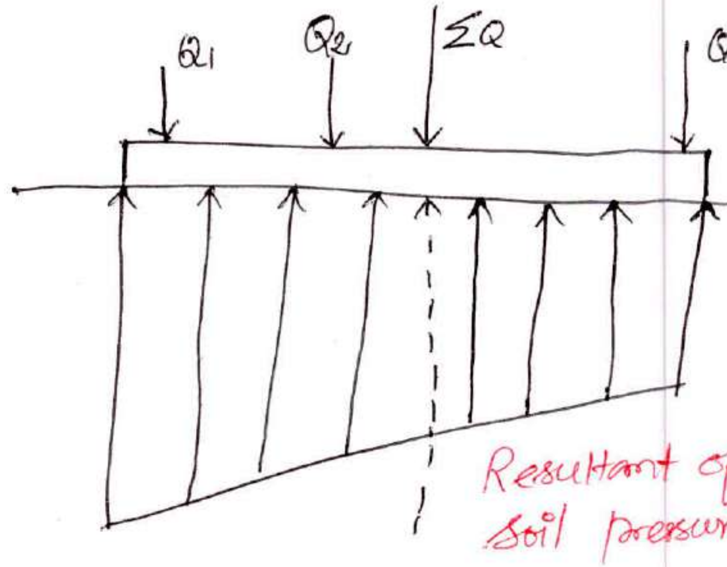
	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
Lo2	proportion of foundation for Conventional Rigid Behaviour, Approximate flexible method	Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen / Apply

Lecture Notes

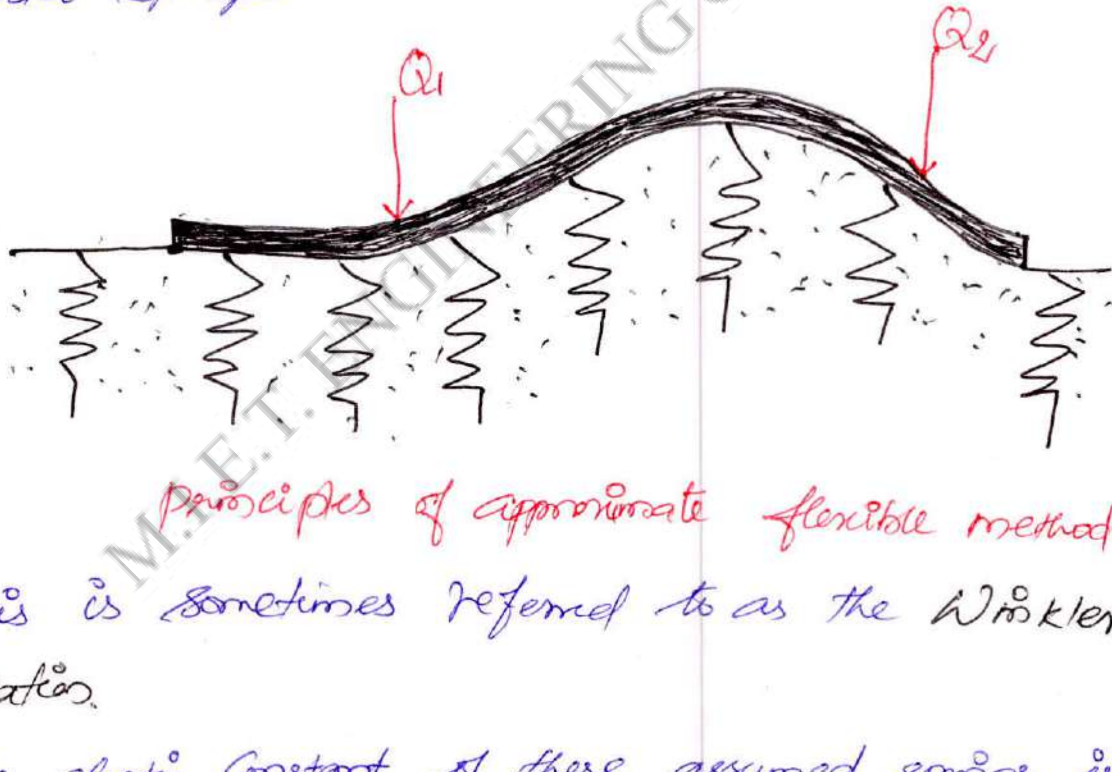
Approximate Flexible Method:

- In the Conventional Rigid method of design, the mat is assumed to be infinitely rigid.
- Also, the soil pressure is distributed in a straight line, and the centroid of the soil pressure is coincidental with the line of action of the resultant column loads.



Principle of design by Conventional Rigid method.

- In the approximate flexible method of design, the soil is assumed to be equivalent to an infinite number of elastic springs.



Principles of approximate flexible method

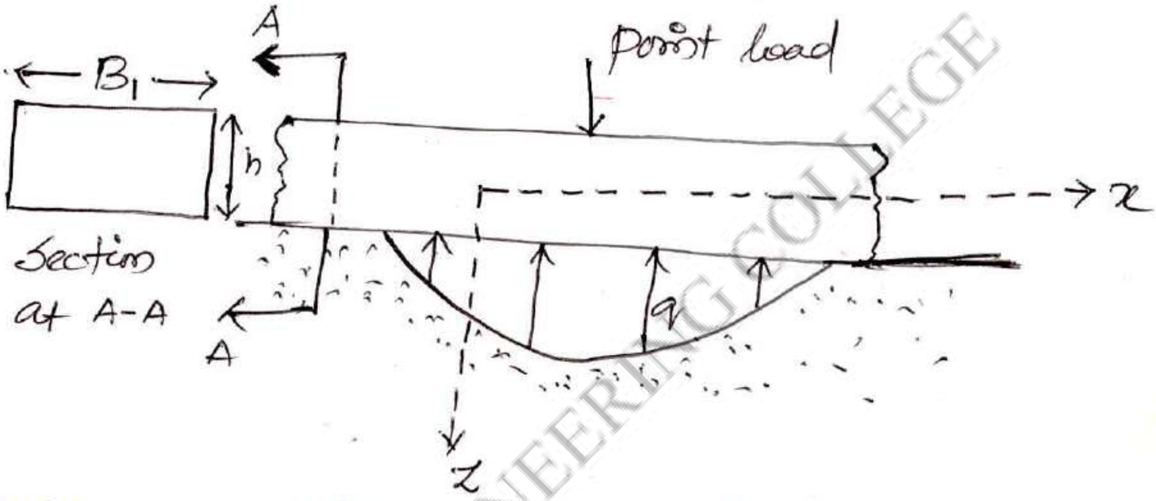
- This is sometimes referred to as the Winkler foundation.
- The elastic constant of these assumed springs is referred to as the Co-efficient of Subgrade reaction k.
- In order to understand the fundamental concept behind flexible foundation design, consider a beam of width B_1 having an infinite length.
- The beam is subjected to a single concentrated load Q. From the fundamentals of mechanics of materials.

$$M = E_F I_F \frac{d^2 z}{dx^2} \quad —①$$

M = moment at any section

E_F = Young's modulus of the material of the beam

I_F = moment of inertia of the cross section of the beam $= (1/12) B_1 h^3$



Beams on Elastic foundation

However,

$$\frac{dM}{dx} = \text{shear force} = V$$

$$\frac{dV}{dx} = \text{soil reaction} = q$$

$$\frac{d^2 M}{dx^2} = q \quad —②$$

① and ②

$$E_F I_F \frac{d^4 z}{dx^4} = q$$

the soil reaction:

$$q = -zk', \quad z = \text{deflection}, \quad k' = kB_1$$

k = Coefficient of subgrade reaction (unit - kN/m³)

$$E_F I_F \frac{d^4 z}{dx^2} - zkB_1$$

$$Z = e^{-\alpha x}(A' \cos \beta x + A'' \sin \beta x)$$

A' & A'' are Constants

$$\beta = \sqrt[4]{\frac{B_1 K}{4 E_F I_F}}$$

- The unit of the term β as defined by the preceding equation is (length)$^{-1}$.
- This is very important parameter in the determination of whether a mat foundation should be designed by conventional rigid method or approximate flexible method.
- The design of mats should be done by the conventional rigid method if the spacings of columns in a strip are less than 1.75/β.
- If the spacings of columns are longer than 1.75/β, the approximate flexible method may be adopted.

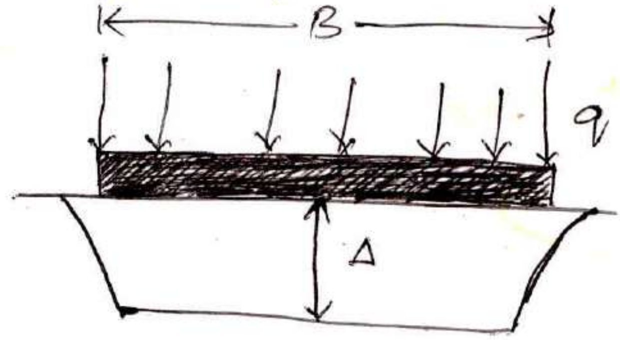
For this section, $I_F = (1/12) B_1 h^3$

$$= (1/12)(4.25)(0.8)^3 = 0.1813 \, m^4$$

Because the actual spacing of column is 7m, which is less than 1.75/β.

- To perform the analysis for the structural design of a flexible mat, one must know the principles of evaluating the co-efficient of subgrade reaction, k.
- Before proceeding with the discussion of the approximate flexible design method, let us discuss this coefficient.

- The unit of k is in kN/m³. The value of the coefficient of subgrade reaction is not a constant for a given soil.
- It depends on several factors such as the length (L) and width (B) of the foundation and also the depth of embedment of the foundation



Co-efficient of subgrade Reaction, k.

The mat has dimensions of 30m x 40m (B x L). The LL and DL on mat 200MN. Cu for the clay is 12.5 kN/m². Required factor of safety against bearing capacity 3, determine Df. unit wt 18.75 kN/m³

$$FS = \frac{5.14\,c_u\left(1+\frac{0.195B}{L}\right)\left(1+0.4\frac{D_f}{B}\right)}{\frac{Q}{A}-\gamma D_f}$$

$Q = 200$ MN $= 200\times10^3$ kN.

$$3 = \frac{(5.14)(12.5)\left[1+(0.195)(0.75)\right]\left[1+0.4\left(\frac{D_f}{30}\right)\right]}{\frac{(200\times10^3)}{(30\times40)}-(18.75)D_f}$$

$$500.01 - 56.25D_f = 73.65 + 0.982D_f$$

$$426.36 = 57.23D_f$$

$$D_f = \frac{426.36}{57.23} = 7.5\,m$$

Suggested Questions / Assignments / Home works / any other

1. Explain about the proportions of foundation for Conventional rigid behaviour?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Foundation Analysis and design	Joseph E bowles	McGraw Hill Education

Any other suggested Materials

Lecture No. 24.

Topic(s) to be covered	Compensated Foundations

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	definition of compensated foundation, what is fully compensated foundation	understand & apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & apply.

Lecture Notes

Compensated Foundations:

- The settlement of a mat foundation can be reduced by decreasing the net pressure increase on soil, which can be done by increasing the depth of embedment, Df.
- This increase is particularly important for mats on soft clays where large consolidation settlements are expected.

$$q = \frac{Q}{A} - \gamma D_f$$

For no increase of the net soil pressure on soil below a raft foundation, q should be equal to zero.

$$D_f = \frac{Q}{A\gamma}$$

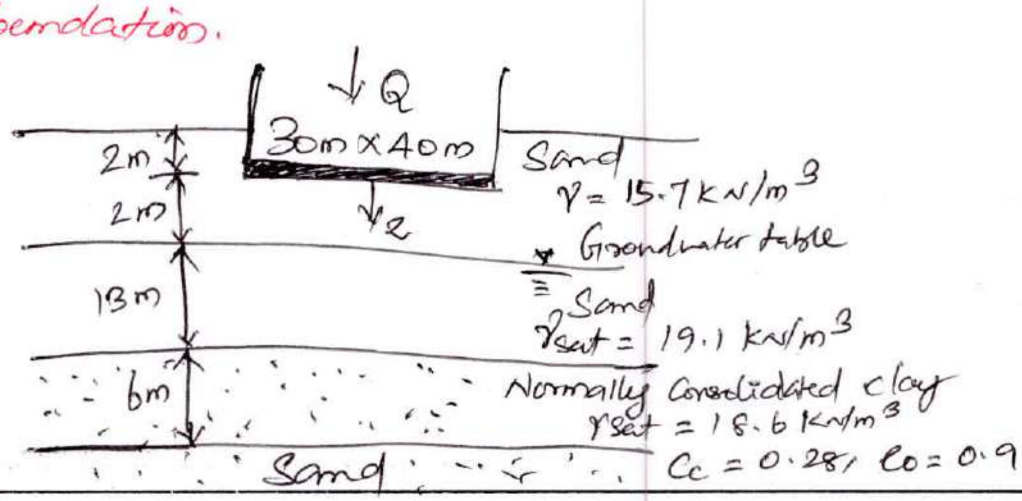
- The relation for D_f, preceding equation is usually referred to as the depth of a fully compensated foundation.
- The factor of safety against bearing capacity failure for partially compensated foundation (that is $D_f < Q/A\gamma$)

$$F_S = \frac{q_{net(u)}}{q} = \frac{q_{net(u)}}{\frac{Q}{A} - \gamma D_f}$$

For saturated clays, the factor of safety against bearing capacity failure can thus be obtained by

$$F_S = \frac{5.14\, c_u \left(1 + \frac{0.195B}{L}\right)\left(1 + 0.4\frac{D_f}{B}\right)}{\frac{Q}{A} - \gamma D_f}$$

Consider a mat foundation 30m x 40m in plan. The total dead load plus the live load on the raft is 200 MN. Estimate the consolidation settlement at the center of the foundation.



Given: $Q = 200 \times 10^3$ kN. the net load per unit area is

$$q = \frac{Q}{A} - \gamma D_f = \frac{200 \times 10^3}{30 \times 40} - (15.7)(2)$$

$$= 166.67 - 31.4$$

$$= 135.27 \text{ kN/m}^2$$

the average pressure increase on the clay layer below the center of the foundation.

$$\Delta\sigma'_{av} = \frac{1}{6}(\Delta\sigma'_t + 4\Delta\sigma'_m + \Delta\sigma'_b)$$

The values of $\Delta\sigma'_t$, $\Delta\sigma'_m$ and $\Delta\sigma'_b$ can be determined by ~~referring~~ to , At the top of the clay layer,

$$\frac{Z}{B} = \frac{15}{30} = 0.5$$

$$\frac{L}{B} = \frac{40}{30} = 1.33$$

So, for $Z/B = 0.5$ and $L/B = 1.33$

$$\frac{\Delta\sigma'_t}{q} = 0.75, \quad \Delta\sigma'_t = (0.75)(135.27)$$

$$= 101.45 \text{ kN/m}^2$$

Similarly, for the middle of the clay layer,

$$\frac{Z}{B} = \frac{18}{30} = 0.6$$

$$\frac{L}{B} = 1.33$$

So, $\Delta\sigma'_m/q = 0.66$ and $\Delta\sigma'_m = 89.3$ kN/m²

At the bottom of the clay layer

$$\frac{Z}{B} = \frac{21}{30} = 0.7$$

$$\frac{L}{B} = 1.33$$

So, $\Delta\sigma'_b/q = 0.58$ and $\Delta\sigma'_b = 75.46\ kN/m^2$

Hence,

$$\Delta\sigma'_{av} = \frac{1}{6}\left[101.45 + 4(89.3) + 75.46\right] = 89\ kN/m^2$$

the consolidation settlement

$$S_c = \frac{C_c H_c}{1+e_o} \log \frac{\sigma'_o + \Delta\sigma'_{av}}{\sigma'_o}$$

$$\sigma'_o = 4(15.7) + 13(19.1 - 9.81) + \frac{6}{2}(18.6 - 9.81)$$

$$= 209.94\ kN/m^2$$

So, $$S_c = \frac{(0.28)(6 \times 1000)}{1+0.9} \log\left(\frac{209.94 + 89}{209.94}\right)$$

$$= 135.7\ mm.$$

Suggested Questions / Assignments / Home works / any other

1. Define Compensated Foundation?
2. Explain about fully Compensated foundation?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Design aids in Soil mechanics and Foundation engineering	S.R. Kaniraj	Tata McGraw Hill publishing Company Ltd.
2.	principles of foundation Engineering	Braja M Das	Cengage learning

Any other suggested Materials

Lecture No. 25.

Topic(s) to be covered	Minimum thickness for rigid behaviour

	Lecture Outcome (LO)	
	At the end of this lecture, students will be able to	Bloom's Level
Lo1	Structural design of mat foundation, conventional rigid method and approximate flexible method.	Understand

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & apply.

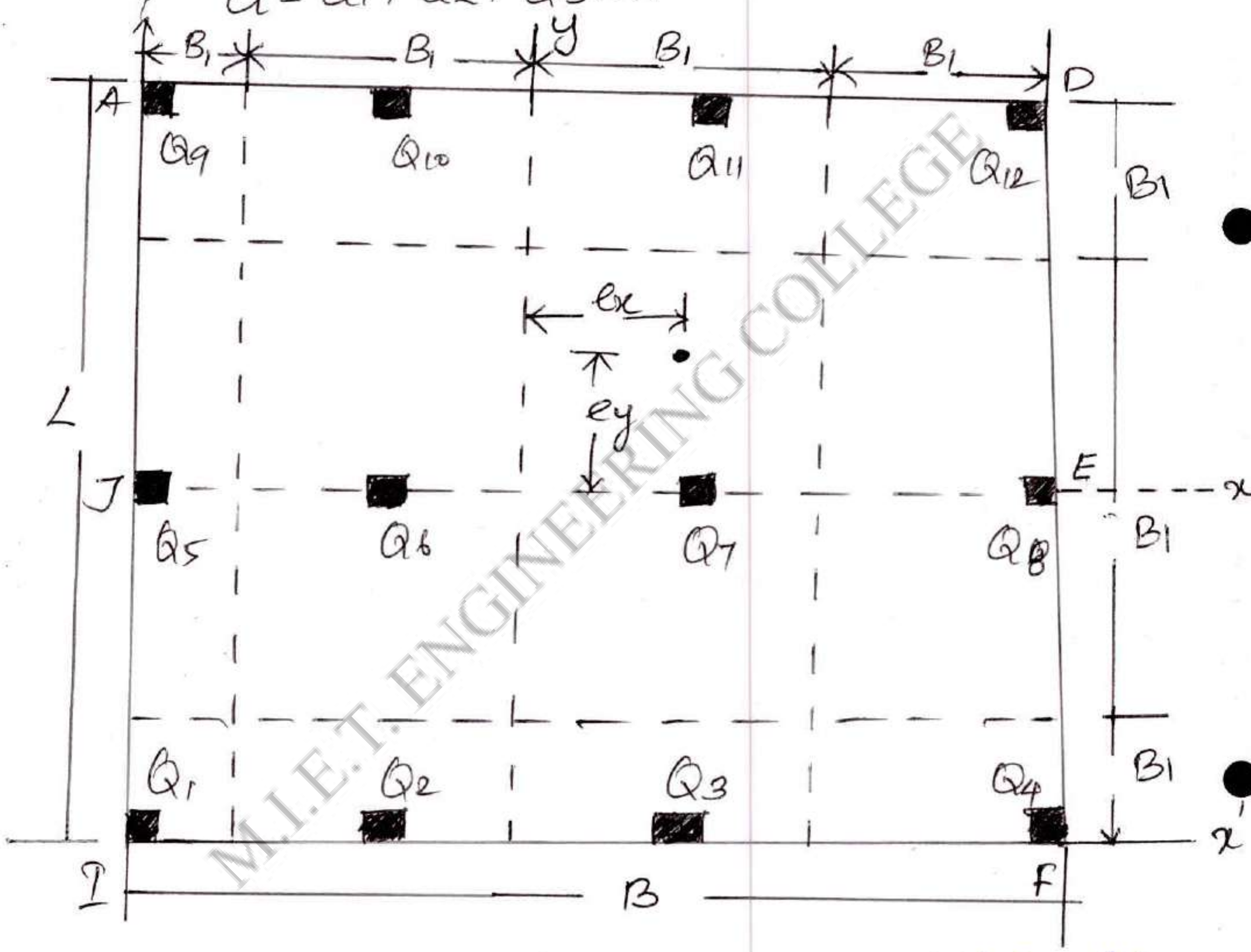
Lecture Notes

- The structural design of mat foundation can be carried out by two conventional methods:
- The conventional rigid method and the approximate flexible method.
- Finite difference and finite element methods can also be used, however this section will cover the basic concepts of the first two design methods.

The Conventional rigid method of mat foundation design can be explained in a step by step manner.

Step 1: The mat has a dimensions of $L \times B$. $Q_1, Q_2, Q_3 \ldots$ are the column loads. calculate the total column load

$$Q = Q_1 + Q_2 + Q_3 \ldots$$



Step 2: Determine the pressure on the soil (q) below the mat at points A, B, C, D by using the equation

$$q = \frac{Q}{A} \pm \frac{M_y x}{I_y} \pm \frac{M_x y}{I_x}$$

$A = BL$

$I_x = (1/12) BL^3$ = moment of inertia about the x axis

$I_y = (1/12) LB^3$ = moment of inertia about the y axis

M_x = moment of column loads about the x axis = Qe_y

M_y = moment of the column loads about the y axis = Qe_x

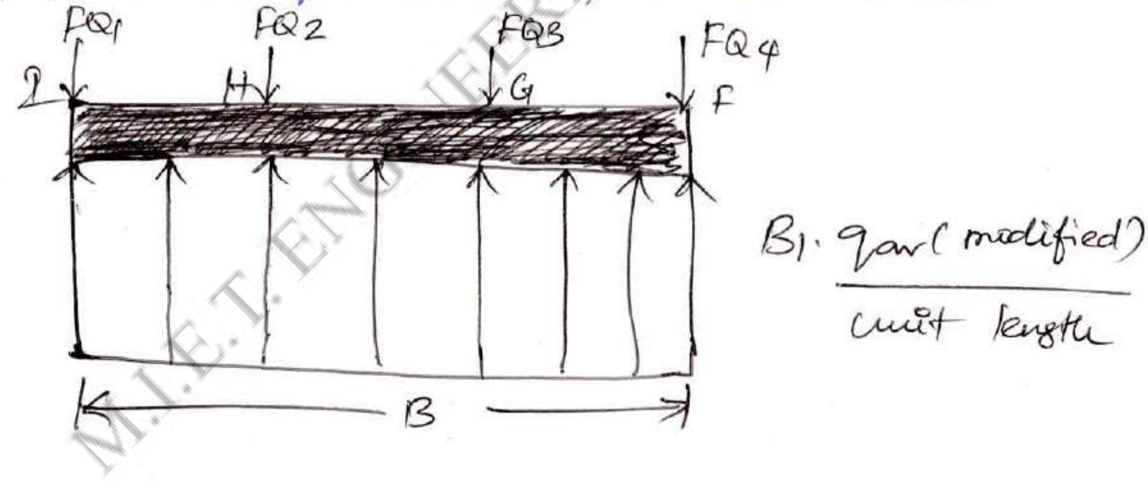
Step3: Compare the values of the soil pressures determined in step2 with the net allowable soil pressure to check if $q \le q_{net(all)}$

Step4: Divide the mat into several strips in x and y directions. Let the width of any strip be B_1.

Step5: Draw the shear (V) and the moment (M) diagrams for each individual strip (in x and y directions). For example take the bottom strip in x direction, its average soil pressure can be given as

$$q_{av} \approx \frac{q_1 + q_F}{2}$$

q_1 and q_2 = Soil pressure at points I and F.



- The total soil reaction is equal to $q_{av} B_1 B$. Now obtain the total column load on the strip as $Q_1 + Q_2 + Q_3 + Q_4$.
- The sum of the column loads on the strip will not been taken into account.
- For this reason the soil reaction and the column loads need to be adjusted

$$\text{Average load} = \frac{q_{av} B_1 B + (Q_1 + Q_2 + Q_3 + Q_4)}{2}$$

Now, the modified average soil reaction

$$q_{av}(\text{modified}) = q_{av}\left(\frac{\text{average load}}{q_{av} B_1 B}\right)$$

Also, the column load modification factor is

$$F = \frac{\text{average load}}{Q_1+Q_2+Q_3+Q_4}$$

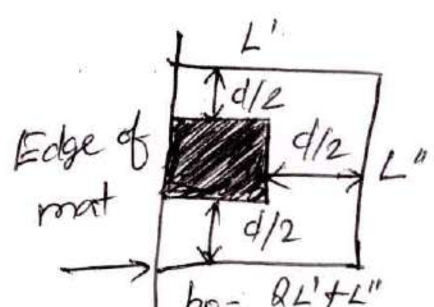
So, the modified column loads are FQ_1, FQ_2, FQ_3 and FQ_4. This modified loading on the strip under consideration

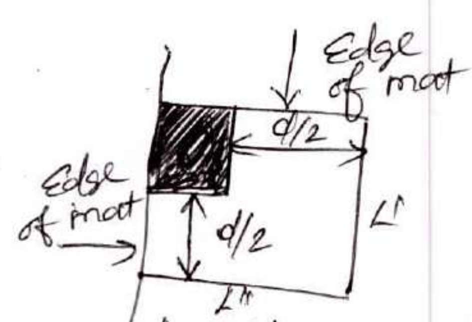
Step 6: Determine the depth of the mat d. This can be done by checking for diagonal tension shear near various columns.

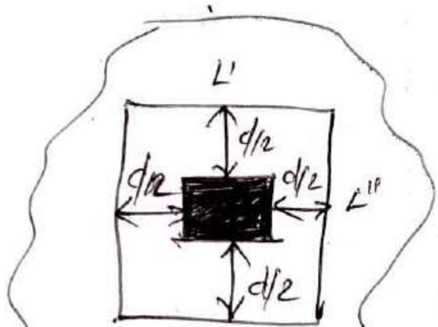
$$U = b_o d\left[\phi (0.34)\sqrt{f'_c}\right]$$

U = factored column load (MN) = Column load × (load factor)
ϕ = Reduction factor = 0.85
f'_c = Compressive strength of concrete at 28 days (MN/m²)

- The cuits of b_o and d in the preceding equation are in meters. The expression for b_o in terms of d, which depends on the location of the column with respect to the plan of the mat, can be obtained.







Step 7: From the moment diagrams of all strips in a given direction (that is, x or y), obtain the maximum positive and negative moments per unit width (that is, $M' = M/B_1$).

Step 8: Determine the areas of steel per unit width for positive and negative reinforcement in x and y directions from the following equations.

$$M_u = (M')(\text{load factor}) = \phi A_s f_y \left(d - \frac{a}{2}\right)$$

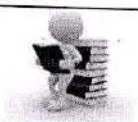
$$a = \frac{A_s f_y}{0.85 f_c' b}$$

A_s = Area of steel per unit width

f_y = yield stress of reinforcement in tension

M_u = factored moment

Suggested Questions / Assignments / Home works / any other
1. Differentiate conventional rigid behaviour and approximate flexible method?



Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundations	B.C. Punmia	Laxmi publication pvt ltd

Any other suggested Materials

Lecture No. 26.

Topic(s) to be covered	Applications of Mat foundations

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO2	Applications of mat foundation and rigid behaviour	Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Apply

Lecture Notes

The plan of a mat foundation with column loads using. calculate the soil pressure at points A, B, C, D, E and F. The size of the mat is 16.5m x 21.5m. All columns are 0.5m x 0.5m in section. Given: $q_{net(all)} = 60\ kN/m^2$. Determine that the soil pressures are less than the net allowable soil bearing capacity.

$$q = \frac{Q}{A} \pm \frac{M_y x}{I_y} \pm \frac{M_x y}{I_x}$$

A = Area of the mat = $(16.5)(21.5)$

$= 354.75 \text{ m}^2$

$I_x = \frac{1}{12} BL^3$

$= \frac{1}{12}(16.5)(21.5)^3$

$= 13,665 \text{ m}^4$

$I_y = \frac{1}{12} LB^3 = \frac{1}{12}(21.5)(16.5)^3$

$= 8050 \text{ m}^4$

Q = Sum of the Column loads

$= 350 + 2(400) + 450 + 2(500) + 2(1200) + 4(1500)$

$= 11,000 \text{ kN}$

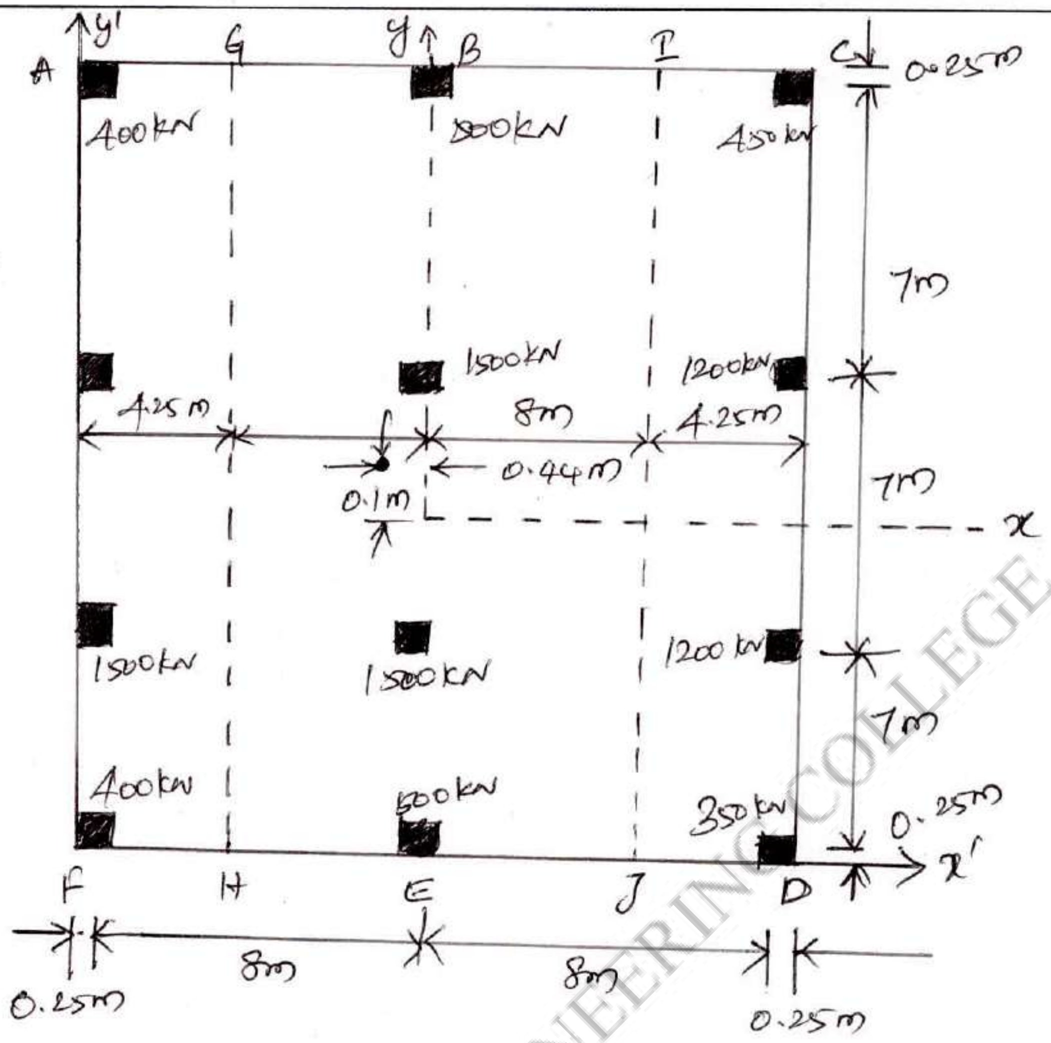
$M_y = Q e_x$

$e_x = X' - \frac{B}{2}$

$$X' = \frac{Q_1 x_1' + Q_2 x_2' + Q_3 x_3' \ldots}{Q}$$

$$= \frac{1}{11,000}\left[(8.25)(500+1500+1500+500) + (16.25)(350+1200+1200+450) + (0.25)(400+1500+1500+400)\right]$$

$= 7.814 \text{ m}$



So,

$$e_x = x' - \frac{B}{2} = 7.814 - 8.25$$

$$= -0.436 \simeq 0.44\text{m}$$

Hence, the resultant line of action is located to the left of the center of the mat. So

$$M_y = (11{,}000)(0.44) = 4840 \text{ kN-m}.$$

Similarly,

$$M_x = Q e_y$$

$$e_y = \left(Y' - \frac{L}{2}\right)$$

$$y' = \frac{Q_1 y_1' + Q_2 y_2' + Q_3 y_3' + \ldots}{Q}$$

$$= \frac{1}{11,000}\left[(0.25)(400+500+350)+(7.25)(1500+1500+1200)+ (14.25)(1500+1500+1200)+(21.25)(400+500+450)\right]$$

$$= 10.85\,m$$

So,

$$e_y = y' - \frac{L}{2} = 10.85 - \frac{21.5}{2} = 0.1\,m$$

The location of the line of action of the resultant column loads,

$$M_x = (11,000)(0.1) = 1100\,kN\text{-}m.$$

So,

$$q = \frac{11,000}{354.75} \pm \frac{(4840)x}{8050} \pm \frac{(1100)y}{13,605} =$$

$$= 31.0 \pm 0.6x \pm 0.08y\ (kN/m^2)$$

Calculations of soil pressure:

At A: $q = 31.0 + (0.6)(8.25) + (0.08)(10.75)$

$= 36.81\ kN/m^2$

At B: $q = 31.0 + (0.6)(0) + (0.08)(10.75)$

$= 31.86\ kN/m^2$

At C: $q = 31.0 - (0.6)(8.25) + (0.08)(10.75)$

$= 26.91\ kN/m^2$

At D: $q = 31.0 - (0.6)(8.25) - (0.08)(10.75)$

$= 25.19\ kN/m^2$

At E: $q = 31.0 + (0.6)(0) - (0.08)(10.75)$

$= 30.14\ kN/m^2$

At F: $q = 31.0 + (0.6)(8.25) - (0.08)(10.75)$

$= 35.09\ kN/m^2$

The soil pressures at all points are less than the given value of

$q_{net(all)} = 60\ kN/m^2.$

Suggested Questions / Assignments / Home works / any other

1. Explain about the applications of mat foundation?
2. Define mat foundation?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundation Engineering	K.R. Arora	Standard, publishers and distributors new delhi

Any other suggested Materials

Lecture No. 27.

Topic(s) to be covered	Codal provisions

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
Lo2	Determination and thickness of walls, strips, reinforcement requirements	Understand & Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Apply

Lecture Notes

Divide the mat into three strips, such as AGHF ($B_1 = 4.25m$) GIJH ($B_1 = 8m$), and ICDJ ($B_1 = 4.25m$). Using the results of ~~Example~~ determine the reinforcement requirements in the y direction.
Given: $f'_c = 20.7\ MN/m^2$, and $f_y = 413.7\ MN/m^2$. Use a load factor of 1.7.

Sol:

Determination of shear and moment diagrams for strips

Strip AGHF

Average soil pressure = $q_{av} = q_{(at\ A)} + q_{(at\ F)}$
$= (36.81 + 35.09)/2 = 35.95\ kN/m^2$

Total Soil reaction = $q_{av} B_1 L$ =

= (35.95) (4.25) (21.50)

= 3285 kN

Total Column load on this Strip = 400 + 1500 + 1500 + 400 = 3800 kN

Average load = (total soil reaction + column loads)/2 = (3285 + 3800)/2

So,

= 3542.5 kN

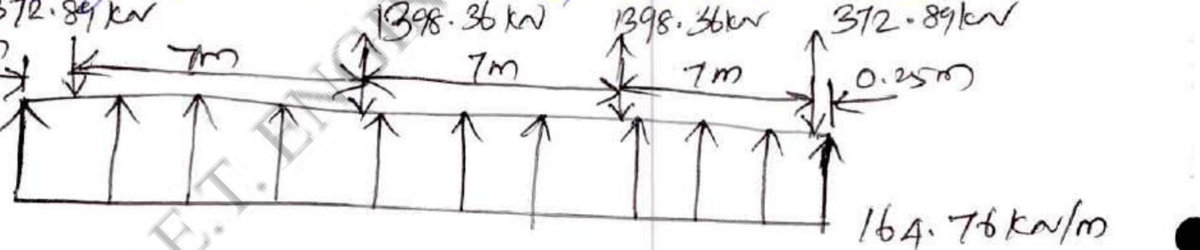
Modified average soil pressure = q_{av} (modified)

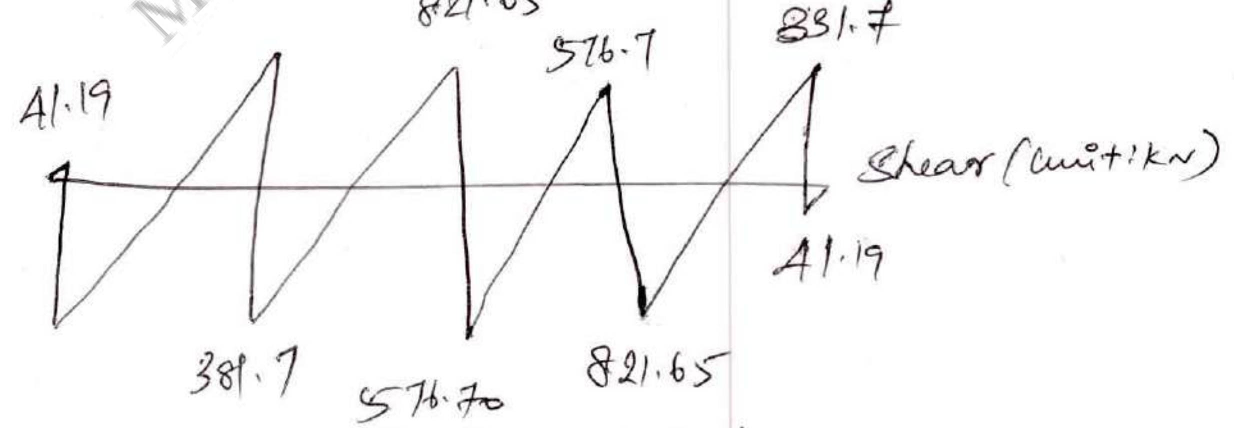
= q_{av} (3542.5/3285)

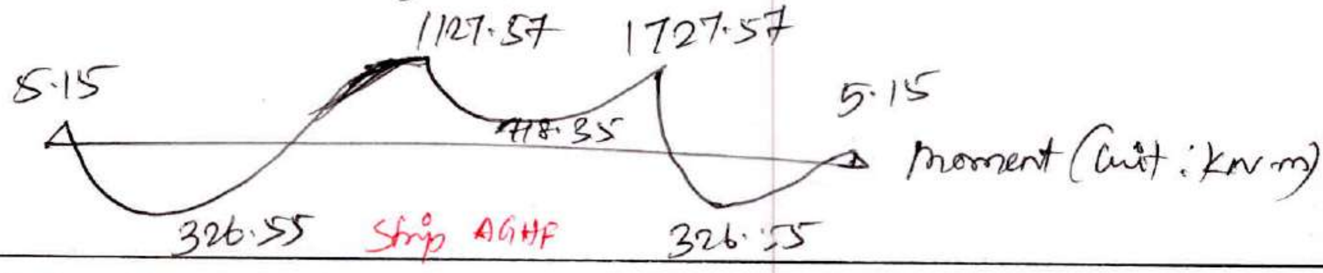
= 35.95

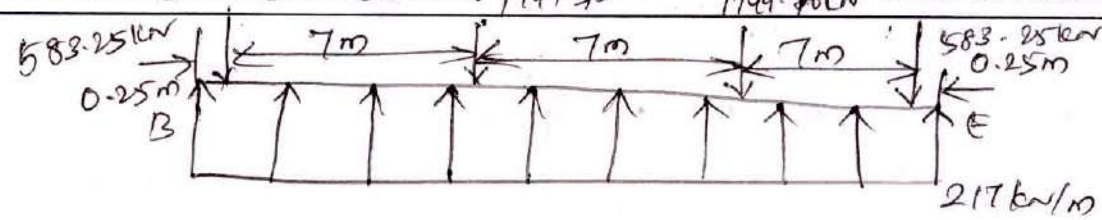
(3542.5/3285) = 38.768 kN/m²

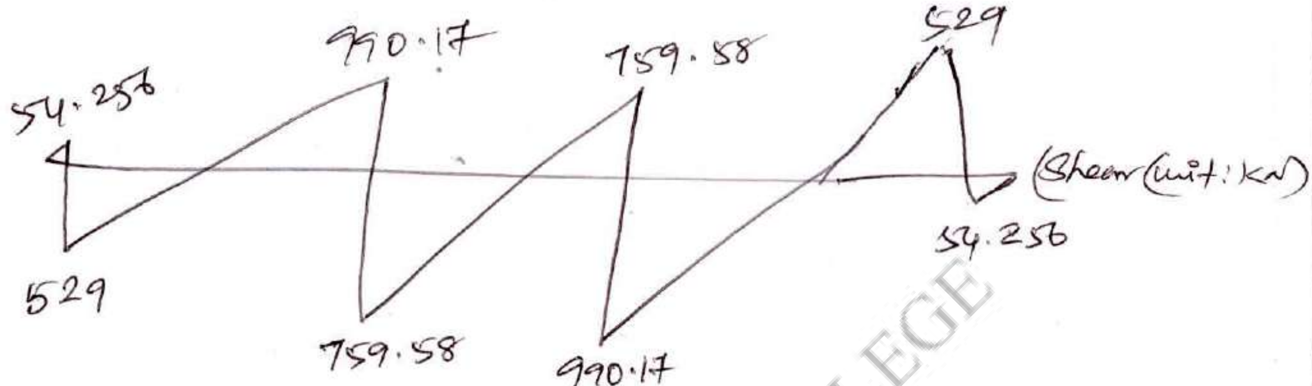
The column loads can be modified in a similar manner by multiplying factor F = 3542.5/3800 = 0.9322

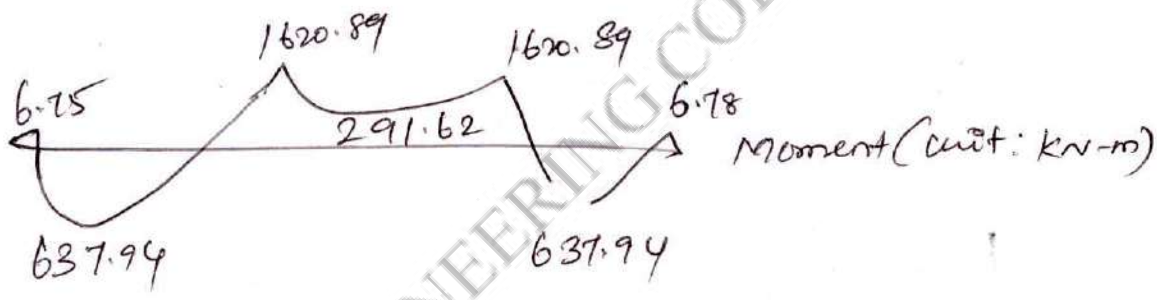












Strip GIJH

Beam multiplied by F = 0.9322. Also, the load per unit length of the beam is equal to

$$B_1 q_{av}(\text{modified}) = (4.25)(38.768) = 164.76\ kN/m$$

Strip GIJH In a similar manner

$$q_{av} = \frac{q(\text{at } B) + q(\text{at } E)}{2} = \frac{31.86 + 30.14}{2} = 31.0\ kN/m^2$$

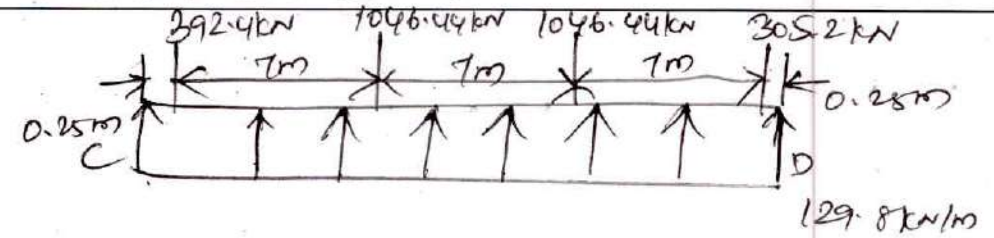
Total soil reaction = (31) (8) (21.5) = 5332 kN

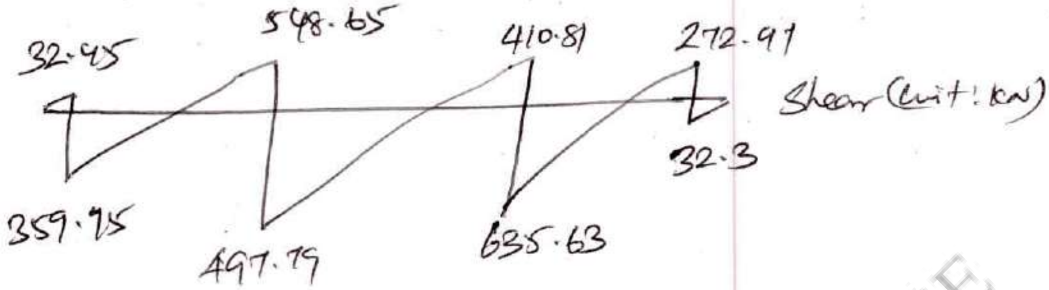
Total Column load = 4000 kN

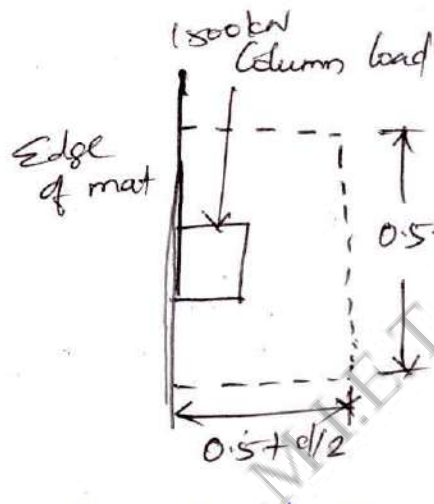
Average load = (5332 + 4000)/2 = 4666 kN

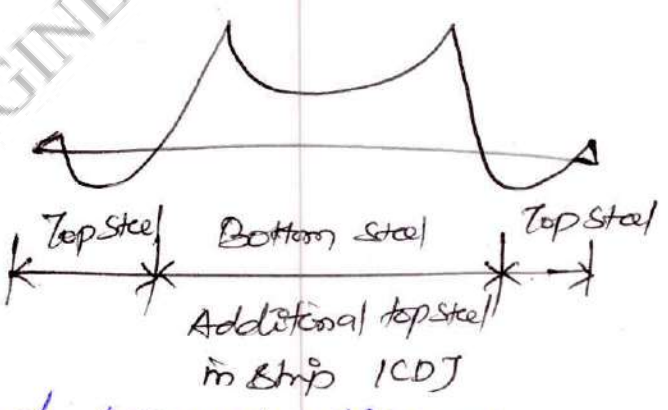
$$q_{av}(\text{modified}) = 31.0\,(4666/5332) = 27.12\ kN/m^2$$

$$F = 4666/4000 = 1.1665$$









The load shear and moment diagrams

Strip ICDJ - shows the load shear and moment diagrams for this strip

Determination of the thickness of the mat:

For this problem, the critical section for diagonal tension shear will be at the column carrying 1500kN load at the edge of the mat

$$b_0 = \left(0.5 + \frac{d}{2}\right) + \left(0.5 + \frac{d}{2}\right) + (0.5 + d) = 1.5 + 2d$$

$U = (b_o d)[(\phi)(0.34)\sqrt{f'c}]$

$U = (1.7)(1500) = 2550\ kN = 2.55\ MN$

$2.55 = (1.5 + 2d)(d)[(0.85)(0.34)\sqrt{20.7})$

(or)

$(1.5 + 2d)d = 1.94$

$d \approx 0.68 m$

Assuming a minimum cover of 76mm over the steel reinforcement and also assuming that the steel bars to be used are 25mm in diameter, the total thickness of the slab is

$h = 0.68 + 0.076 + 0.025$

$= 0.781\ m = 0.8m$

The thickness of this mat will satisfy the wide beam shear condition across the three strips under consideration.

Suggested Questions / Assignments / Home works / any other

1. Determine the thickness of wall?

	**Text Books / Reference Books**		
S.No	**Title**	**Author**	**Publisher**
1.	Text books of soil mechanics and foundation engineering	V.N.S. Murthy	CBS publishers distribution Ltd

Any other suggested Materials

Lecture No. 28. UNIT- IV PILE FOUNDATION

Topic(s) to be covered	Types of piles and their functions

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Definition of piles. types of piles, uses of piles and its functions	Understand apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & apply.

Lecture Notes

Introduction:

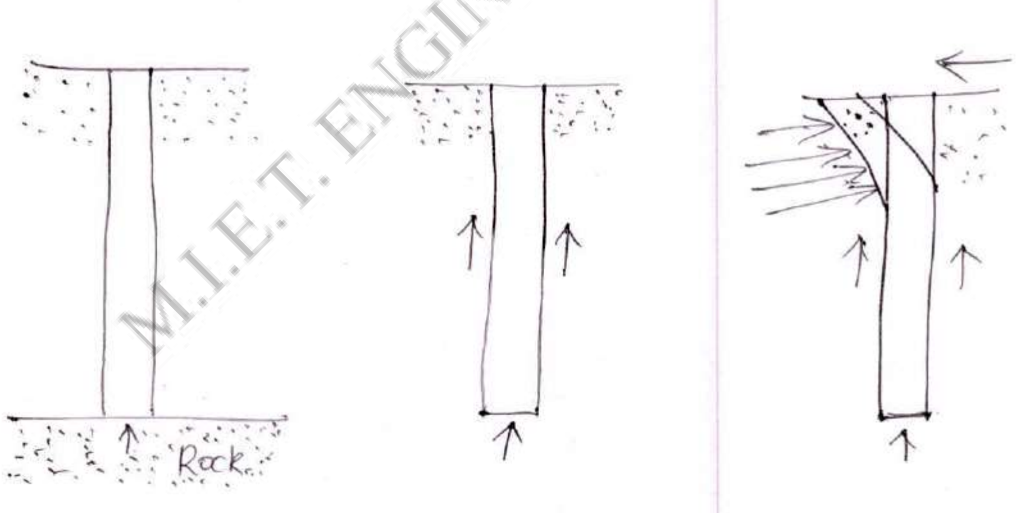
- Piles are structural members that are made of steel, concrete and timber. They are used to build pile foundations, which are deep and which cost more than shallow foundations.
- Despite the cost, the use of piles often becomes necessary to ensure that the structure under

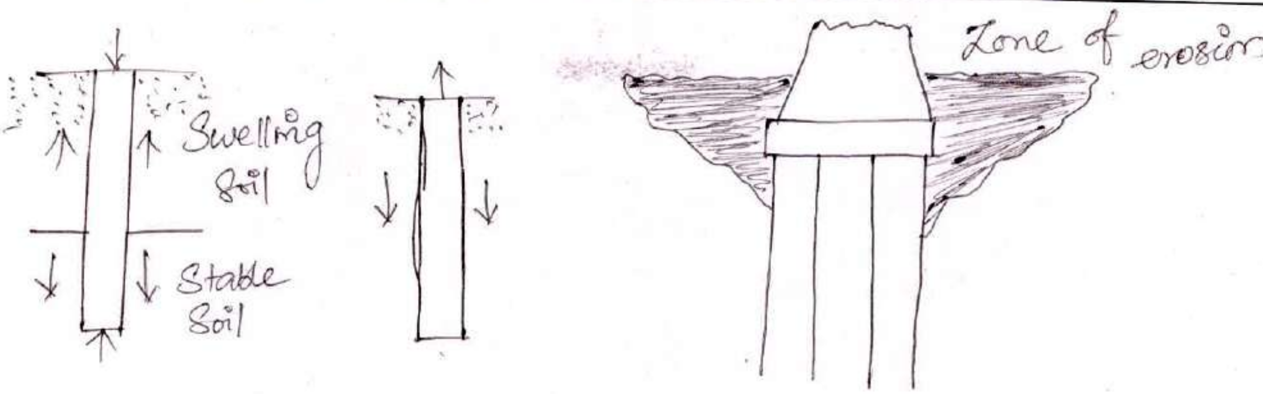
Consideration is safe.

1. When the upper soil layers is highly compressible and too weak to support the load transmitted by the superstructure, piles are used to transmit the load to underlying bedrock.

2. When subjected to horizontal forces, pile foundations can resist by bending, while still supporting the vertical load transmitted by the super structure.

- This type of situation is generally encountered in the design and construction of earth-retaining structures and foundations of tall structures that are subjected to high wind earthquake forces.





Conditions for use of pile foundations

3. Expansive and Collapsible soils may be encountered at the site of a proposed structure.

- Expansive soils swell and shrink depending on the increase or decrease of moisture content.
- The swelling pressure of such soils can be considerably high. If shallow foundations are used in such circumstances, the structure may encounter considerable damage.

Types of pile in use:

- Different types of pile are used in construction work depending on the type of load to be carried, the subsoil conditions, and the ground water table.
- Piles can be divided into the following categories (a) Steel piles, (b) Concrete piles, (c) Wooden (timber) piles, (d) Composite piles.

Steel piles:

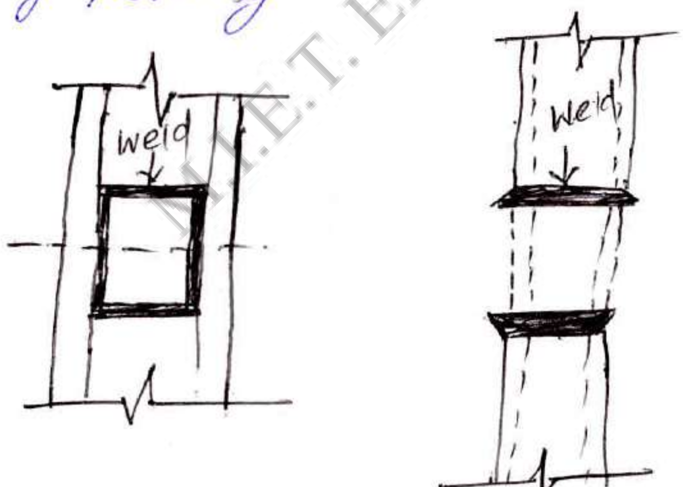
- The steel piles generally used are either pipe piles or rolled steel H-section piles.

- Pipe piles can be driven into the ground with their ends open or closed. Wide - flange and I- section steel beams can also be used as piles.
- However, H- Section piles are usually preferred because their web and flange thickness are equal
- Wide- flange and I- section beams, the web thickness are smaller than the thickness of the flange.

$$Q_{all} = A_s \sigma_{all}$$

A_s = Cross Sectional area of the steel
σ_{all} = allowable stress of steel.

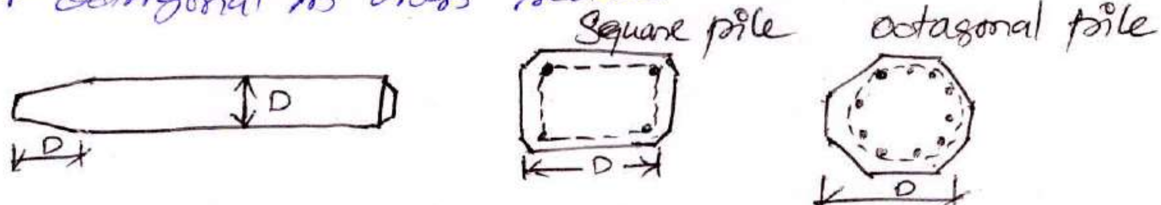
* Based on geotechnical considerations, once the design load for a pile is fixed it is always advisable to check if $Q_{(design)}$ is within the allowable range.
- Steel piles, when necessary, are spliced by welding or by riveting



- Steel piles may be subject to Corrosion. For example swamps, peats and other organic soils are corrosive.
- Soils that have a pH greater than 7 are not so Corrosive.

Concrete piles:

- Concrete piles can be divided into two basic categories (a) precast piles, (b) cast-in-site piles. precast piles can be prepared by using ordinary reinforcement. they can be square or octagonal in cross section

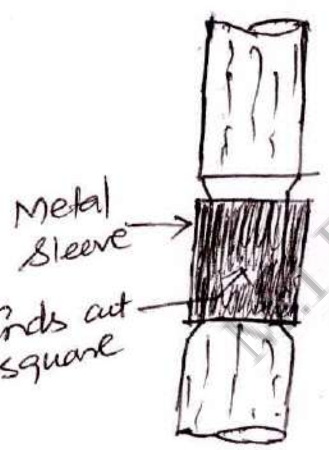


precast piles with ordinary Reinforcement

Cast-in site, or cast-in-place piles are built by making a hole in ground and then filling it with concrete. (a) Cased (b) uncased. both types may have a pedestal at bottom.

Timber piles:

- Timber piles are tree trunks that have had their branches carefully trimmed off. The maximum length of most timber piles is 10 to 20m.



Splicing of timber piles
use of piles Sleeves.

Composite piles:

- The upper and lower portions of Composite piles are made of different materials. Composite may be made of steel and Concrete or timber and Concrete.
- Steel and Concrete piles Consists of a lower portion of steel and an upper portion of cast in place Concrete.

Suggested Questions / Assignments / Home works / any other

1. Define piles?
2. What are the types of piles?
3. Uses of piles?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundations	B.C. Punmia	Laxmi Publications Pvt Ltd.

Any other suggested Materials

Lecture No. 29.

Topic(s) to be covered	Carrying capacity of single pile in Granular and Cohesive soil

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	point Bearing piles, friction, Compaction piles, load transfer mechanism	Understand & Apply

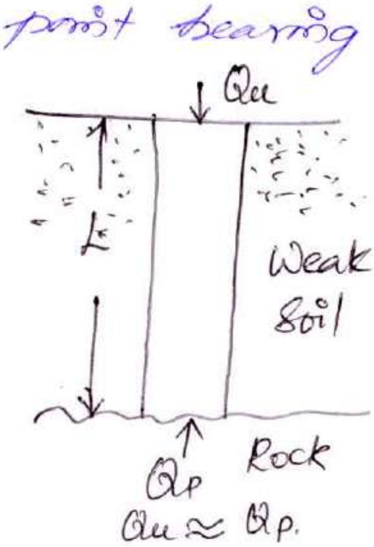
Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Apply

Lecture Notes

point Bearing piles:

- If bedrock or rock-like material is located at a given site within a reasonable depth that has been well established by soil-boring records, piles can be extended to the rock layer.
- In this case, the ultimate capacity of the piles entirely depends on the load-bearing capacity of firm material, thus the piles are

called point bearing piles.



$$Q_u = Q_p + Q_s$$

Q_p = load carried at pile point

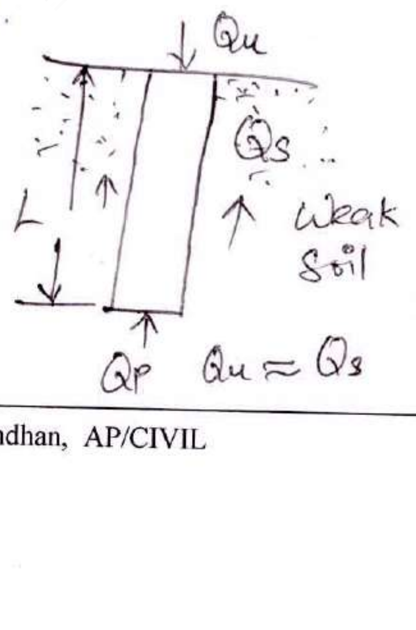
Q_s = load carried skin friction developed at side of pile

If Q_s is very small, then $Q_u \approx Q_p$

In this case, necessary pile length can also be accurately estimated if proper subsoil exploration.

Friction piles:

- When there is no layer of rock or rock-like material located at a reasonable depth at a given site, point bearing piles become very long and uneconomical.
- For this type of subsoil condition, piles are driven through the softer material to specified depths.

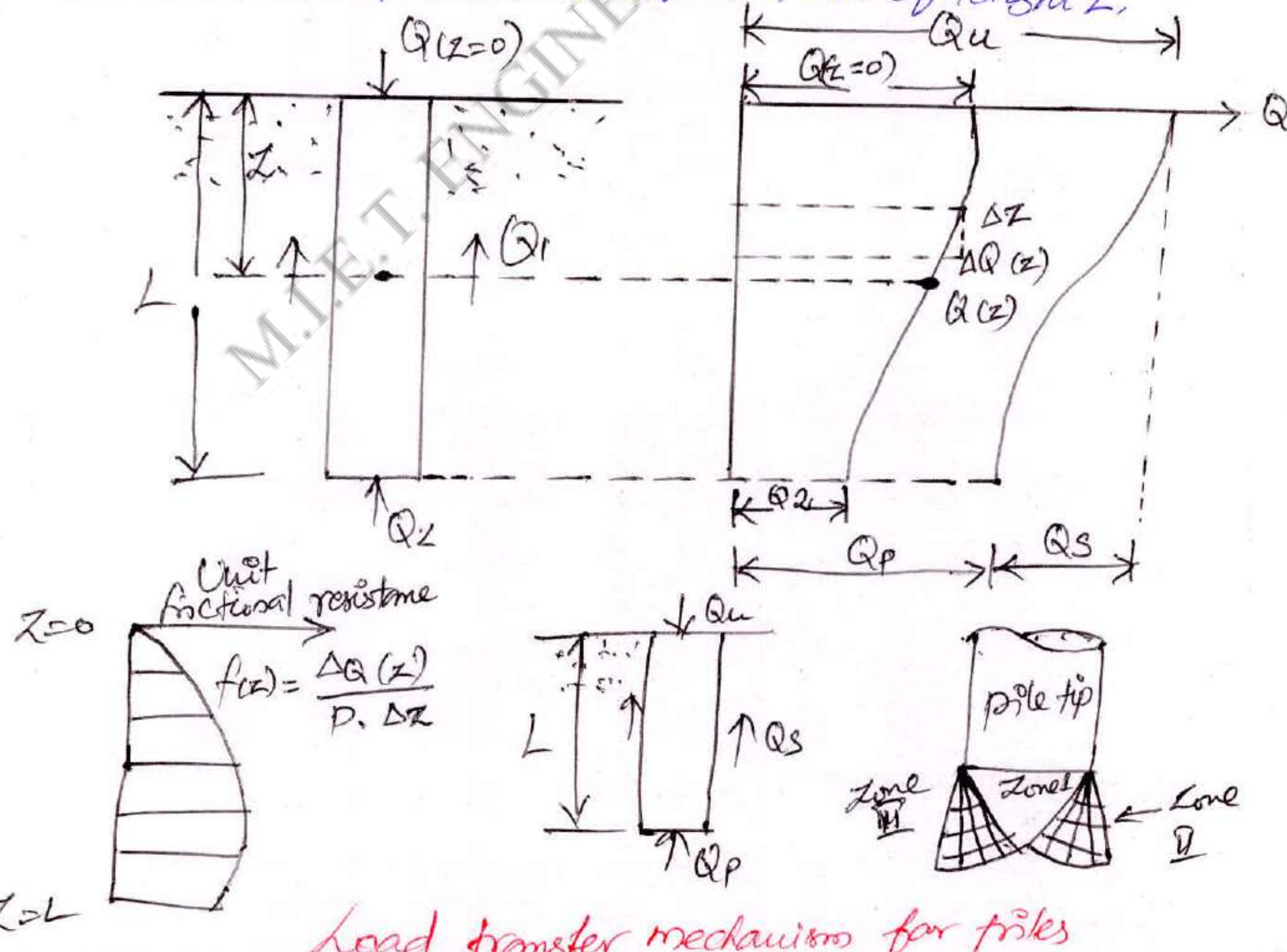


$$Q_u \approx Q_s$$

- These piles are called friction piles because most of the resistance is derived from skin friction.
- However, the term friction pile, although used often in literature, is a misnomer, in clayey soils, the resistance to applied load is also caused by adhesion.
- The length of friction piles depends on the shear strength of the soil, the applied load, and the pile size.
- To determine the necessary lengths of these piles one needs a good understanding of the soil-pile interaction, good judgement, and experience.

Load Transfer Mechanism:

- The load transfer mechanism from a pile to the soil complicated.
- To understand it, consider a pile of length L.



Load transfer mechanism for piles

the pile, Q_2. Now, how are Q_1 and Q_2 related to the total load.

- If measurements are made to obtain the load carried by the pile shaft, $Q(z)$, at any depth z, the nature of the variation found will be like that.
- The frictional resistance per unit area at any depth z may be determined as

$$f(z) = \frac{\Delta Q(z)}{(P)(\Delta z)}$$

P= Perimeter of cross section of the pile.

- If the load Q at the ground surface is gradually increased, maximum frictional resistance along the pile shaft will be fully mobilized when the relative displacement between the soil and the pile is about 5 to 10mm, irrespective of the pile size and length L.
- However, the maximum point resistance $Q_2 = Q_p$ will be not be mobilized until the tip of the pile has moved about 10 to 25% of the pile width.
- At ultimate load $Q_{(z=0)} = Q_u$

$$Q_1 = Q_s$$
$$Q_2 = Q_p$$

The preceding explanation indicates that Q_s (or the unit skin friction, f, along the pile shaft) is developed at a much smaller pile displacement compared with the point resistance, Q_p.

- At ultimate load, the failure surface in the soil at the pile tip (a bearing capacity failure caused by Q_p) is like that.

- Note that pile foundations are deep foundations and that the soil fails mostly in a punching mode,

- This is a triangular zone, I, is developed at the pile tip, which is pushed downward without producing any other visible slip surface.

- In dense sands and stiff clayey soils, a radial shear zone, II, may partially develop. Hence the load displacement curves of piles will resemble. ~~Hence~~.

Suggested Questions / Assignments / Home works / any other

1. Explain about the carrying capacity of single pile?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundations	B.C. Punmia	Laxmi publications pvt Ltd new delhi

Any other suggested Materials

Lecture No. 30.

Topic(s) to be covered	Equations for Estimating pile capacity

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	point bearing capacity, frictional Resistance, Meyerhof's method for Estimation Qp, Janbu's method for Estimating Qp.	Understand & Apply.

Teaching Learning Material	Student Activity
Chalk & Talk	Listen and Apply

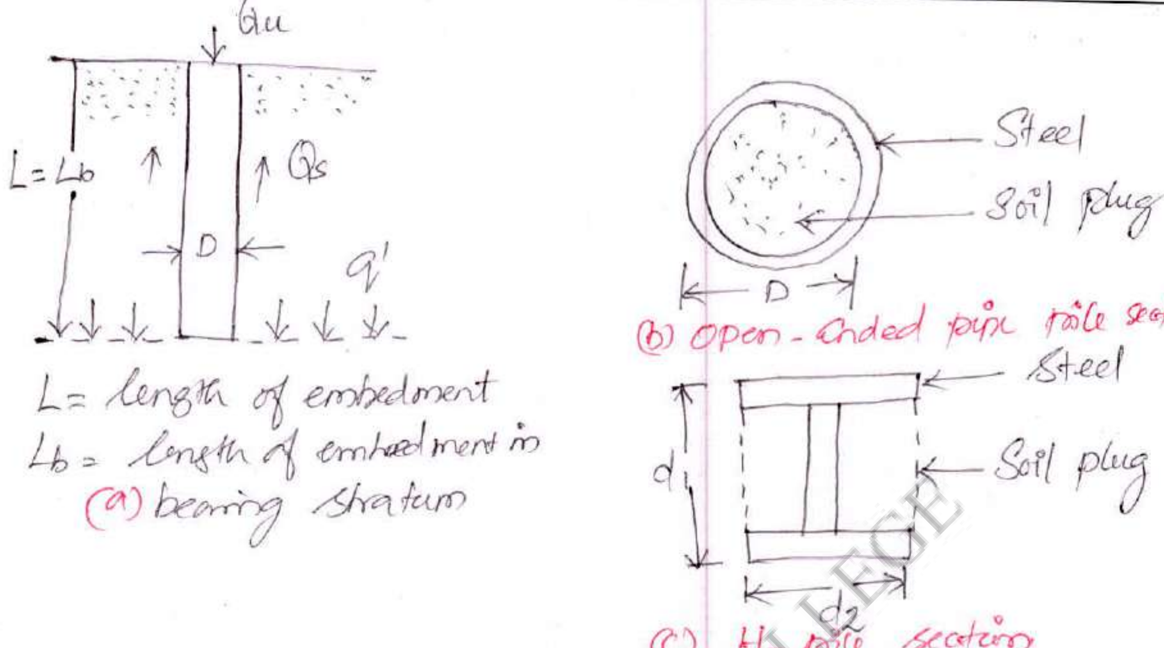
Lecture Notes

The ultimate load carrying capacity Q_u of a pile is

$$Q_u = Q_p + Q_s$$

Q_p = load carrying capacity of the pile point

Q_s = frictional resistance (skin friction) derived from the soil - pile interface.



Point Bearing Capacity, Q_p:

According to Terzaghi's equation

$$q_u = 1.3c'N_c + qN_q + 0.4\gamma BN_\gamma \text{ (shallow square foundation)}$$

Similarly, the general bearing capacity equation for shallow foundation is

$$q_u = c'N_c F_{cs} F_{cd} + qN_q F_{qs} F_{qd} + \frac{1}{2}\gamma BN_\gamma F_{\gamma s} F_{\gamma d}$$

Hence, in general, the ultimate load bearing capacity may be expressed as

$$q_u = c'N_c^* + qN_q^* + \gamma BN_\gamma^*$$

N_c^*, N_q^*, N_γ^* are the bearing capacity factors that include the necessary shape and depth factors.

Pile foundations are deep. However, the ultimate resistance per unit area developed at pile tip, q_p

may be expressed as $q_u = c'N^*_c + qN^*_q + \gamma B N^*_\gamma$, although the values of N^*_c, N^*_q and N^*_γ will change.

$$q_u = q_p = c'N^*_c + qN^*_q + \gamma D N^*_\gamma$$

- Because the width D of a pile is relatively small, the term $\gamma D N^*_\gamma$ may be dropped from the right side of the preceding equation without introducing a serious error.

$$q_p = c'N^*_c + q'N^*_q$$

Note that the term q has been replaced by q' to signify effective vertical stress. Thus the point bearing of piles is

$$Q_p = A_p q_p = A_p (c'N^*_c + q'N^*_q)$$

A_p = Area of pile tip
c' = Cohesion of the soil supporting the pile tip
q_p = unit point resistance
q' = effective vertical stress at the level of the pile tip
N^*_c, N^*_q = the bearing capacity factors.

Frictional Resistance Q_s

The frictional, or skin resistance of a pile may be

$$Q_s = \Sigma p \Delta L f$$

p = perimeter of the pile section
ΔL = incremental pile length over which p and f are taken to be constant

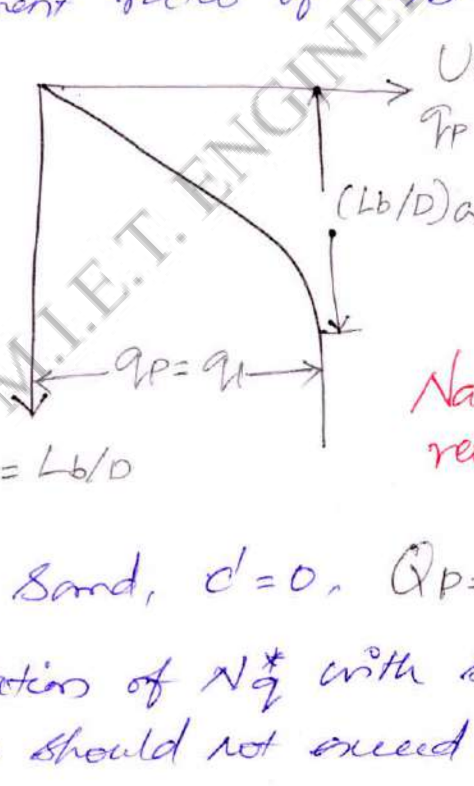
f = unit friction resistance at any depth z.

The various methods for estimating Qp and Qs are needed to be reemphasized that, in the field, for full mobilization of the point resistance (Qp), the pile tip must go through a displacement of 10 to 25 % of the pile width (or) diameter.)

Meyerhof's Method for Estimating Qp:

Sand:

The point bearing capacity q_p of a pile in Sand generally increases with the depth of embedment in the bearing stratum and reaches a maximum value at an embedment ratio of $L_b/D = (L_b/D)_{cr}$.



Nature of Variation of unit point resistance in a homogeneous Sand

Pile in Sand, $c' = 0$, $Q_p = A_p q_p = A_p q' N_q^*$

. The variation of N_q^* with soil friction angle ϕ.

However, Qp should not exceed the limiting value $A_p q_l$

$$Q_p = A_p q' N_q^* \leq A_p q_l$$

Limiting point Resistance is $q_l = 0.5 P_a N_q^* \tan\phi'$

Where,

P_a = atmospheric pressure = (100 kN/m²)

ϕ' = effective soil friction angle of the bearing stratum

On the basis of field observations, Meyerhof also suggested that the ultimate point resistance q_p in a homogeneous granular soil ($L = L_b$) obtained from standard penetration number

$$q_L = 0.4\, P_a\, N_{60} \frac{L}{D} \leq 4\, P_a\, N_{60}$$

N_{60} = average value of standard penetration number near pile point,

P_a = atm. pressure ≈ 100 kN/m²

clay ($\phi = 0$), piles $Q_p = N_c^* C_u A_p = 9 c_u A_p$

c_u = undrained cohesion of the soil below the tip of pile.

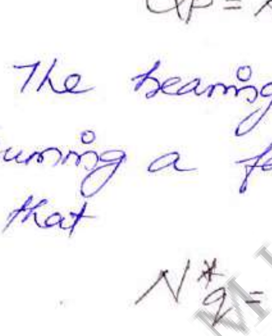
Janbu's Method for Estimating Q_p

$$Q_p = A_p (c' N_c^* + q' N_q^*)$$

- The bearing capacity factors N_c^* and N_q^* are calculated by assuming a failure surface in soil at the pile tip similar to that

$$N_q^* = (\tan\phi' + \sqrt{1+\tan^2\phi'})^2 (e^{2\eta'\tan\phi'})$$

angle η' = $N_c^* = (N_q^* - 1)\cot\phi'$



angle η' varies from 60° for soft clays to about 105° for dense sandy soils. $60° \leq \eta' \leq 90°$

Failure surface at the pile tip

Suggested Questions / Assignments / Home works / any other

1. Describe point load bearing capacity?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundation Engineering	K.R. Arora	Standard publishers and distributors new delhi

Any other suggested Materials

Lecture No. 31.

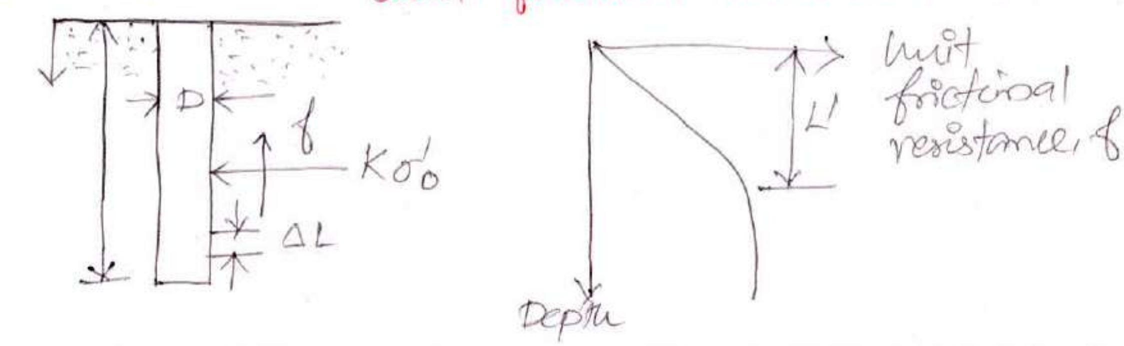
Topic(s) to be covered	Capacity from insitu tests (SPT & SCPT)

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Calculating Qp with SPT and CPT, frictional resistance (Qs) in sand, frictional (skin) resistance in clay.	Understand & Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & apply

Lecture Notes

- For calculating Qp, on the basis of standard penetration test and cone penetration test results conducted in the field. Unit frictional resistance for piles in sand



$z = 0, L'$ $f = K\sigma_0' \tan\delta'$ K = effective earth pressure coefficient

$z = L'$ to L, $f = f_{z=L'}$ σ_0' = effective vertical stress at the depth under consideration

δ' = soil-pile friction angle

Frictional Resistance (Q_s) in Sand:

The unit frictional resistance, f is hard to estimate,

1. The nature of the pile installation, driven piles in sand, the vibration caused during pile driving helps densify the soil around the pile.
2. It has been observed that the nature of variation of f in the field is approximately. A conservative estimate would be $L' = 15D$
3. At similar depths, the unit skin friction in loose sand is higher for a high displacement pile, compared with a low-displacement pile.

$$K \cdot \tan\delta' = 0.18 + 0.0065 D_r$$

$$K = 0.5 + 0.008 D_r$$

D_r = relative density (%)

$$Q_s = f_{av} PL = (K\bar{\sigma}_0' \tan\delta') PL$$

$\bar{\sigma}_0'$ = average effective overburden pressure

δ' = soil-pile friction angle $= 0.8\phi'$

$$Q_s = K\bar{\sigma}_0' \tan(0.8\phi') PL$$

Correlation with standard penetration test:

The average unit frictional resistance, f_{av} for

for high displacement driven piles may be obtained from average standard penetration resistance value as

$$f_{av} = 0.02 P_a (\bar{N}_{60})$$

$\bar{N}_{60}$ = average value of standard penetration resistance
P_a = atmospheric pressure = $(100\ kN/m^2)$

Low displacement driven piles

$$f_{av} = 0.01 P_a (\bar{N}_{60}), \quad Q_s = pL f_{av}$$

A Concrete pile is 16m (L) long and 410mm x 410mm in cross section. The pile is fully embedded in sand for which $\gamma = 17\ kN/m^3$ and $\phi' = 30°$. Calculate the ultimate point load Q_p

(a) Meyerhof's method, (b) Janbu's method, use $\eta' = 90°$

$$Q_P = A_P q' N_q^* = A_P \gamma L N_q^*$$

For $\phi' = 30°$, $N_q^* \approx 55$,

$$Q_P = (0.41 \times 0.41\ m^2)(16 \times 17)(55) = 2515\ kN$$

$$q_P = (0.5 p_a N_q^* \tan \phi') A_P$$

$$= [(0.5)(100)(55) \tan 30](0.41 \times 0.41) = 267\ kN$$

Hence,

$$Q_P = 267\ kN$$

part b, $c' = 0$

$$Q_P = A_P q' N_q^*$$

for $\phi' = 30°$ and $\eta' = 90°$, the value of $N_q^* \approx 18.4$.

$$Q_P = (0.41 \times 0.41)(16 \times 17)(18.4)$$

$$= 841\ kN$$

Frictional (skin) Resistance in clay

Estimating the frictional (or skin) resistance of piles in clay is almost as difficult a task as estimating that in sand, due to presence of several variables that cannot easily be quantified.

λ method

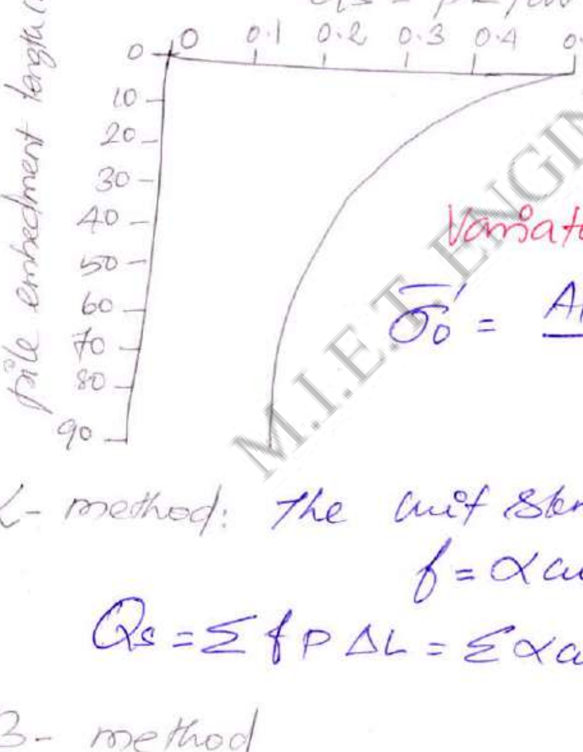
- It is based on the assumption that the displacement of soil caused by pile driving result in a passive lateral pressure at any depth and that the average unit skin

$$f_{av} = \lambda (\bar{\sigma}_o' + 2c_u)$$

$\bar{\sigma}_o'$ = mean effective vertical stress for the entire embedment length

c_u = mean undrained shear strength ($\phi = 0$)

$$Q_s = pLf_{av}$$



Variation of λ with pile embedment length

$$\bar{\sigma}_o' = \frac{A_1 + A_2 + A_3 + \ldots}{L}$$ → areas of the vertical effective stress

α-method: The unit skin resistance in clayey soils can be

$f = \alpha c_u$, α = empirical adhesion factor.

$$Q_s = \sum f p \Delta L = \sum \alpha c_u p \Delta L$$

β-method

- When piles are driven into saturated clays, the pore water pressure in the soil around the piles increases. The excess pore water pressure in normally consolidated clays may be four to six times c_u.

$f = \beta \sigma_o'$, σ_o' = vertical effective stress

$\beta = k \tan \phi_R'$

ϕ_R' = drained friction angle of remolded clay

k = earth pressure co-efficient

$$Q_s = \sum f p \Delta L$$

a. Given that $K = 1.3$, $\delta' = 0.8\phi'$, determine the frictional resistance Q_s.

b. Using the results of (previous sum), part a of this sum, estimate the allowable load carrying capacity of the pile. Let $FS = 4$.

part a.

$$L \approx 15D = 15(0.41m) = 6.15m$$

$$z = 0,\ \sigma_o' = 0,\ f = 0,\ z = L' = 6.15m$$

$$\sigma_o' = \gamma L' = (17)(6.15) = 104.55\ kN/m^2$$

So, $f = K\sigma_o' \tan\delta' = (1.3)(104.55)[\tan(0.8 \times 30)] = 60.51\ kN/m^2$

Thus,

$$Q_s = \left(\frac{f_{z=0} + f_{z=6.15m}}{2}\right) pL' + f_{6.15m}\, p(L - L')$$

$$= \left(\frac{0 + 60.51}{2}\right)(4 \times 0.41)(6.15) + (60.51)(4 \times 0.41)(16 - 6.15)$$

$$= 305.2 + 977.5 = 1282.7\ kN$$

part b

We have $Q_u = Q_p + Q_s$, $Q_p = \frac{267 + 841}{2} = 554\ kN$

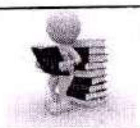
So $$Q_{all} = \frac{Q_u}{FS}$$

$$= \frac{1}{4}(554 + 1282.7)$$

$$= 459\ kN$$

Suggested Questions / Assignments / Home works / any other

1. Explain standard penetration test?
2. Explain types of soil tests?



Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Foundation Analysis and design	Joseph E Bowles	McGraw Hill Education

Any other suggested Materials

Lecture No. 32.

Topic(s) to be covered	Group capacity by different methods

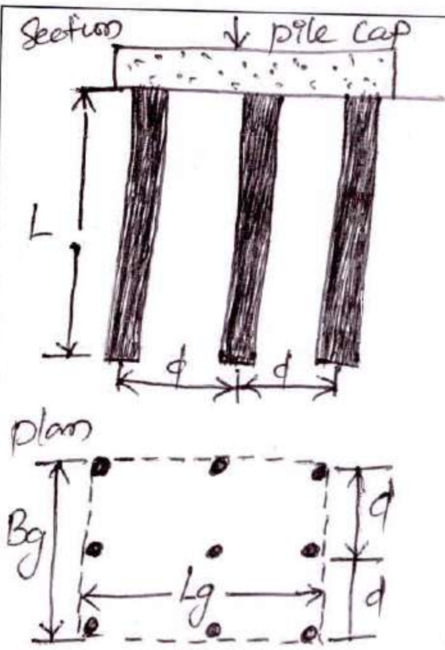
	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Group piles efficiency, piles in Sand, piles in clay, piles in Rock.	Understand & Apply

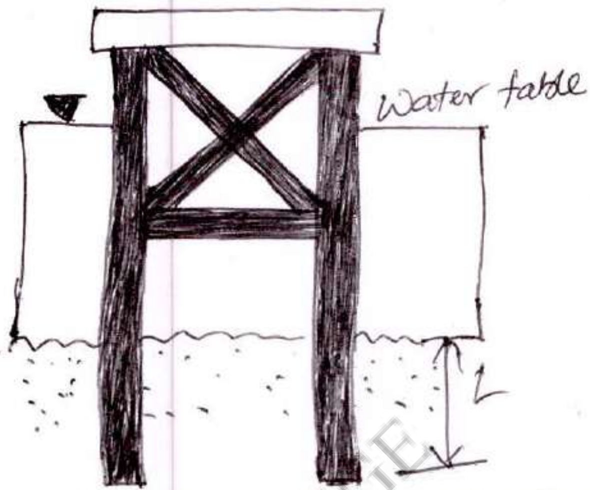
Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Apply

Lecture Notes

· To transmit the structural load to the soil, A pile cap is constructed over group piles. The pile cap can be in contact with the ground, as in most of the cases, or it may be well above the ground, as in the case of construction of offshore platforms.

· The preceding sections have discussed the load bearing capacity of single piles.

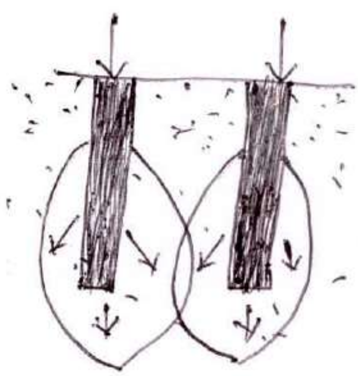




Number of piles in group = $n_1 \times n_2$

$(L_g \geq B_g)$ $L_g = (n_1 - 1)d + 2(D/2)$

$B_g = (n_2 - 1)d + 2(D/2)$



pile groups

piles in Sand:

- depending on their spacing within the group, the piles may act in one of the two following ways
  (1) as a block with dimensions $L_g \times B_g \times L$
  (2) as individual piles.

- If the piles act as a block, the frictional capacity can be $f_{av} p_g L \simeq Q_{g(u)}$.

p_g - perimeter of cross section of block = $2(n_1 + n_2 - 2)d + 4D$, and f_{av} = average unit frictional resistance.

$Q_u = pLf_{av}$ (p = perimeter of cross section of each pile)

$$\eta = \frac{Q_{g(u)}}{\Sigma Q_u} = \frac{f_{av}[2(n_1+n_2-2)d+4D]L}{n_1 n_2 pL f_{av}}$$

$$= \frac{2(n_1+n_2-2)d+4D}{p n_1 n_2}$$

$$Q_{g(u)} = \left[\frac{2(n_1+n_2-2)d+4D}{p n_1 n_2}\right]\Sigma Q_u$$

If the center to center spacing (d) are large, one may obtain $\eta > 1$. In that case, the piles will behave as individual piles. In practice, in $\eta < 1$,

$$Q_{g(u)} = \eta \Sigma Q_u$$

if $\eta \geq 1$ $\quad Q_{g(u)} = \Sigma Q_u$

Another equation that is quoted often among design is Converse - labarre equation,

$$\eta = 1 - \left[\frac{(n_1-1)n_2 + (n_2-1)n_1}{90\, n_1 n_2}\right]\theta$$

$$\theta(\text{deg}) = \tan^{-1}(D/d)$$

1. For driven group piles in sand with $d \geq 3D$, $Q_{g(u)}$ may be taken to be equal to ΣQ_u. This includes the frictional and the point bearing capacity of individual piles.

2. For bored group piles in sand at conventional spacings (that is $d = 3D$), $Q_{g(u)}$ may be taken to be equal to 2/3 to 3/4 times ΣQ_u (frictional and point bearing capacity of individual piles).

piles in clay:

- The ultimate load-bearing capacity of group piles in clay can be estimated in following manner:

Step 1: Determine $\Sigma Q_u = n_1 n_2 (Q_p + Q_s)$

$$Q_p = A_p [9 c_{u(p)}]$$

$c_{u(p)}$ = undrained cohesion of the clay at the pile tip

$$Q_s = \Sigma \alpha p c_u \Delta L$$

So,

$$\Sigma Q_u = n_1 n_2 [9 A_p c_{u(p)} + \Sigma \alpha p c_u \Delta L]$$

Step 2: Determine the ultimate capacity assuming that the piles in the group act as a block with dimensions $L_g \times B_g \times L$.

Skin resistance of the block $= \Sigma p_g c_u \Delta L = \Sigma 2(L_g + B_g) c_u \Delta L$

point bearing capacity $= A_p q_p = A_p c_{u(p)} N_c^* = (L_g B_g) c_{u(p)} N_c^*$

$$\Sigma Q_u = L_g B_g c_{u(p)} N_c^* + \Sigma 2 (L_g + B_g) c_u \Delta L.$$

Step 3: ~~Compare the two~~ The lower of the two values is equal to $Q_{g(u)}$ while comparing the step 1 and step 2 equations.

piles in Rock:

- For point bearing pile resting on rocks, most building codes specify that $Q_{g(u)} = \Sigma Q_u$, provided that the minimum center to center spacing of piles is equal to D + 300mm, for H-piles and piles with square cross sections, the value of D is equal to the diagonal dimension of the pile cross section

Refer 1st fig: Given: $n_1 = 4$, $n_2 = 3$, $D = 305$ mm, $d = 1220$ mm and $L = 15$ m. The piles are square in cross section and embedded in a homogeneous clay with $c_u = 70$ kN/m². Using a factor of safety equal to 4, determine the allowable load-bearing capacity of the group pile.

$$\Sigma Q_u = n_1 n_2 [9 A_p c_{u(p)} + \Sigma \alpha p c_u \Delta L)$$

$$A_p = (0.305)(0.305) = 0.093 \, m^2$$

$$p = (4)(0.305) = 1.22 m$$

$c_u = 70$ kN/m². From $c_u = 70$ kN/m², $\alpha = 0.63$

So, $\Sigma Q_u = (4)(3)[(9)(0.093)(70) + (0.63)(1.22)(70)(15)]$

$$= 12(58.59 + 807.03) \approx 10,387 \text{ kN}$$

Again the ultimate block capacity is

$$L_g B_g c_{u(p)} N_c^* + \Sigma 2(L_g + B_g) c_u \Delta L.$$

$$L_g = (n_1 - 1) d + 2\left(\frac{D}{2}\right) = (4-1)(1.22) + 0.305 = 3.965 m$$

$$B_g = (n_2 - 1) d + 2\left(\frac{D}{2}\right) = (3-1)(1.22) + 0.305 = 2.745 m$$

$$\frac{L}{B_g} = \frac{15}{2.745} = 5.46$$

$$\frac{L_g}{B_g} = \frac{3.965}{2.745} = 1.44$$

$N_c^* \approx 8.6$ so,

$$\text{Block capacity} = (3.965)(2.745)(70)(8.6) + 2(3.965 + 2.745)(70)(15)$$

$$= 6552 + 14091 = 20,643 \text{ kN}$$

So, $Q_{g(u)} = 10,387 \text{ kN} < 20,643 \text{ kN}$

$$Q_{g(all)} = \frac{Q_{g(u)}}{FS} = \frac{10,387}{4} = 2597 \text{ kN}.$$

Suggested Questions / Assignments / Home works / any other

1. Explain Group capacity of different methods?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Principles of foundation Engineering	Braja M. Das	Cengage Learning

Any other suggested Materials

Lecture No. 33.

Topic(s) to be covered	Settlement in pile groups

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Consolidation settlement, group piles, stress distribution method	Understand & Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & apply

Lecture Notes

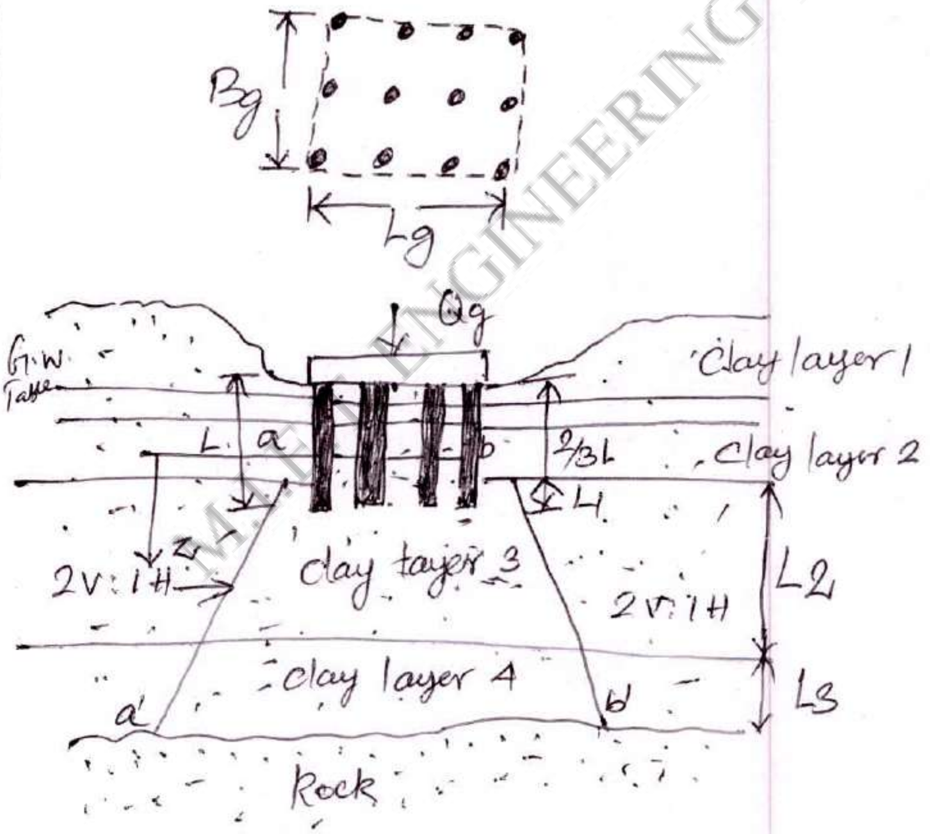
The Consolidation settlement of a group pile in clay can be approximately estimated by using the 2:1 Stress distribution method.

Step 1:

Let the depth of embedment of the piles be equal to L. The group is subjected to a total load of Qg. If the pile cap is below the original ground surface, Qg is equal to the total load of the superstructure on the piles minus the effective weight of soil above the pile group removed by excavation.

Step 2:

Assume that the load Qg is transmitted to the soil beginning at a depth of 2L/3 from the top of the pile.



This is depth z=0 in the figure. The load Qg spreads out along 2 vertical : 1 horizontal lines from lines from this depth. Lines aa' and bb' are the two 2:1 lines.

Step 3: Calculate the stress increase caused at the middle of each soil layer by the load Qg:

$$\Delta\sigma_i' = \frac{Q_g}{(B_g+z_i)(L_g+z_i)}$$

$\Delta\sigma_i'$ = effective stress increase at the middle of layer i

L_g, B_g = length and width of the plan of pile group.

z_i = distance from z=0, to the middle of clay layer, i

Step 4: Calculate the settlement of each layer caused by the increased stress.

$$\Delta S_{c(i)} = \left[\frac{\Delta e_{(i)}}{1+e_{o(i)}}\right] H_i$$

$\Delta S_{c(i)}$ = Consolidation settlement of layer i

$\Delta e_{(i)}$ = Change of void ratio caused by the stress increase in layer i.

$e_{o(i)}$ = initial void ratio of layer (i) (before construction)

H_i = thickness of layer i

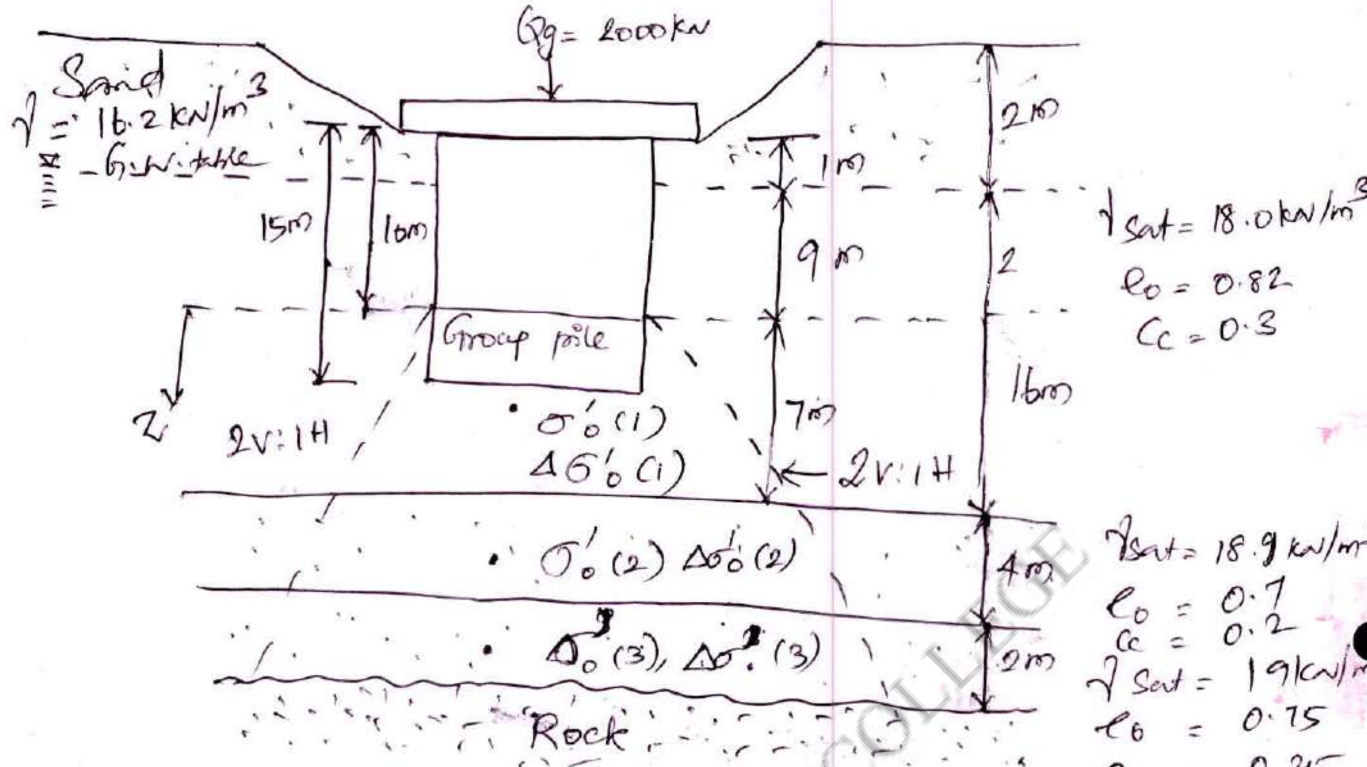
Step 5: Total Consolidation settlement of the pile group

$$\Delta S_{c(g)} = \Sigma \Delta S_{c(i)}$$

A group pile in clay. Determine the consolidation settlement of a pile groups. All clays are normally consolidated.

- Length of pile are 15m each, the stress distribution starts at a depth of 10m below the top of the pile.

$Q_g = 2000$ kN.



pile group : $L_g = 3.3m$, $B_g = 2.2m$

Clay layer 1, for normally consolidated clays

$$\Delta S_{c(1)} = \left[\frac{C_{c(1)} H_1}{1+e_{o(1)}}\right] \log\left[\frac{\sigma'_{o(1)} + \Delta\sigma'_{(1)}}{\sigma'_o(1)}\right]$$

$$\Delta\sigma'_{(1)} = \frac{Q_g}{(L_g+Z_1)(B_g+Z_1)} = \frac{2000}{(3.3+3.5)(2.2+3.5)} = 51.6 \text{ kN/m}^2$$

$$\sigma'_o(1) = 2(16.2) + 12.5(18.0-9.81) = 134.8 \text{ kN/m}^2$$

So,

$$\Delta S_{c(1)} = \frac{(0.3)(7)}{1+0.82} \log\left(\frac{134.8+51.6}{134.8}\right) = 0.1624 \text{ m} = 162.4 \text{ mm}$$

Settlement of layer 2

$$\Delta S_{c(2)} = \frac{C_{c(2)} H_2}{1+e_{o(2)}} \log\left[\frac{\sigma'_o(2) + \Delta\sigma'_{(2)}}{\sigma'_o(2)}\right]$$

$$\sigma'_{o(2)} = 2(16.2) + 16(18.0-9.81) + 2(18.9-9.81) = 181.62 \text{ kN/m}^2$$

$$\Delta\sigma'_{(2)} = \frac{2000}{(3.3+9)(2.2+9)} =$$

$$= 14.52 \text{ kN/m}^2$$

Hence,

$$\Delta S_{c(2)} = \frac{(0.2)(4)}{1+0.7} \log\left[\frac{181.62+14.52}{181.62}\right]$$

$$= 0.0157 \text{ m}$$

$$= 15.7 \text{ mm}$$

Settlement of layer 3

$$\sigma'_{o(3)} = 181.62 + 2(18.9-9.81) + 1(19-9.81)$$

$$= 208.99 \text{ kN/m}^2$$

$$\Delta\sigma'_{(3)} = \frac{2000}{(3.3+12)(2.2+12)} = 9.2 \text{ kN/m}^2$$

$$\Delta S_{c(3)} = \frac{(0.25)(2)}{1+0.75} \log\left[\frac{208.99+9.2}{208.99}\right]$$

$$= 0.0054 \text{ m}$$

$$= 5.4 \text{ mm}$$

Hence, total settlement $= \Delta S_{c(g)} = 162.4 + 15.7 + 5.4$

$$= 183.5 \text{ mm.}$$

Suggested Questions / Assignments / Home works / any other

1. Define pile groups?
2. Explain in detail about settlement in pile groups?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and foundations	B.C. Punmia	Laxmi publication pvt Ltd New delhi - 2017

Any other suggested Materials

Lecture No. 34.

Topic(s) to be covered	Coyle and Castellots Method for Estimating Qp in Sand

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Coyle and Castellots method for estimating Qp in sand to determine driven pile pile in Sand clay.	Understand & Apply.

Teaching Learning Material	Student Activity
Chalk & Talk	Listen and apply

Lecture Notes

For the pile described, estimate Qall using Coyle and Castellots method.

$$Q_u = Q_p + Q_s = q' N_q^* A_p + K \overline{\sigma_o}' \tan(0.8\phi') pL$$

and

$$\frac{L}{D} = \frac{16}{0.41} = 39$$

For $\phi' = 30°$ and $L/D = 39$, $N_q^* = 25$, and $K \approx 0.2$

Coyle and Castello's method for Estimating Qp in Sand:

$$Q_p = q' N_q^* A_p$$

q' - effective vertical stress at the pile tip

N^*_q - bearing capacity factor

N^*_q with L/D and the soil friction angle φ'

$$Q_u = (17 \times 16)(25)(0.41 \times 0.41) + (0.2)\left(\frac{17 \times 16}{2}\right) \tan (0.8 \times 30)(4 \times 0.41)(16)$$

$$= 1143 + 317.8 = 1460.8 \text{ kN}$$

and

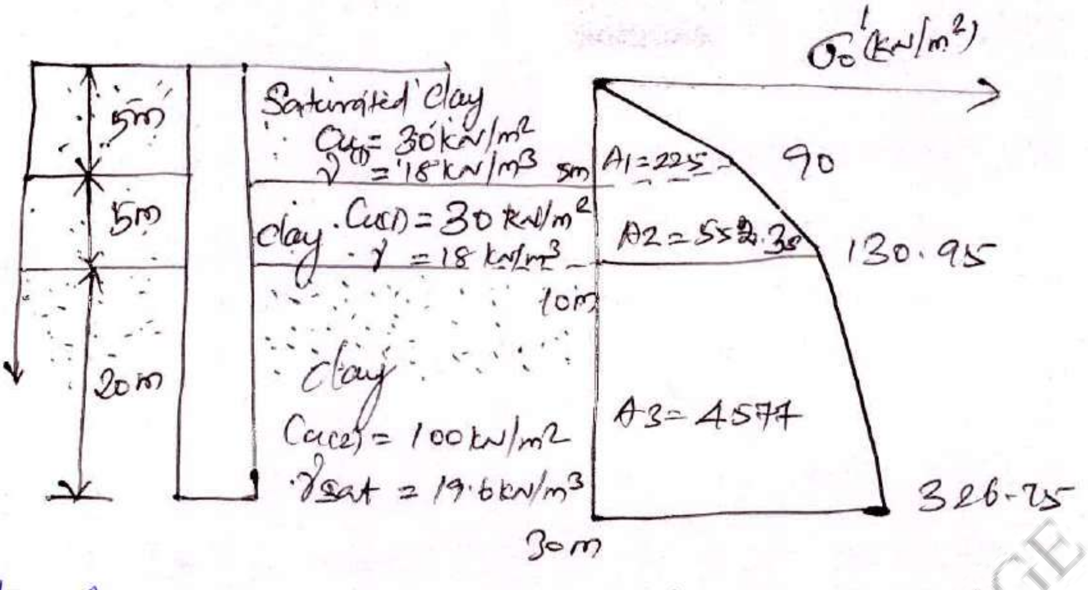
$$Q_{all} = \frac{Q_u}{FS} = \frac{1460.8}{4} = 365.2 \text{ kN}$$

A driven pipe pile in clay. The pipe has an outside diameter of 406mm, and wall thickness is 6.35mm

(a) Calculate the net point bearing capacity

(b) Calculate the skin resistance (1) by (α method) (2) λ method (3) β method. Given φR = 30° for all clay layers. The top 10m of clay is normally consolidated. The bottom clay layer has an OCR of 2.

(c) Estimate the net allowable pile capacity. FS=4



Sol: Area of cross section of pile including the soil inside the pile is

$$A_p = \frac{\pi}{4} D^2 = \frac{\pi}{4}(0.406)^2 = 0.1295\ m^2$$

Part a: Calculation of Net point bearing capacity

$$Q_p = A_p q_p = A_p N_c^* C_{u(2)} = (0.1295)(9)(100)$$
$$= 116.55\ kN$$

Part b: Calculation of Skin Resistance:

$$Q_s = \Sigma \alpha\, c_u P\, \Delta L.$$

For the top soil layer, $c_{u(1)} = 30\ kN/m^2$. According to the average plot of, $\alpha_1 = 1.0$. Similarly, for the bottom soil layer, $C_{u(2)} = 100\ kN/m^2$; $\alpha_2 = 0.5$.

$$Q_s = \alpha_1 C_{u(1)} [(\pi)(0.406)]10 + \alpha_2 C_{u(2)} [(\pi)(0.406)]20$$

$$= (1)(30)[(\pi)(0.406)]10 + (0.5)(100)(\pi)(0.406)]20$$

$$= 382.7 + 1275.5$$

$$= 1658.2\ kN$$

(2) $f_{av} = \lambda(\bar{\sigma}_o' + 2c_u)$

The average value of c_u is equal to

$$\frac{c_{u(1)}(10) + c_{u(2)}(20)}{30} = \frac{(30)(10) + (100)(20)}{30}$$

$$= 76.7 \, kN/m^2$$

The obtain the average value of $\bar{\sigma}_o'$ the diagram for vertical effective stress variation with depth is plotted.

$$\bar{\sigma}_o' = \frac{A_1 + A_2 + A_3}{L} = \frac{225 + 552.38 + 4577}{30}$$

$$= 178.48 \, kN/m^2$$

The value of λ can be obtained from

$$f_{av} = 0.14[178.48 + (2)(76.7)]$$

$$= 46.46 \, kN/m^2$$

Hence,

$$Q_s = pLf_{av} = \pi(0.406)(30)(46.46)$$

$$= 1777.8 \, kN.$$

(3) The top clay layer (10m) is normally consolidated $\phi_R' = 30°$, for $z = 0-5m$

$$f_{av(1)} = (1 - \sin\phi_R')\tan\phi_R' \sigma_{o(av)}'$$

$$= (1 - \sin 30°)(\tan 30°)\left(\frac{0 + 90}{2}\right)$$

$$= 13.0 \, kN/m^2$$

Similarly, for $z = 5-10m$

$$f_{av(2)} = (1-\sin 30^\circ)(\tan 30^\circ)\left(\frac{90+130.95}{2}\right)$$

$$= 31.9\ kN/m^2$$

For $z = 10-30m$

$$f_{av} = (1-\sin \phi'_R)\tan \phi'_R \sqrt{OCR}\ \sigma'_{o(av)}$$

OCR = 2, so

$$f_{av(3)} = (1-\sin 30^\circ)(\tan 30^\circ)\sqrt{2}\left(\frac{130.95+326.75}{2}\right)$$

$$= 93.43\ kN/m^2$$

So,

$$Q_s = p[f_{av(1)}(5) + f_{av(2)}(5) + f_{av(3)}(20)]$$

$$= \pi(0.406)[(13)(5) + (31.9)(5) + (93.43)(20)]$$

$$= 2669.7\ kN$$

part c: Calculation of net ultimate capacity. Q_u

If we compare the three values just given, we see that the α and λ methods give close results. So use

$$Q_s = \frac{1658.1 + 1777.8}{2} \approx 1718\ kN$$

Thus,

$$Q_u = Q_p + Q_s = 116.46 + 1718 = 1834.46\ kN$$

$$Q_{all} = \frac{Q_u}{FS} = \frac{1834.46}{4} = 458.6\ kN$$

Suggested Questions / Assignments / Home works / any other

1. Describe the Castellos method for Estimating in sand and clay?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundations	B.C. Punmia	Laxmi Publications pvt Ltd New delhi 2014

Any other suggested Materials

Lecture No. 35.

Topic(s) to be covered	Elastic settlement of piles

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Elastic settlement of piles Various types of distribution of unit friction, embedded precast and precast Concrete piles.	Understand and Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen and Apply

Lecture Notes

Elastic Settlement of piles:

• The total settlement of a pile under a vertical working load Q_w is given by

$$S_e = S_{e(1)} + S_{e(2)} + S_{e(3)}$$

where,

$S_{e(1)}$ = elastic settlement of pile

$S_{e(2)}$ = Settlement of pile caused by the load at pile tip

$S_{e(3)}$ = Settlement of pile caused by load transmitted along the pile shaft.

- If the pile material is assumed to be elastic the deformation of the pile shaft can be evaluated in accordance with the fundamental principles of mechanics of materials

$$S_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p}$$

where,

Q_{wp} = load carried at the pile point under working load condition.

Q_{ws} = load carried by frictional (skin) resistance under working load condition

A_p = area of cross section of pile

L = length of pile

E_p = modulus of elasticity of the pile material

- The magnitude of ξ will depend on the nature of the distribution of the unit friction (skin) resistance along the pile shaft.
- The settlement of a pile caused by the load carried at the pile point may be expressed in the form:

$$S_{e(2)} = \frac{q_{wp} D}{E_s}(1 - \mu_s^2) I_{wp}$$

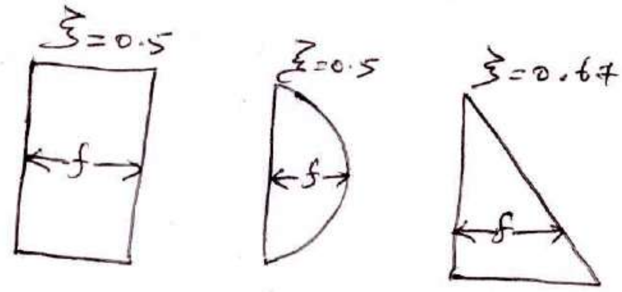
D - width or diameter of pile

q_{wp} - point load per unit area at the pile point - Q_{wp}/A_p

E_s = modulus of elasticity of soil at or below the pile point

μ_s = Poisson's Ratio of soil

I_{wp} = Influence factor ≈ 0.85



Various types of distribution of unit friction (skin) resistance along the pile shaft.

Vesic, proposed a semi-empirical method for obtaining the magnitude of settlement of $S_{e(2)}$

$$S_{e(2)} = \frac{Q_{wp} C_p}{D q_p}$$

q_p - ultimate point resistance of the pile

C_p - an empirical Co-efficient

The settlement of a pile caused by the load carried by the pile shaft

$$S_{e(3)} = \left(\frac{Q_{ws}}{pL}\right)\frac{D}{E_s}\left(1-\mu_s^2\right)I_{ws}$$

P = perimeter of the pile

L = embedded length of pile

I_{ws} = influence factor

$$I_{ws} = 2 + 0.35\sqrt{\frac{L}{D}}$$

Vesic also proposed simple empirical relation for obtaining $S_{e(3)}$

$$S_{e(3)} = \frac{Q_{ws}\, C_s}{L q_p}$$

In this equation

C_s = an empirical constant $= (0.93 + 0.16\sqrt{L/D})\, C_p$

The fully embedded precast, prestressed concrete pile is 12m long and is driven into a homogeneous layer of sand ($c' = 0$). The pile is square in cross section, with sides measuring 305mm. The dry unit weight of sand (γ_d) is 16.8 kN/m³, and the average effective soil friction angle is 35°. The allowable working load is 338 kN. 240 kN is contributed by the frictional resistance and 98 kN is from the point load. Determine the elastic settlement of the pile. Use $E_p = 21\times10^6$ kN/m², $E_s = 30{,}000$ kN/m², and $\mu_s = 0.3$.

Sol:

$$S_e = S_{e(1)} + S_{e(2)} + S_{e(3)}$$

$$S_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p}$$

Let $\xi = 0.6$ and $E_p = 21\times10^6$ kN/m²

$$S_{e(1)} = \frac{[(97) + (0.6)(240)]\,12}{(0.305)^2(21\times10^6)} = 0.00148\,m = 1.48\,mm$$

$$S_{e(2)} = \frac{q_{wp} D}{E_s}(1-\mu_s^2) I_{wp}$$

$I_{wp} = 0.85$

$$q_{wp} = \frac{Q_{wp}}{A_p} = \frac{97}{(0.305)^2} = 1042.7 \text{ kN/m}^2$$

So

$$S_{e(2)} = \left[\frac{(1042.7)(0.305)}{30{,}000}\right](1-0.3^2)(0.85)$$

$$= 0.0082 \text{ m} = 8.2 \text{ mm}$$

$$S_{e(3)} = \left(\frac{Q_{wp}}{pL}\right)\left(\frac{D}{E_s}(1-\mu_s^2) I_{ws}\right)$$

$$I_{ws} = 2 + 0.35\sqrt{\frac{L}{D}} = 2 + 0.35\sqrt{\frac{12}{0.305}} = 4.2$$

$$S_{e(3)} = \frac{240}{(4\times(0.305)(12)}\left(\frac{0.305}{30{,}000}\right)(1-0.3^2)(4.2)$$

$$= 0.00064 \text{ m} = 0.64 \text{ mm}$$

The total settlement is

$$S_e = 1.48 + 8.2 + 0.64 = 10.32 \text{ mm.}$$

Suggested Questions / Assignments / Home works / any other

1. Explain in detail about Elastic settlement of piles?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundations	B.C. Punmia	Laxmi publications pvt ltd new delhi 2017

Any other suggested Materials

Lecture No. 36.

Topic(s) to be covered	Laterally loaded piles

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Laterally loaded piles, Granular Soil. Soil Resistance on pile caused by lateral load	Understand & Apply

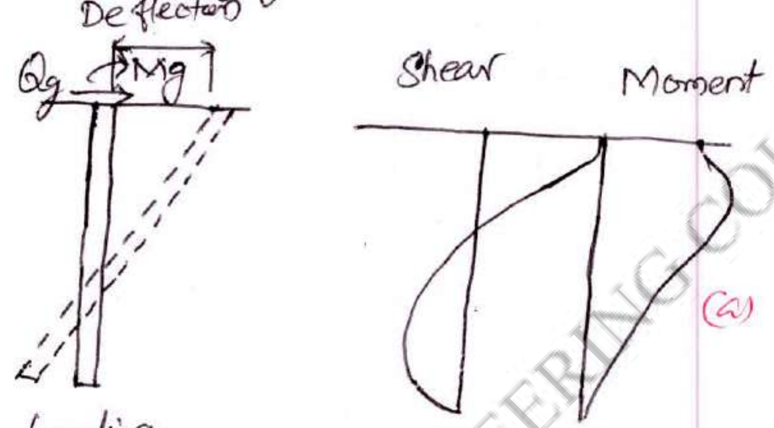
Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Apply

Lecture Notes

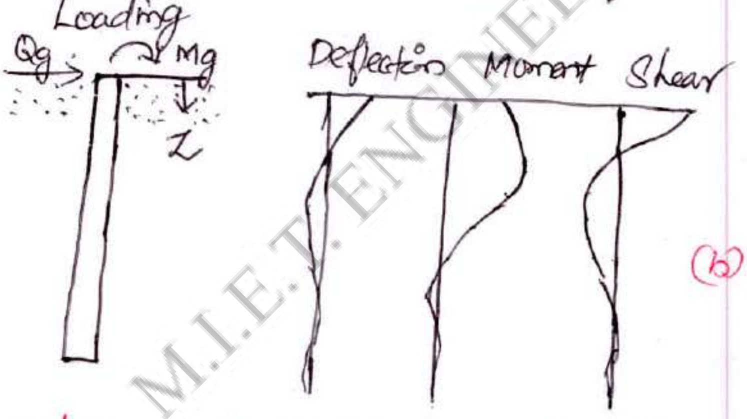
- The vertical pile resists a lateral load by mobilizing passive pressure in the soil surrounding it
- The degree of distribution of the soil's reaction depends on
  (a) the Stiffness of the pile

(b) the stifness of the soil
(c) the fixity of the ends of the pile.

Laterally loaded piles can be divided into two major categories
- Short or rigid piles
- Long or elastic piles



(a) a rigid pile



(b) An elastic pile

Nature of variation of pile deflection, moment and shear force for (a) rigid pile (b) an elastic pile

Granular soil:

· General method for determining moments and displacements of a vertical pile embedded in a is a granular soil and subjected to lateral load and moment at the ground surface was given by Matlock and Reese.

- Consider a pile of length L subjected to a lateral force Q_g and a moment M_g at the ground surface $(z=0)$.

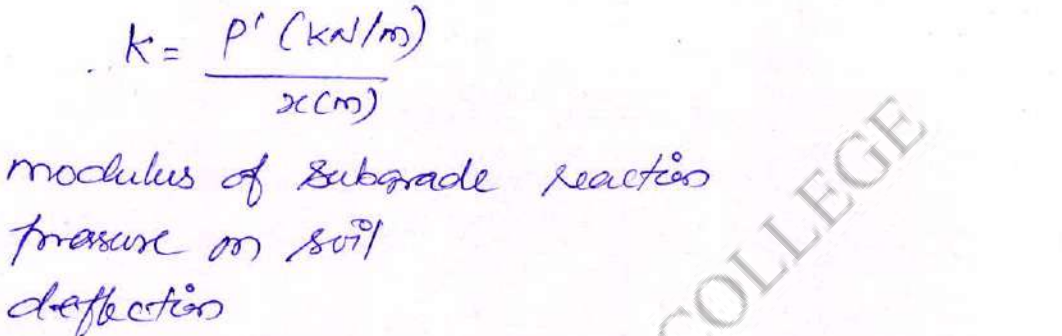
$$K = \frac{p' \,(kN/m)}{x\,(m)}$$

K = modulus of subgrade reaction
p' = pressure on soil
x = deflection

The subgrade modulus for granular soils at a depth z is defined as

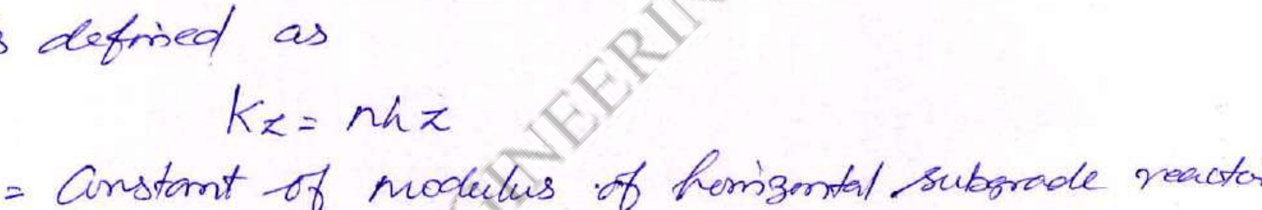
$$K_z = n_h z$$

n_h = Constant of modulus of horizontal subgrade reaction.



(a) laterally loaded pile

Soil Resistance on pile caused by lateral load



Sign Conventions for displacement

$$E_p I_p \frac{d^4x}{dz^4} = p'$$

E_p = modulus of elasticity in the pile material

I_p = moment of inertia of the pile section

Based on Winkler's model

$$p' = -kx$$

$$E_p I_p \frac{d^4 x}{dz^4} + kx = 0$$

pile deflection at any depth $[x_z(z)]$

$$x_z(z) = A_x \frac{Q_g T^3}{E_p I_p} + B_x \frac{M_g T^2}{E_p I_p}$$

Slope of pile at any depth $[\theta_z(z)]$

$$\theta_z(z) = A_\theta \frac{Q_g T^2}{E_p I_p} + B_\theta \frac{M_g T}{E_p I_p}$$

Moment of pile at any depth $[M_z(z)]$

$$M_z(z) = A_m Q_g T + B_m M_g$$

Shear Force on pile at any depth $[V_z(z)]$

$$V_z(z) = A_v Q_g + B_v \frac{M_g}{T}$$

Soil Reaction at any depth $[p'_z(z)]$

$$p'_z(z) = A_{p'} \frac{Q_g}{T} + B_{p'} \frac{M_g}{T^2}$$

Cohesive soil:

Elastic solutions similar to piles embedded in cohesive soils

$$x_z(z) = A'_x \frac{Q_g R^3}{E_p I_p} + B'_x \frac{M_g R^2}{E_p I_p}$$

$$M_z(z) = A'_m Q_g R + B'_m M_g$$

where A'_x, B'_x, A'_m and B'_m are co-efficients and

$$R = \sqrt[4]{\frac{E_p I_p}{k}}$$

The values of the cofficients A' and B'.

$$Z = \frac{z}{R}$$

$$Z_{max} = \frac{L}{R}$$

- However, in cohesive soils, the subgrade reaction may be assumed to be approximately constant with depth.

$$k = 0.65 \sqrt[12]{\frac{E_s D^4}{E_p I_p}} \frac{E_s}{1-\mu_s^2}$$

E_s - modulus of elasticity of soil

D - pile width (or diameter)

μ_s - poisson's ratio for the soil.

Suggested Questions / Assignments / Home works / any other
1. Define cohesive soil and cohesionless soil? 2. Describe laterally loaded piles?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and foundation Engineering	Arora. K.R	Standard publishers distributors new delhi

Any other suggested Materials

Lecture No. 37 UNIT-V RETAINING WALLS

Topic(s) to be covered	Types of Retaining wall

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Types of retaining wall, Gravity Retaining wall, Semi gravity retaining wall, Cantilever retaining wall, Counterfort retaining wall	Understand

Teaching Learning Material	Student Activity
Chalk & Talk	Listen

Lecture Notes

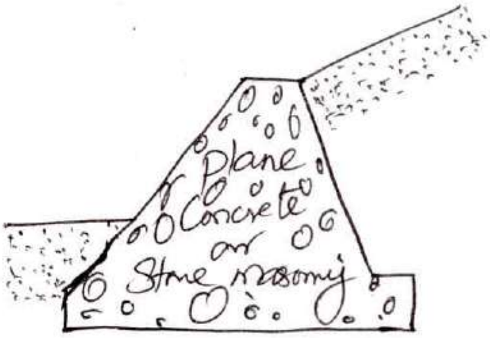
Retaining Wall:

- A Retaining wall is a wall that provides lateral support for a vertical or near vertical slope of soil.
- It is a common structure used in many construction projects.

Types of Retaining wall:

Gravity Retaining wall:

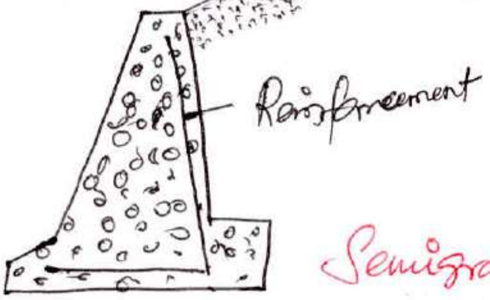
- Gravity Retaining walls are constructed with plain concrete or stone masonry.
- These walls depends on their own weight and any soil resting on the masonry for their stability.
- This type of construction is not very economical for high walls.



Gravity Retaining wall

Semi Gravity Retaining wall:

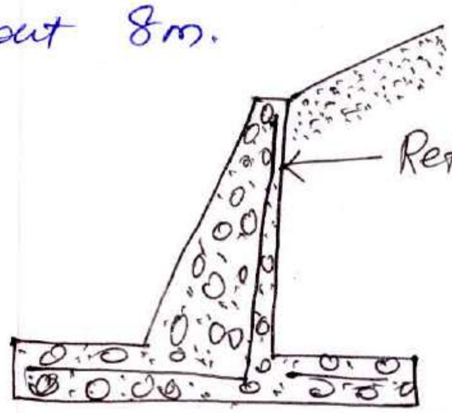
- In many cases, a small amount of steel may be used for the construction of gravity walls, thereby minimizing the size of the wall sections.
- Such walls are generally refered as Semigravity walls



Semigravity Retaining wall

Cantilever Retaining wall:

- Cantilever Retaining walls are made of reinforced concrete that consists of a thin stem and a base slab. This type of wall is economical up to a height of about 8m.



Cantilever wall

Counterfort Retaining walls:

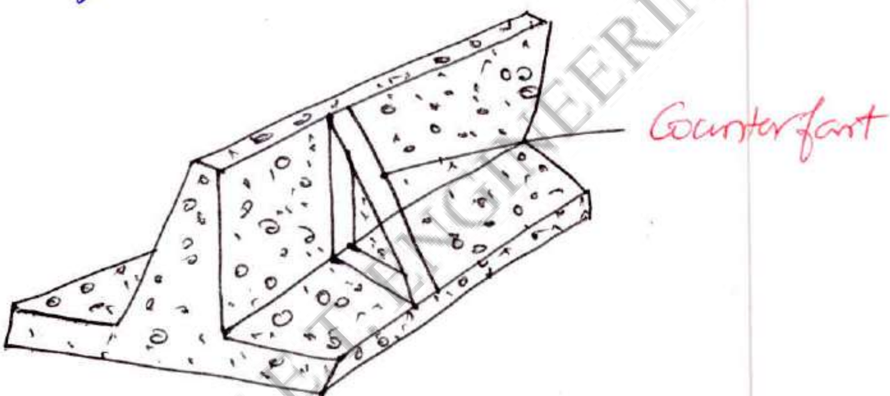
- Counterfort retaining walls are similar to cantilever walls except for the fact that, at regular intervals, they have thin vertical concrete slabs known as counterforts that tie the wall and the base slab together. The purpose of the counterforts is to reduce the shear and the bending moments.

To properly design retaining walls, one must know the basic soil parameters that is, the unit weight, angle of friction, and cohesion, for the soil retained behind the wall and the soil below the base slab.

Knowing the properties of the soil behind the wall enables an engineer to determine the lateral force for which the design has to be made.

- There are two phases in the design of a retaining wall. First, with the lateral earth pressure known, the structure as a whole is checked for stability. This includes checking for possible overturning, sliding and bearing capacity failures.

- Second each component of the structure is checked for adequate strength, and the steel reinforcement of each component is determined.

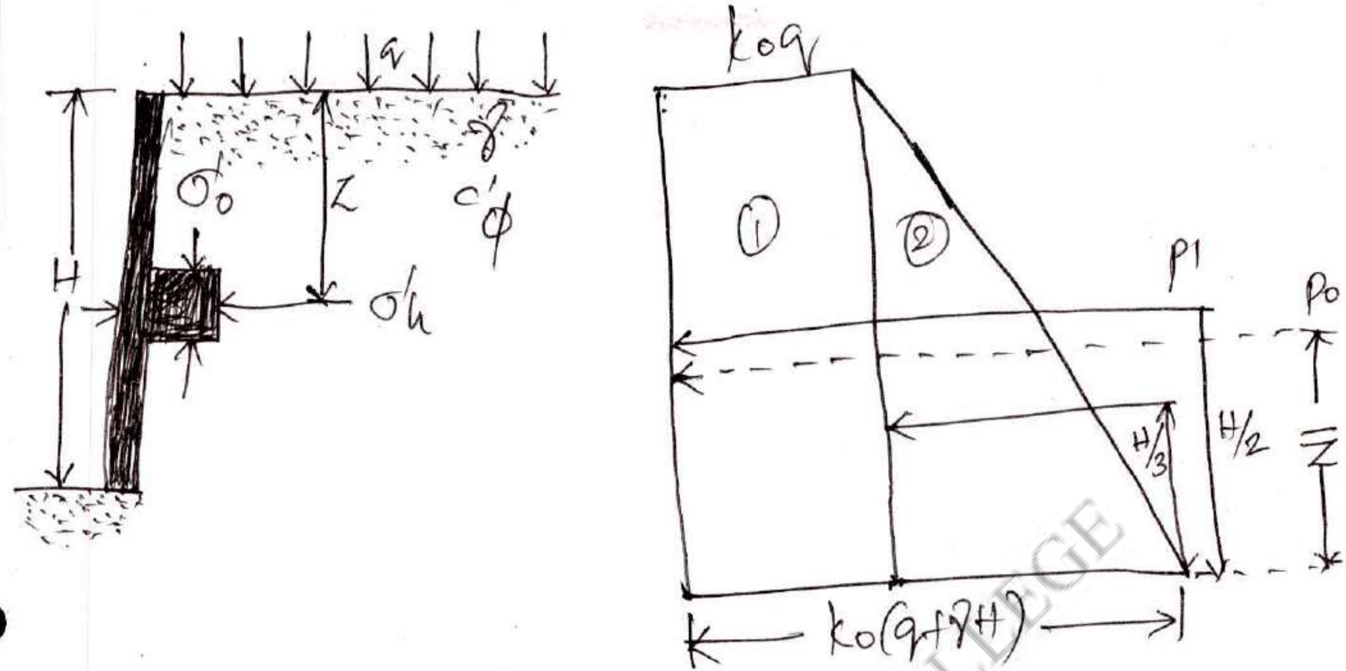


Counterfort Retaining wall

Lateral Earth Pressure:

- Consider a vertical wall of height H, retaining a soil having a unit weight of γ. A uniformly distributed load, q/unit area, is also applied at the ground surface.

The shear strength of soil is $S = c' + \sigma' \tan \phi'$



At rest earth pressure:

where,

c' = Cohesion

ϕ' = effective angle of friction

σ' = effective normal stress

At any depth z below the ground surface, the vertical subsurface stress is

$$\sigma'_0 = q + \gamma z$$

Suggested Questions / Assignments / Home works / any other

1. What are all the types of Retaining wall?
2. Define Retaining walls?
3. Where it is used?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Text book of soil Mechanics and Foundation Engineering	V.N.S. Murthy	CBS publishers distribution Ltd new delhi 2014

Any other suggested Materials

Lecture No. 38.

Topic(s) to be covered	Lateral Earth pressure at Rest

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	lateral Earth pressure at rest, Overconsolidated, normally Consolidated	understand & Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & Apply.

Lecture Notes

- If the wall is at rest and is not allowed to move at all, either away from the soil mass or in to the soil mass (ie) there is zero horizontal strain the lateral pressure at a depth z is a

$$\sigma_h = K_0 \sigma_0' + u$$

where u = pore water pressure.

K_0 = Co-efficient of at rest earth pressure
For normally Consolidated soil, the relation for K_0

$$K_0 \approx 1 - \sin \phi'$$

For normally Consolidated clays, the Co-efficient of earth pressure at rest can be approximated.

$$K_0 \approx 0.95 - \sin \phi'$$

Where ϕ' = drained peak friction angle.

- On the basis of Brooker and Ireland's experimental results, the value of K_0 for normally Consolidated clays may be approximately Correlated with the plasticity index (PI).

$$K_0 = 0.4 + 0.007(PI) \quad (\text{between } 0 \text{ and } 40)$$

$$K_0 = 0.64 + 0.001(PI) \quad (40 \text{ and } 80)$$

For over Consolidated clays:

$$K_0(\text{overconsolidated}) \approx K_0(\text{normally consolidated})\sqrt{OCR}$$

- With a properly selected value of the at-rest earth pressure Co-efficient, Can be used to determine the variation of lateral earth pressure with depth z.
- The variation of σ'_h with depth for the wall.
- If the surcharge $q = 0$

The pore water pressure $u = 0$,

The total force, P_o, per unit length of the wall.

$$P_o = P_1 + P_2 = qK_oH + \frac{1}{2}\gamma H^2 K_o$$

P_1 = area of rectangle 1

P_2 = area of triangle 2

The location of the line of action of the resultant force, P_o, can be obtained by taking the moment about the bottom of the wall.

$$\bar{z} = \frac{P_1\left(\frac{H}{2}\right) + P_2\left(\frac{H}{3}\right)}{P_o}$$

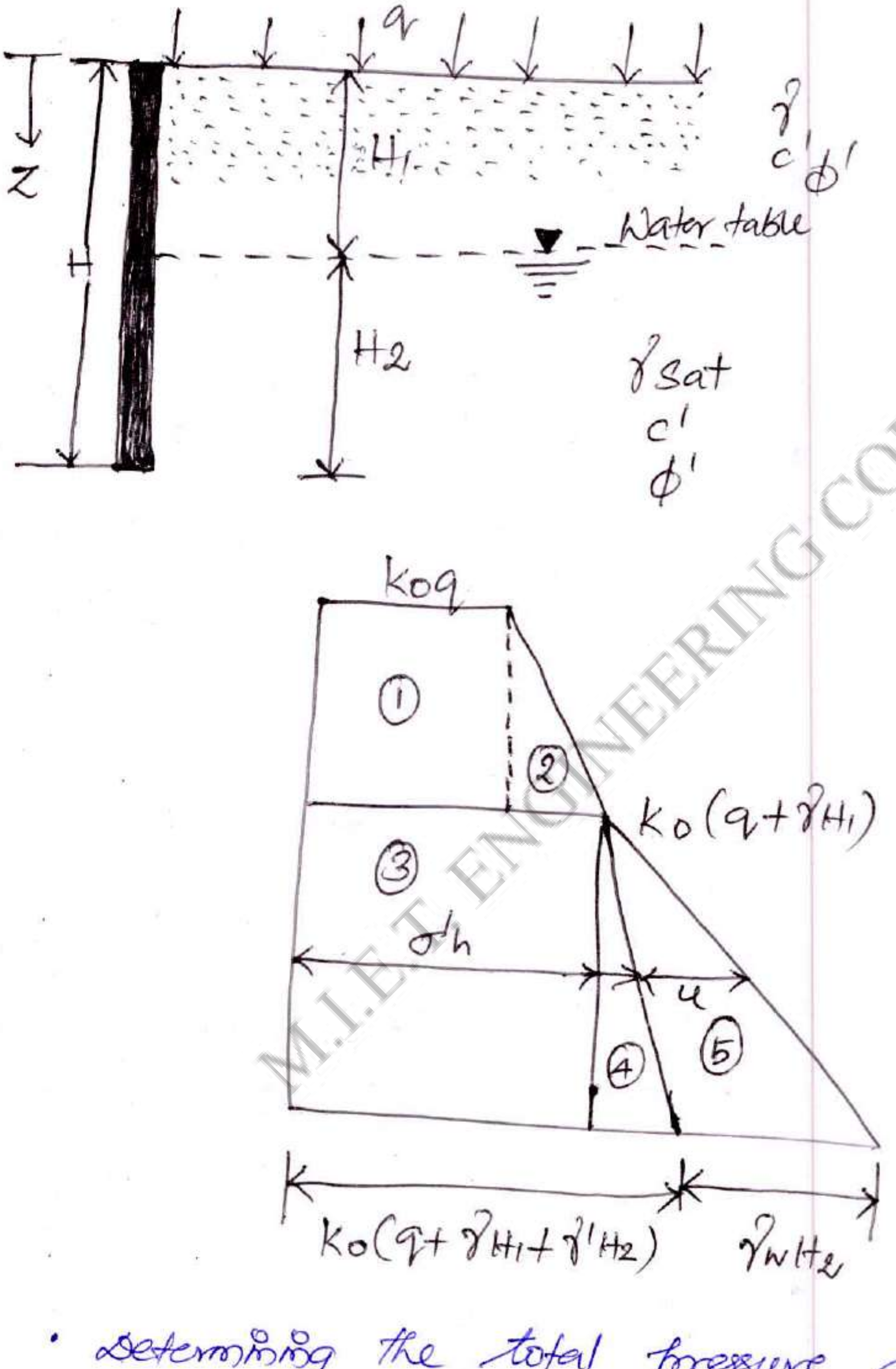
- If the water table is located at a depth $z < H$, the at-rest pressure.
- To be somewhat modified, if the effective unit weight of soil below the water table equals $\gamma' \cdot (\gamma_{sat} - \gamma_w)$

$$\text{At } z = 0, \quad \sigma_h' = K_o\sigma_o' = K_o q$$

$$\text{At } z = H_1, \quad \sigma_h' = K_o\sigma_o' = K_o(q + \gamma H_1)$$

$$\text{At } z = H_2, \quad \sigma_h' = K_o\sigma_o' = K_o(q + \gamma H_1 + \gamma' H_2)$$

Note that in the preceding equations σ_o' and σ_h' are effective vertical and horizontal pressures respectively.



- Determining the total pressure distribution on the wall requires adding the hydrostatic pressure u, which is zero from $z=0$ to $z=H_1$ and is $H_2\gamma_w$ at $z=H_2$.

- The Variation of σ'_h and u with depth..
- Hence, the total force per unit length of the wall can be determined from the area of the pressure.

$$P_0 = A_1 + A_2 + A_3 + A_4 + A_5$$

Where A = area of the pressure,

$$P_0 = K_0 q H_1 + \frac{1}{2} K_0 \gamma H_1^2 + K_0 (q + \gamma H_1) H_2 + \frac{1}{2} K_0 \gamma' H_2^2 + \frac{1}{2} \gamma_w H_2^2.$$

Suggested Questions / Assignments / Home works / any other

1. Explain in detail about Lateral Earth pressure at rest in Retaining wall?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil mechanics and foundation	B.C. Punmia	Laxmi publication pvt ltd, new delhi 2017

Any other suggested Materials

Lecture No. 39.

Topic(s) to be covered	Rankine Active Earth pressure

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1	Frictionless, Mohr's circle rankine active pressure, active pressure Coefficient	Understand

Teaching Learning Material	Student Activity
Chalk & Talk	Listen

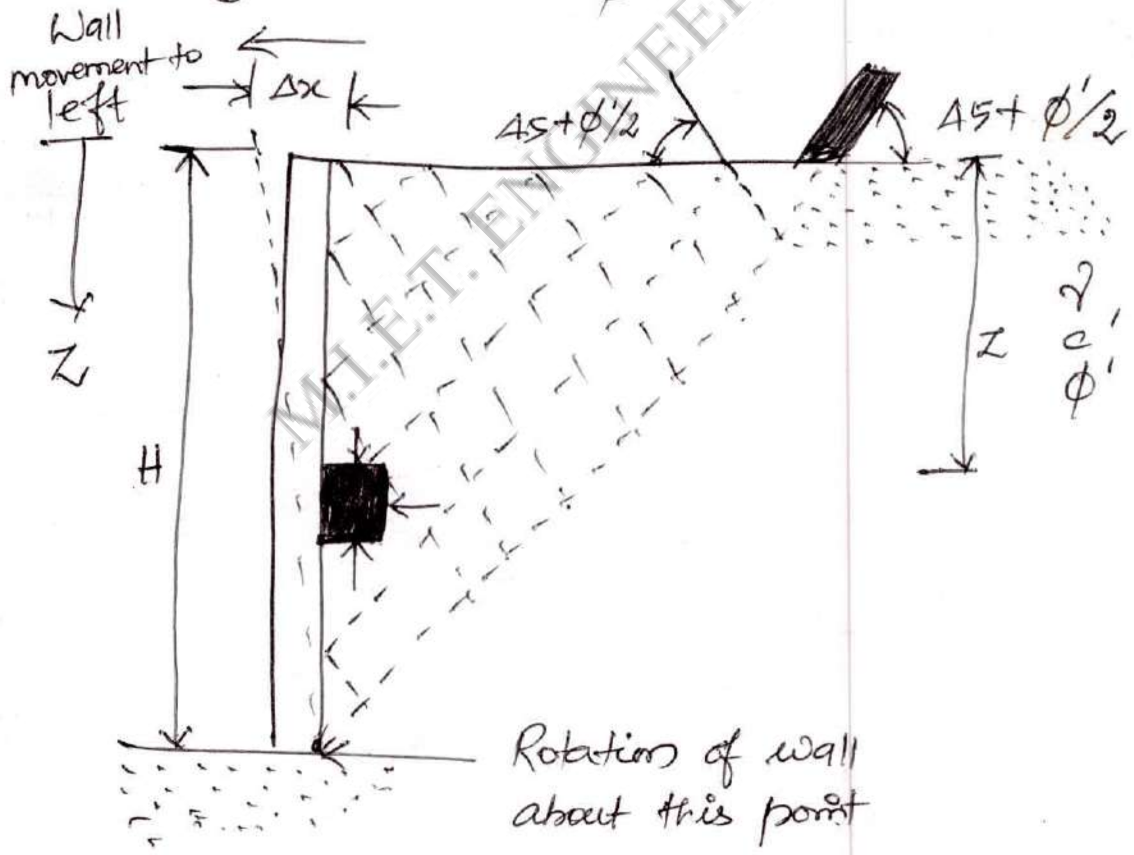
Lecture Notes

- The lateral earth pressure involves walls that do not yield at all.
- If a wall tends to move away from the soil a distance Δx.
- The soil pressure on the wall at any depth will decrease, For a wall that is frictionless,

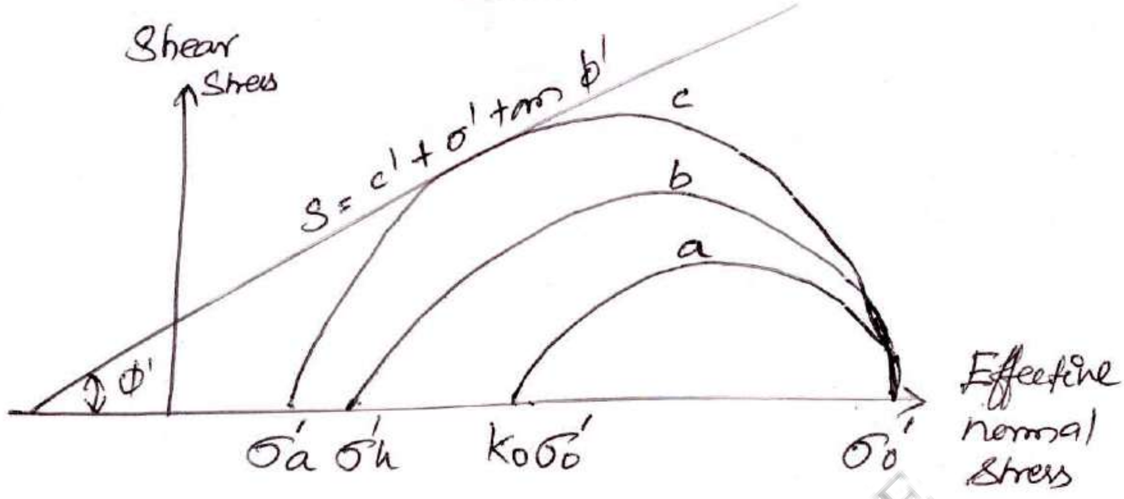
the horizontal stress, σ'_h, at depth z will equal $K_o \sigma'_o (= K_o \gamma z)$ when Δx is zero.

- However, with $\Delta x > 0$, σ'_h will be less than $K_o \sigma'_o$.
- The mohr's circles corresponding to wall displacement of $\Delta x = 0$ and $\Delta x > 0$, circles a and b respectively.
- If the displacement of the wall, Δx, continues to increase, the corresponding Mohr's circle eventually will just touch the mohr-Coulomb failure envelope defined by the equation

$$S = c' + \sigma' \tan \phi'$$



Rankine Active pressure



- The circle marked 'c' in the represents the failure condition in the soil mass, the horizontal stress then equal σ'_a, referred to as the Rankine active pressure.
- The slip lines (failure planes) in the soil mass will then make angles of $\pm(45 + \phi'/2)$ with the horizontal.

$$\sigma_1' = \sigma_3' \tan^2\left(45 + \frac{\phi'}{2}\right) + 2c' \tan\left(45 + \frac{\phi'}{2}\right)$$

Major principal stress: $\sigma_1' = \sigma_0'$

and

Minor principal stress $\sigma_3' = \sigma_a'$

$$\sigma_0' = \sigma_a' \tan^2\left(45 + \frac{\phi'}{2}\right) + 2c' \tan\left(45 + \frac{\phi'}{2}\right)$$

$$\sigma_a' = \frac{\sigma_o'}{\tan^2(45+\frac{\phi'}{2})} - \frac{2c'}{\tan(45+\frac{\phi'}{2})}$$

(or)

$$\sigma_a' = \sigma_o' \tan^2(45-\frac{\phi'}{2}) - 2c' \tan(45-\frac{\phi'}{2})$$

$$= \sigma_o' K_a - 2c'\sqrt{K_a}.$$

Where $K_a = \tan^2(45-\phi'/2)$ = Rankine Active pressure coefficient.

- The Variation of the active pressure with depth for the wall.
- Note that $\sigma_o' = 0$ at $z=0$ and $\sigma_o' = \gamma H$ at $z=H$.
- The pressure distribution that at $z=0$ the active pressure equals $-2c\sqrt{K_a}$, indicating a tensile stress that decreases with depth and becomes zero at a depth $z = z_c$.

$$\gamma z_c K_a - 2c'\sqrt{K_a} = 0$$

$$z_c = \frac{2c'}{\gamma\sqrt{K_a}}$$

- The depth z_c is usually referred to as the depth of tensile crack, because the tensile stress in the soil will eventually cause a crack along the soil - wall interface.

The total Rankine active force per unit length of the wall before the tensile crack occurs is

$$P_a = \int_0^H \sigma_a' dz = \int_0^H \gamma z k_a dz - \int_0^H 2c' \sqrt{k_a}\, dz$$

$$= \frac{1}{2}\gamma H^2 k_a - 2c' H \sqrt{k_a}$$

After the tensile crack appears, the force per unit length on the wall will be caused only by the pressure distribution between depths $z = z_c$ and $z = H$

$$P_a = \frac{1}{2}(H - z_c)(\gamma H k_a - 2c' \sqrt{k_a})$$

(or)

$$P_a = \frac{1}{2}\left(H - \frac{2c'}{\gamma\sqrt{k_a}}\right)(\gamma H k_a - 2c' \sqrt{k_a})$$

Suggested Questions / Assignments / Home works / any other

1. What is Rankine active Earth pressure?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundation	B.C. Punmia	Laxmi publication pvt Ltd new delhi 2017

Any other suggested Materials

Lecture No. 40.

Topic(s) to be covered	Rankine Active Earth pressure for inclined Backfill.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Active force before the tensile crack appeared, active force after the tensile crack is appeared	understand & Apply

Teaching Learning Material	Student Activity
Chalk and Talk	Listen & apply

Lecture Notes

- If the backfill of a frictionless retaining wall is a granular soil ($c'=0$) and rises at an angle α with respect to the horizontal, the active pressure co-efficient may be in the form of

$$K_a = \cos\alpha \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}$$

ϕ' = angle of friction of soil.

At any depth z, the Rankine active pressure is as

$$\sigma_a' = \gamma z K_a$$

The total force per unit length of the wall is

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

· The direction of the resultant force Pa is inclined at an angle . a with the horizontal and intersects the wall at a distance H/3 from the base of the wall.

· The values of Ka (active earth pressure) for various values of α and ϕ'.

· A 6m high Retaining wall is to support a soil with unit weight γ = 17.4 kN/m³, soil friction angle ϕ' = 26; and Cohesion c' = 14.36 kN/m². Determine the Rankine active force per unit length of the wall both before and after the tensile crack occurs, and determine the line of action of the resultant in both cases.

$\phi = 26°$

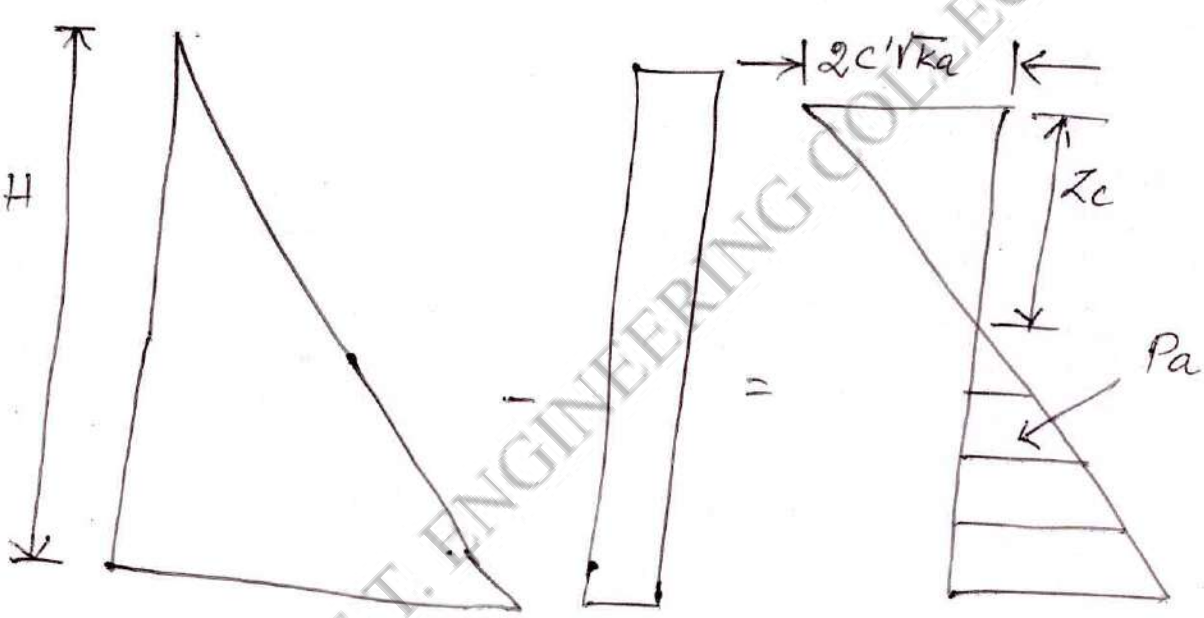
$\phi' = 26^\circ$

$K_a = \tan^2\left(45 - \frac{\phi'}{2}\right)$

$= \tan^2(45-13) = 0.39$

$\sqrt{K_a} = 0.625$

$\sigma_a' = \gamma H K_a - 2c'\sqrt{K_a}$



At $z=0$, $\sigma_a' = -2c'\sqrt{K_a} = -2(14.36)(0.625)$

$= -17.95\ kN/m^2$

and

At $z = 6m$: $\sigma_a' = (17.4)(6)(0.39) - 2(14.36)(0.625)$

$= 40.72 - 17.95$

$= 22.77\ kN/m^2$

Active force before the tensile crack appeared

$$P_a = \frac{1}{2}\gamma H^2 K_a - 2c' H\sqrt{K_a}$$

$$= \frac{1}{2}(6)(40.72) - (6)(17.95)$$

$$= 122.16 - 107.7$$

$$= 14.46 \text{ kN/m}$$

The line of action of the resultant can be determined by taking the moment of the area of the pressure about the bottom of the wall,

$$P_a \bar{z} = (122.16)(6/3) - (107.7)(6/2)$$

Thus,

$$\bar{z} = \frac{244.32 - 323.1}{14.46}$$

$$= -5.45 \text{ m}$$

Active force after the tensile crack appeared

$$z_c = \frac{2c'}{\gamma\sqrt{K_a}}$$

$$= \frac{2(4.36)}{(17.4)(0.625)}$$

$$= -2.64 \text{ m}$$

$$P_a = \frac{1}{2}(H - Z_c)(\gamma H K_a - 2c'\sqrt{K_a})$$

$$= \frac{1}{2}(6 - 2.64)(22.77)$$

$$= 38.25 \text{ kN/m}$$

. It indicates that the force $P_a = 38.25$ kN/m is the area of the hatched triangle.

. Hence, the line of action of the resultant will be located at a height $\bar{z}$

$$\bar{z} = (H - Z_c)/3$$

Above the bottom of the wall

$$\bar{z} = \frac{6 - 2.64}{3}$$

$$= 1.12 \text{ m.}$$

Suggested Questions / Assignments / Home works / any other

1. Describe the Rankine active force in Retaining Wall?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundation Engineering	K.R. Arora	Standard publishers and distributors New delhi 2017

Any other suggested Materials

Lecture No. 41

Topic(s) to be covered	Coulomb's Active Earth pressure

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
Lo1 Lo2	Active Earth-pressure Co-efficient Ka, Coulomb's active pressure	Understand & Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen and Apply

Lecture Notes

Coulomb's Active Earth pressure:

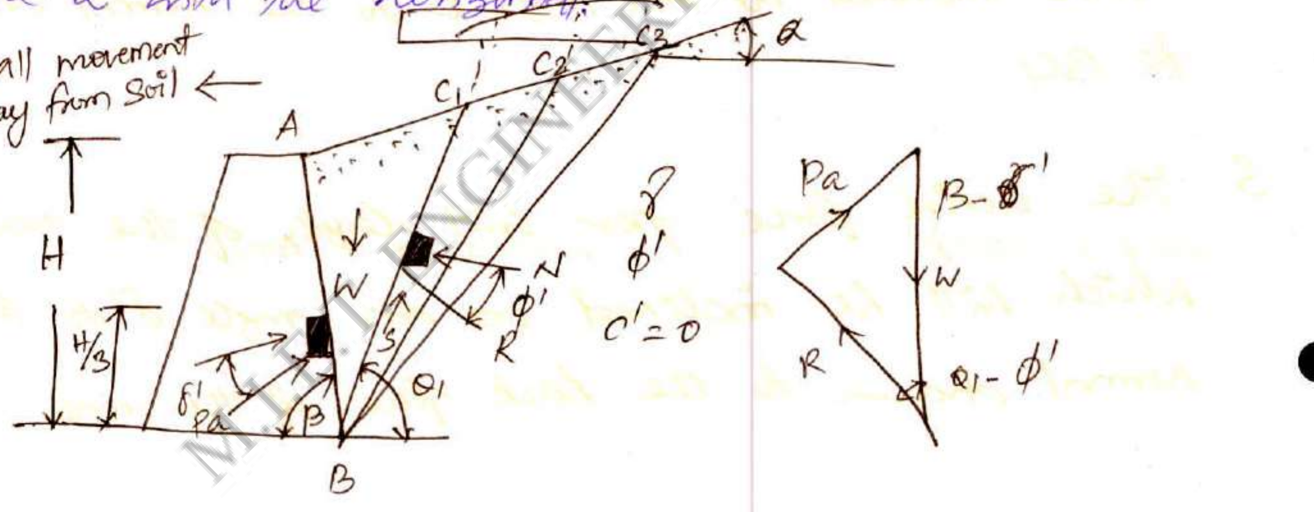
- Coulomb's Active Earth pressure is the lateral earth pressure on a retaining wall with granular soil backfill.

- To apply coulomb's active earth pressure theory let us consider a retaining wall with its back face inclined at an angle β with the horizontal

Active Earth pressure Co-efficient.

↓ α deg \ φ' (deg) →	28	30	32	34	36	38	40
0	0.361	0.333	0.307	0.283	0.260	0.238	0.217
5	0.366	0.337	0.311	0.286	0.262	0.240	0.219
10	0.380	0.350	0.321	0.294	0.270	0.246	0.225
15	0.409	0.373	0.341	0.311	0.283	0.258	0.235
20	0.461	0.419	0.374	0.338	0.306	0.274	0.250
25	0.573	0.494	0.434	0.385	0.343	0.307	0.275

- The backfill is a granular soil that slopes at an angle α with the horizontal.



Coulomb's active pressure

- Also, let δ' be the angle of friction between the soil and the wall (i.e) the angle of wall friction.
- Under the active pressure ~~between the soil and~~ wall will move away from the soil mass (to the

left in the figure).

- Coulomb assumed that, in such a case, the failure surface in the soil mass would be a plane (eg. BC_1, BC_2)
- So, to find the active force, consider a possible soil failure wedge ABC_1. The forces acting on this wedge (per unit length at right angles to the cross section)

1. The weight of the wedge, W.
2. The resultant R, of the normal and resisting Shear forces along the surface, BC_1. The force R will be inclined at an angle ϕ' to the normal drawn to BC_1.
3. The active force per unit length of the wall, Pa which will be inclined at an angle δ' to the normal drawn to the back face of the wall.

- For equilibrium purposes, a force triangle can be drawn,
- Note that θ_1 is the angle that BC_1 makes with the horizontal.
- Because the magnitude of W, as well as the directions of all of three forces are known, the value of Pa can now be determined.

- Similarly, the active forces of other trial wedges, such as ABC_2, ABC_3, can be determined.
- The maximum value of P_a thus determined is Coulomb's active force, is

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

where,

K_a = Coulomb's active earth pressure co-efficient

$$= \frac{\sin^2(\beta + \phi')}{\sin^2\beta \sin(\beta - \delta')\left[1 + \sqrt{\frac{\sin(\phi' + \delta')\sin(\phi' - \alpha)}{\sin(\beta - \delta')\sin(\alpha - \beta)}}\right]^2}$$

and H = height of the wall.

- The values of the active pressure coefficient, K_a for a vertical retaining wall ($\beta = 90°$) with horizontal backfill ($\alpha = 0°$).
- Note that the line of the action of the resultant force (P_a) will act at a distance $H/3$ above the base of the wall and will be inclined at an angle δ' to the normal drawn to the back of the wall.

• In the actual design of retaining walls, the value of the wall friction angle δ' is assumed to be between φ'/2 and $\frac{2}{3}$φ'.

• The active earth pressure coefficients for various values of φ', α and β with δ' = ½ φ' and ⅔ φ' are respectively. These coefficients are very useful design considerations.

Suggested Questions / Assignments / Home works / any other

1. Define Coulombs active pressure?
2. What is active pressure Co-efficient?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Text Book of Soil mechanics and foundation Engineering	V.N.S. Murthy	CBS publishers distribution Ltd new delhi 2014

Any other suggested Materials

Lecture No. 42.

Topic(s) to be covered	Rankine passive Earth pressure

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	passive force on frictionless inclined retaining wall, passive earth pressure in Retaining wall	understand and Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen and apply

Lecture Notes

- A vertical frictionless retaining wall with a horizontal backfill.
- At depth z, the effective vertical pressure on a soil element is $\sigma_0' = \gamma z$.
- Initially, if the wall does not yield at all, the lateral stress at that depth will be $\sigma_h' = K_0 \sigma_0'$
- This state of stress is illustrated by Mohr's

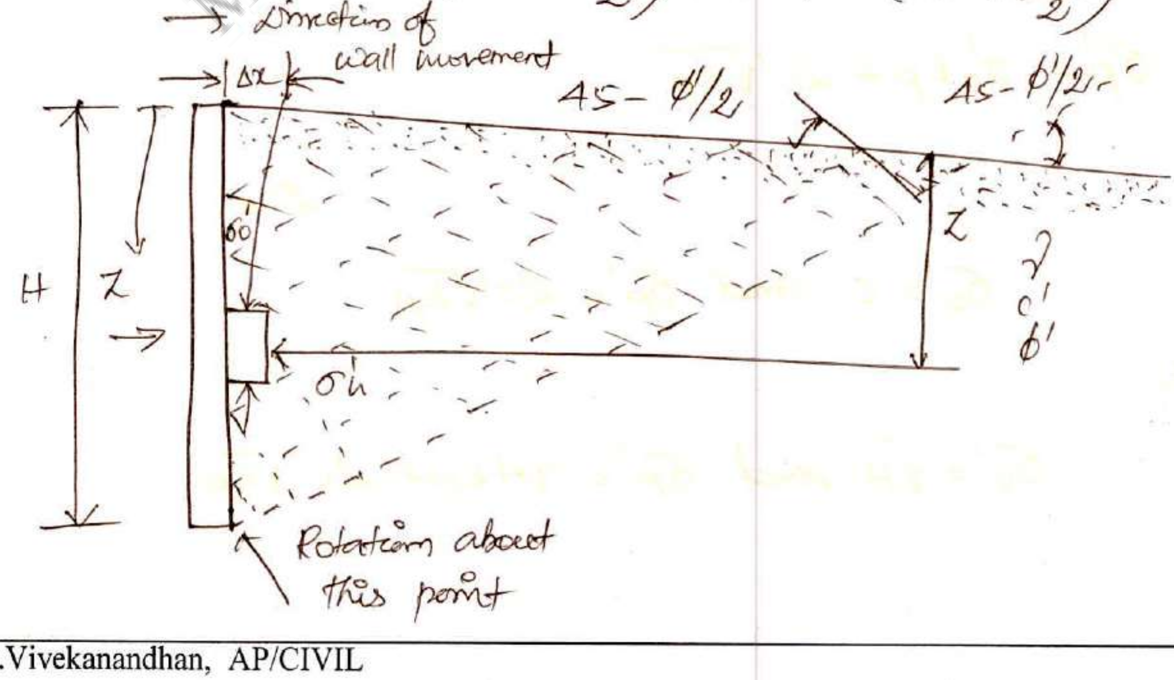
circle. Now, if the wall is pushed into the soil mass by an amount Δx, the vertical stress at depth z will stay the same: however, the horizontal stress will increase.

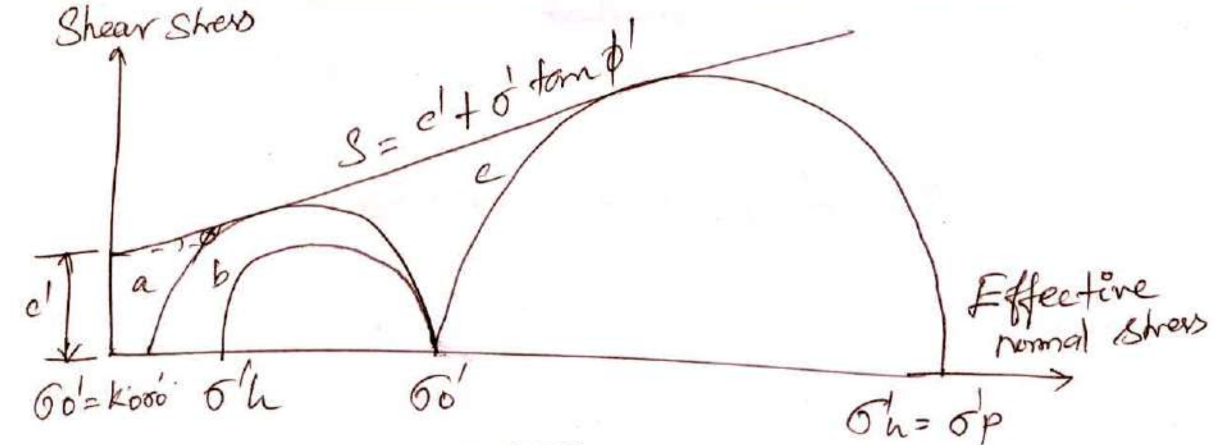
- Thus, σ'_h will be greater than $K_o \sigma'_o$. The state of stress can now be represented by the Mohr's circle b. If the wall moves farther inward (i.e) Δx is increased still more), the stresses at depth z will ultimately reach the state represented by Mohr's circle c.

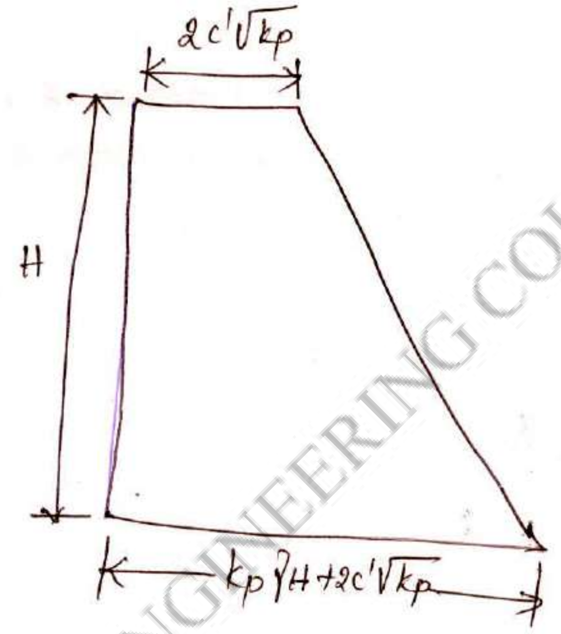
- Note that this Mohr's circle touches the Mohr-Coulomb failure envelope, which implies that the soil behind the wall will fail by being pushed upward.

The horizontal stress σ'_h, at this point is referred as the Rankine passive pressure, $\sigma'_h = \sigma'_p$.

$$\sigma'_p = \sigma'_o \tan^2\left(45 + \frac{\phi'}{2}\right) + 2c' \tan\left(45 + \frac{\phi'}{2}\right)$$







k_p = Rankine passive earth pressure Co-efficient

$$= \tan^2\left(45 + \frac{\phi'}{2}\right)$$

$$\sigma_p' = \sigma_0' k_p + 2c'\sqrt{k_p}$$

The passive pressure for the wall $z = 0$

$$\sigma_0' = 0 \text{ and } \sigma_p' = 2c'\sqrt{k_p}$$

$Z = H,$

$$\sigma_0' = \gamma H \text{ and } \sigma_p' = \gamma H k_p + 2c'\sqrt{k_p}$$

The passive force per unit length of the wall can be determined from the area ~~failu~~ of the pressure

$$P_p = \frac{1}{2} \gamma H^2 K_p + 2c' H \sqrt{K_p}$$

The approximate magnitudes of the wall movements, Δx, required to develop failure under passive condition

Soil type	Wall movement for passive condition Δx
Dense sand	0.005H
Loose sand	0.01 H
Stiff clay	0.01H
Soft clay	0.05 H

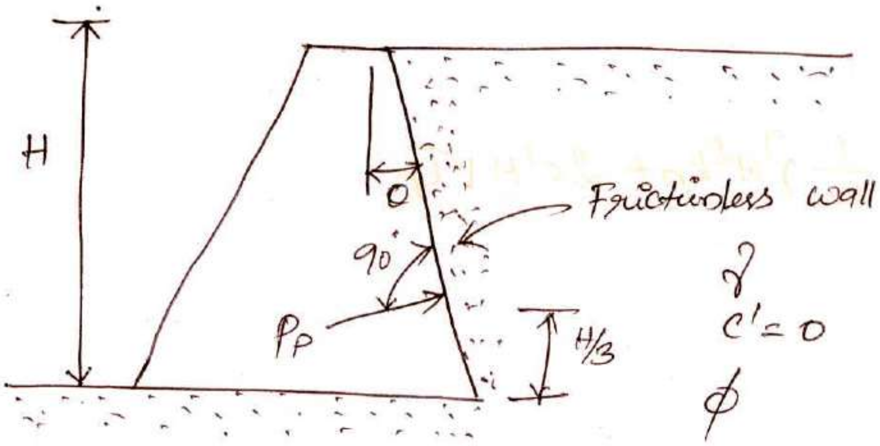
If the backfill behind the wall is granular soil (i.e) $c' = 0$, the passive force per unit length of the wall will be

$$P_p = \frac{1}{2} \gamma H^2 K_p$$

- The passive force on a frictionless inclined retaining wall, with a horizontal granular backfill ($c' = 0$) can also be expressed.

$$P_p = \frac{1}{2} \gamma H^2 K_p$$

- The variation of K_p for this case with wall inclination θ and effective soil friction angle ϕ'



passive force on a frictionless inclined Retaining wall

Suggested Questions / Assignments / Home works / any other

1. What is Rankine passive Earth pressure?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundation	B.C. Punmia	Laxmi publications pvt ltd. new delhi, 2017

Any other suggested Materials

Lecture No. 43.

Topic(s) to be covered	Rankine passive force.

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Rankine passive force, Earth pressure, inclined backfill, and Coulomb's passive earth pressure	understand & Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & apply

Lecture Notes

A 3m high wall. Determine the Rankine passive force per unit length of the wall.

For the top soil layer,

$$K_{p(1)} = \tan^2\left(45 + \frac{\phi_1'}{2}\right)$$

$$= \tan^2(45+15)$$

$$= 3$$

For the bottom soil layer,

$$K_{p(2)} = \tan^2\left(45 + \frac{\phi_2'}{2}\right)$$

$$= \tan^2(45 + 13)$$

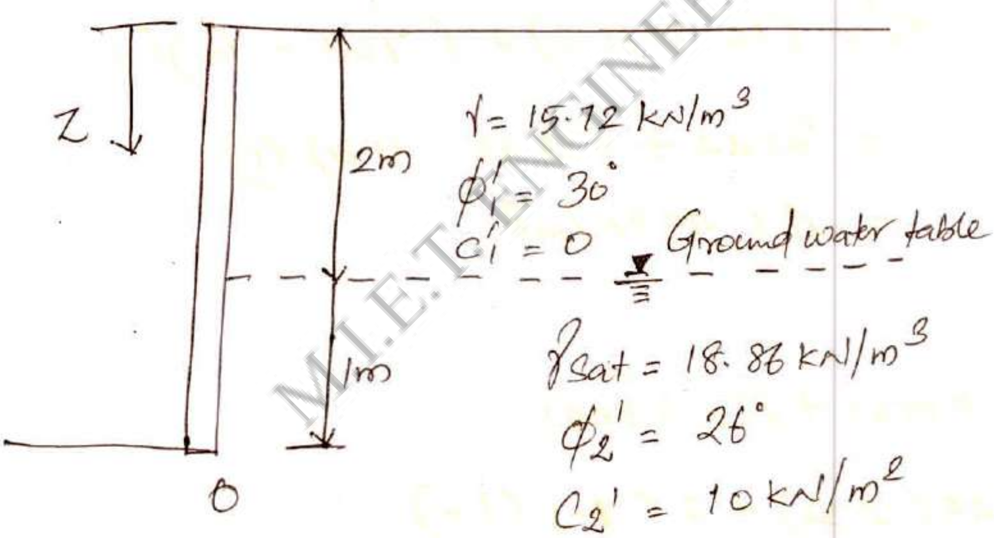
$$= 2.56$$

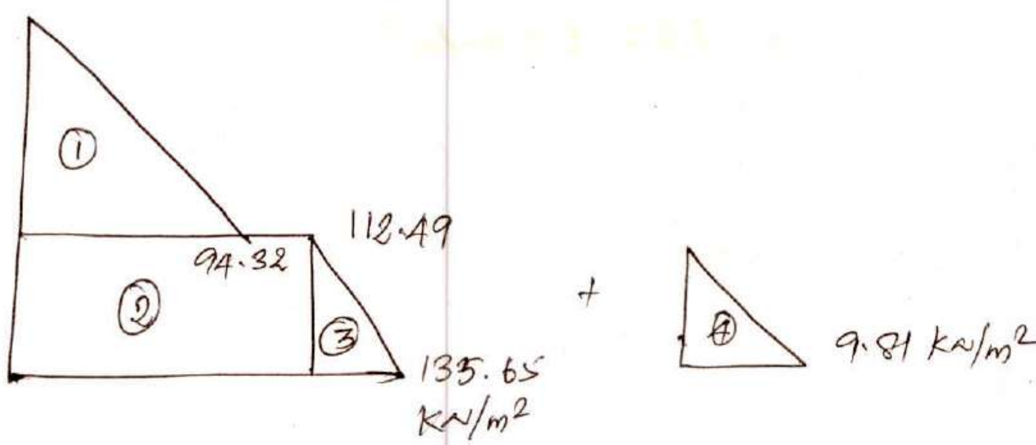
$$\sigma_p = \sigma_o' K_p + 2c'\sqrt{K_p}$$

Where σ_o' = Effective vertical stress

At $z = 0$, $\sigma_o' = 0$, $c_1' = 0$, $\sigma_p = 0$

At $z = 2m$, $\sigma_o' = (15.72)(2) = 31.44\ kN/m^2$, $c_1' = 0$





So, for the top soil layer,

$$\sigma_p' = 31.44 k_{p(1)} + 2(0)\sqrt{k_p}$$

$$= 31.44(3)$$

$$= 94.32 \text{ kN/m}^2$$

At this depth, that is $z_1 = 2m$, for the bottom soil layer,

$$\sigma_p' = \sigma_o' k_{p(2)} + 2c_2' \sqrt{k_{p(2)}} = 31.44(2.56) + 2(10)\sqrt{2.56}$$

$$= 80.49 + 32 = 112.49 \text{ kN/m}^2$$

Again,

$$\text{At } z = 3m, \ \sigma_o' = (15.72)(2) + (\gamma_{sat} - \gamma_w)(1)$$

$$= 31.44 + (18.86 - 9.81)(1)$$

$$= 40.49 \text{ kN/m}^2$$

Hence,

$$\sigma_p' = \sigma_o' k_{p(2)} + 2c_2' \sqrt{k_{p(2)}}$$

$$= 40.49(2.56) + 2(10)(1.6)$$

$$= 135.65 \text{ kN/m}^2.$$

Rankine passive Earth pressure: Inclined Backfill

- A frictionless vertical retaining wall with a granular backfill ($c' = 0$), Rankine passive pressure at any depth can be determined in a manner similar to that done in the case of active pressure.

$$\sigma_p' = \gamma z k_p$$

and the passive force is

$$P_p = \frac{1}{2} \gamma H^2 k_p$$

Where,

$$k_p = \cos\alpha \frac{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi'}}{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi'}}$$

As in the case of the active force, the resultant force, P_p is inclined at an angle α with the horizontal and intersects the wall at a distance H/3 from the bottom of the wall. The values of kp (the passive earth pressure co-efficient) for various values of α and ϕ'.

Coulomb's passive Earth pressure:

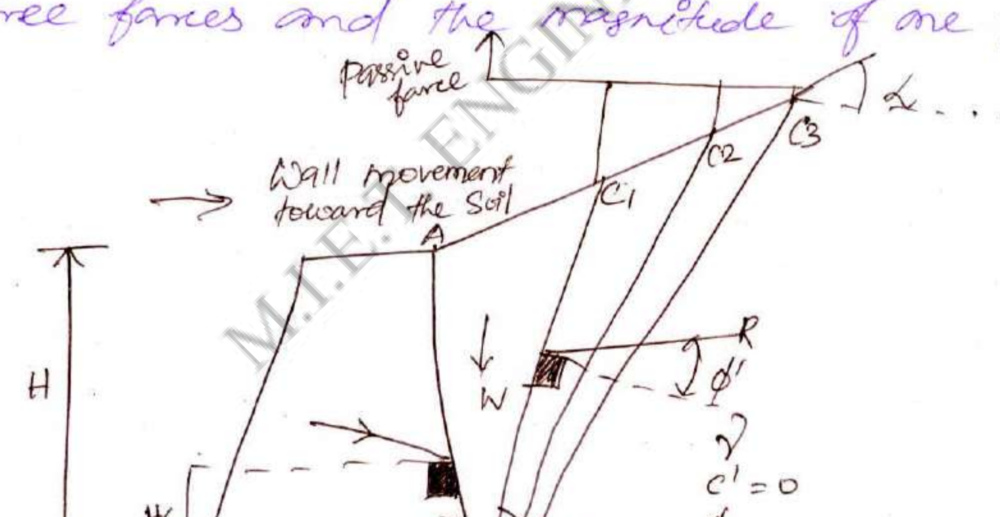
- An analysis for determining the passive earth pressure (ie) (when the wall moves into the soil mass) for walls possessing friction (δ' = angle of wall friction) and retaining a granular backfill material similar to that

- To understand the determination of Coulomb's passive force, P_p, consider the wall.
- As in the case of active pressure, Coulomb's assumed

is the that the potential failure surface in soil is a plane. For a trail failure wedge soil, such as ABC, the forces per unit length of the wall acting on the wedge are.

1. The weight of the wedge, W
2. The resultant, R, of the normal and shear forces on the plane BC, and
3. The passive force, P_P.

The force triangle at equilibrium for the trail wedge ABC, from this force triangle, the value of P_P can be determined, because the direction of all three forces and the magnitude of one force are known.



Coulomb's passive pressure:

Suggested Questions / Assignments / Home works / any other

1. What is Earth pressure?
2. Explain passive force earth pressure in inclined backfill in Retaining wall?

Text Books / Reference Books

S.No	Title	Author	Publisher
1.	Soil Mechanics and foundation	B.C. punmia	Laxmi publications pvt ltd, newdelhi 2017

Any other suggested Materials

Lecture No. 44.

Topic(s) to be covered	Stability of Retaining walls

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	proportioning Retaining walls, Applications of lateral Earth pressure Theories to design, Equivalent fluid method for Determination of Earth pressure	understand & Apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & apply.

Lecture Notes

Proportioning Retaining walls:

- In designing retaining walls, assume some of the dimensions called proportioning, such assumptions allow the engineer to check trail sections of the walls for stability.
- If the stability checks yield undesirable results the section can be changed and rechecked.

· The general proportions of various retaining wall components that can be used for initial checks.

· Note that the top of the stem of any retaining wall should not be less than about 0.3m for proper placement of concrete.

· The depth, D to the bottom of the base slab should be a minimum of 0.6m. However, the bottom of the base slab should be positioned below the seasonal frost line.

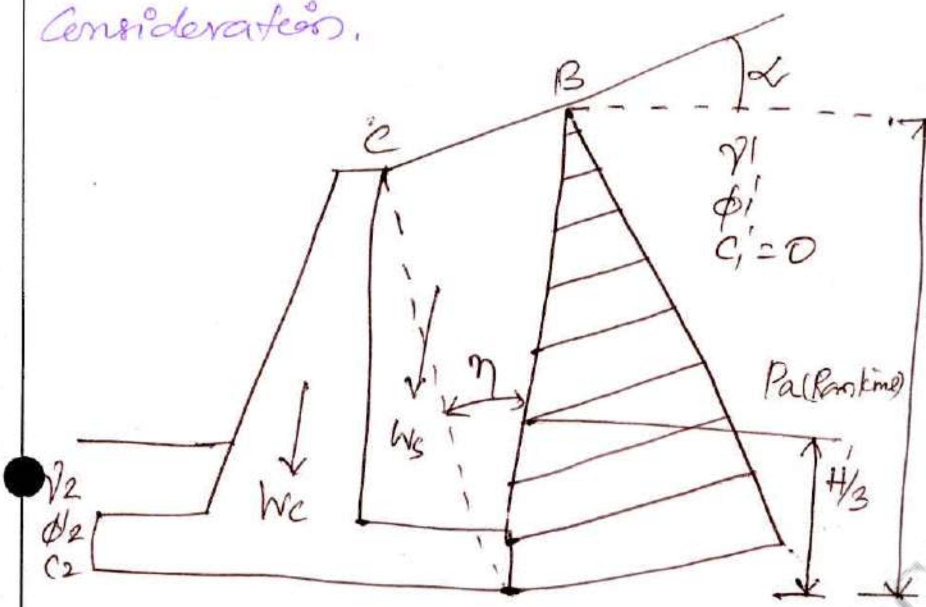
Application of lateral Earth pressure theories to design:

· The fundamental for calculating lateral earth pressure were to use these theories in design, several simple assumptions. In the case of cantilever walls, the use of Rankine earth pressure theory for stability checks involves drawing a vertical line AB through point A, located at the edge of the heel of the base slab.

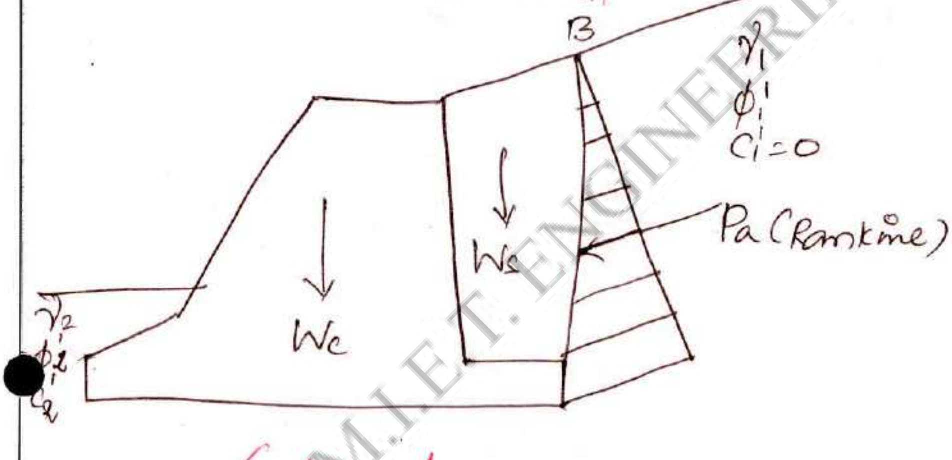
· The Rankine active condition is assumed to exist along the vertical plane AB. Rankine active earth pressure equations may then be used to calculate the lateral pressure on the face AB of the wall.

· In the analysis of the wall's stability, the force

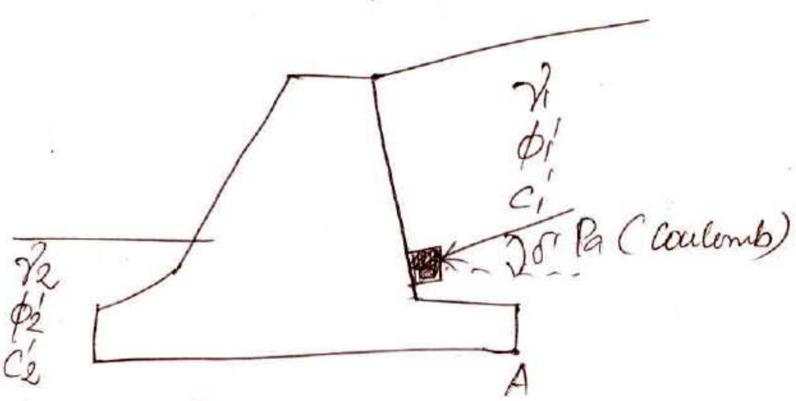
Pa (Rankine), the weight of soil above the heel, and the weight Wc of the concrete all should be taken into consideration.



Cantilever wall



Continued wall



Gravity wall

AC is not obstructed by the stem of the wall. The angle, η, that the line AC makes with the vertical is

$$\eta = 45 + \frac{\alpha}{2} - \frac{\phi'}{2} - \sin^{-1}\left(\frac{\sin\alpha}{\sin\phi'}\right)$$

A similar type of analysis may be used for gravity walls, however Coulomb's active earth pressure theory also may be used.

- If P_t is used, the only forces to be considered are Pa (Coulomb) and the weight of the wall, Wc.

- It will be necessary to know the range of the wall friction angle δ' with various types of backfill material.

Backfill Material	Range of δ' (deg)
Gravel	27-30
Coarse Sand	20-28
Fine sand	15-25
Stiff clay	15-20
Silty clay	12-16

In the case of ordinary retaining walls, water table problems and hence hydrostatic pressure are not encountered. Facilities for drainage from the soils that are retained are always provided.

Equivalent Fluid Method for Determination of Earth pressure:

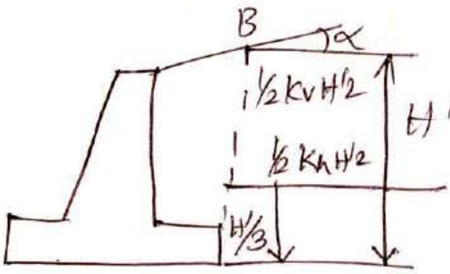
- The equivalent fluid method for determining earth pressure during the design of retaining walls
- This method assumes that the retaining wall is back filled with an "equivalent fluid".
- According to these charts, the horizontal force P_h and the vertical force P_v per unit length of the wall on the plane AB can be expressed as

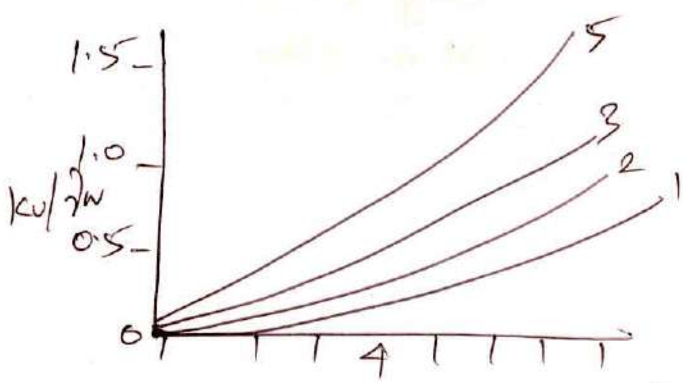
$$P_h = \frac{1}{2} K_h H'^2$$

and

$$P_v = \frac{1}{2} K_v H'^2$$

- Note that K_h and K_v will have a unit of kN/m³ and will be a function of the type of soil usually used for backfill.
- The types of soil referred to in backfills with plane surfaces.





Suggested Questions / Assignments / Home works / any other
1. Explain the types of stability in Retaining walls?

	Text Books / Reference Books		
S.No	**Title**	**Author**	**Publisher**
1.	Soil Mechanics and Foundation?	B.C. punmia	Laxmi publication pvt. ltd. newdelhi 2018

Any other suggested Materials

Lecture No. 45.

Topic(s) to be covered	Construction Joints and Drainage from Backfill

	Lecture Outcome (LO) At the end of this lecture, students will be able to	Bloom's Level
LO1 LO2	Construction Joints, Contraction Joints, Expansion Joints, Drainage from the backfill	understand & apply

Teaching Learning Material	Student Activity
Chalk & Talk	Listen & apply

Lecture Notes

Construction Joints:

- Construction Joints are vertical and horizontal joints that are placed between two successive pours of concrete. To increase the shear at the joints, key may be used.
- If keys are not used, the surface of the first pour is cleaned and roughened before

the next pour of concrete.

Contraction joints:

Contraction joints are vertical joints (grooves) placed in the face of a wall (from the top of the base slab to the top of the wall) that allow the concrete to shrink without noticeable harm. The grooves may be about 6 to 8 mm wide and 12 to 16 mm deep.

Expansion joints:

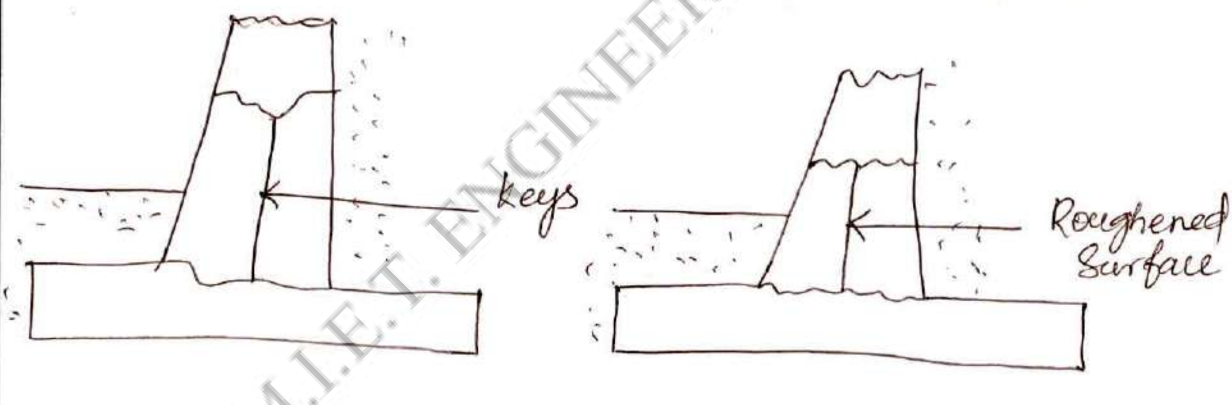
Expansion joints allow for the expansion of concrete caused by temperature changes, vertical expansion joints from the base to the top of the wall may also be used.

. These joints may be filled with flexible joint fillers. In most cases, horizontal reinforcing steel bars running across the stem are continuous through all joints. The steel is greased to allow the concrete to expand.

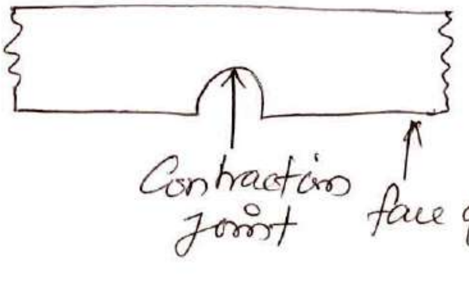
Drainage from the Backfill:

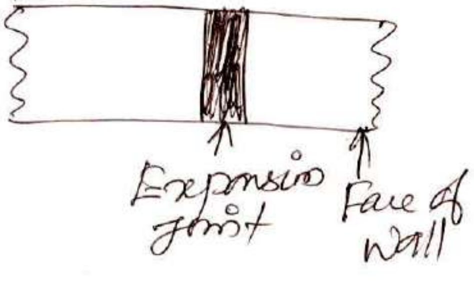
- The result of rainfall or other wet conditions, the backfill material for a retaining wall may become saturated, thereby increasing the pressure on the wall and perhaps creating an unstable condition.

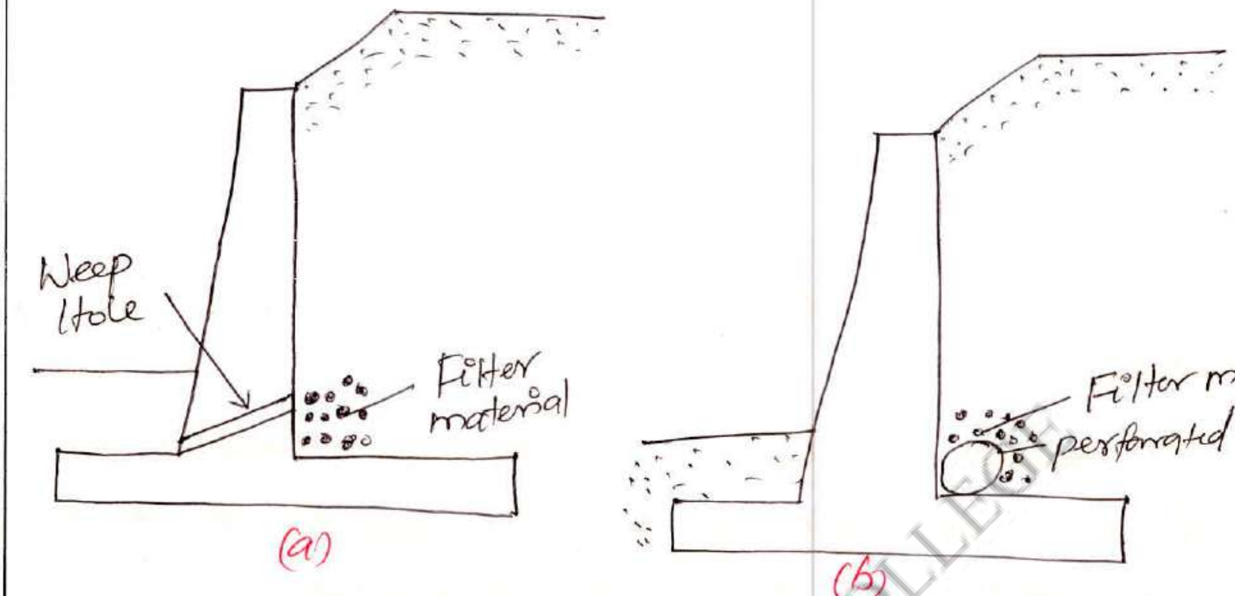
- For this reason, adequate drainage must be provided by means of weep holes a perforated grating or castable drainage pipes.



Construction joints







Drainage provisions for the backfill of a retaining wall (a) by weep holes, (b) by a perforated drainage pipe.

- When provided, weep holes should have a minimum diameter of about 0.1 m and be adequately spaced. Note that there is always a possibility that back-fill material may be washed into weep holes or drainage pipes and ultimately clog them.
- Thus a filter material needs to be placed behind the weep holes or around the drainage pipes, as the case may be geotextiles now serve

that purpose.

- Two main factors influence the choice of filter material. The grain size distribution of the materials should be such that

(a) the soil to be protected is not washed into the filter.

(b) excessive hydrostatic pressure head is not created in the soil with a lower hydraulic conductivity (in this case, the backfill material).

$$\frac{D_{15(F)}}{D_{85(B)}} < 5 \quad \text{to satisfy condition}$$

$$\frac{D_{15(F)}}{D_{15(B)}} > 4 \quad \text{to satisfy condition}$$

- In these relations, the subscripts F and B refer to the filter and the base material (i.e. the backfill soil), respectively.

- Also, D_{15} and D_{85} refer to diameter through which 15% and 85% of the soil (filter or base) will pass.

Suggested Questions / Assignments / Home works / any other
1. What are all the types of joints in Retaining wall? 2. What is Expansion joint in Retaining wall?

	Text Books / Reference Books		
S.No	Title	Author	Publisher
1.	Soil Mechanics and Foundation	B.C. Punmia	Laxmi publication pvt ltd, New delhi., 2017

Any other suggested Materials