Chapter 6

Seepage Analysis, Stress Distribution and Compaction

CHAPTER HIGHLIGHTS

- *Introduction*
- *Seepage analysis*
- *Characteristic of flow net*
- *Uses of flow net*
- *Flow Net in anisotropic soils*
- *Flow net in a non-homogeneous soil mass*
- *Flow net in a non-homogeneous soil*
- *Flow net in earth dams*
- *Stresses due to applied loads*

Introduction

In this chapter, the concept of seepage analysis and the stresses due to applied loads are discussed. This chapter also outlines the concept of compaction and optimum levels of moisture content.

Seepage Analysis

- Seepage is the flow of water under gravitational force in a permeable medium.
  1. **Flow line:** The path taken by a water particle is represented by a flow line.
  2. **Equipotential line:** The lines connecting the points of equal total head is known as a equipotential line.
  3. **Flow net:** Flow lines and equipotential lines together form a flow net. Flow net gives a pictorial representation of the path taken by water particles and head variation along the path.

Characteristic of Flow Net

1. A flow line and equipotential line always should be at right angles.
2. The discharge between any two adjacent flow lines to be constant.
3. The drop in head between adjacent equipotantial lines is constant.
4. The ratio of length and width of each field is constant, that is, flow net consists of approximate squares.
   - **(i) Flow channel:** The space between two adjacent flow lines is known as a flow channel.
   - **(ii) Flow field:** The space between two adjacent flow lines and two adjacent equipotential lines is known as flow field.
   - **(iii) Equipotential drop:** The difference between two adjacent equipotentential lines is known as equipotential drop.

Uses of Flow Net

1. **Discharge:**

Total discharge, $\boxed{q = \dfrac{K \cdot h \cdot N_f}{N_d}}$

Where

K = Coefficient of permeability

H = Difference between upstream and downstream level

N_f = Number of flow channels

N_d = Number of potential drops

The ratio $\frac{N_f}{N_d}$ is a characteristic of the flow net. It is known as shape factor. It is independent of permeability of soil and depends only on the configuration or shape of soil mass.

2. **Total head:** The loss of head from one equipotential line to the next is $\frac{h}{N_d}$.

   Total head at any point (P);

$$h_p = h - n\Delta h$$

$$\boxed{h_p = h - n \times \left(\frac{h}{N_d}\right)}$$

3. **Pressure head:** The pressure head at any point is equal to total head minus the elevation head.
   - Pressure head at point p, $(h_p)_p$ = total head (h_p) – elevation head $(h_e)_p$

$$\boxed{(h_p)_p = h_p - (h_e)_p}$$

4. **Hydraulic gradient:** For any flow field, hydraulic gradient is given by:

$$\boxed{i = \frac{\Delta h}{\Delta L}}$$

Where
Δh = Loss of head
ΔL = Length of the flow field

Flow Net in Anisotropic Soils

The discharge through an anisotropic soil mass is given by:

$$\boxed{q = K'h\left(\frac{N_f}{N_d}\right)}$$

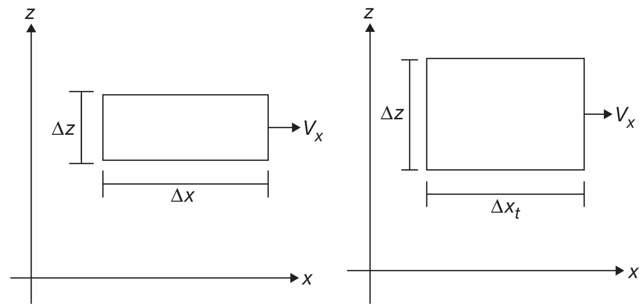
Where

$$\boxed{K' = \sqrt{K_X K_Z}}$$

- Laplace equation used in the construction of flow in isotopic soils is given by:

$$\boxed{\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial z^2} = 0}$$

- In case of anisotropic soils, Laplace equation is not valid.
- In order to satisfy the Laplace equation, original section has to be transformed by, $x_t = x\sqrt{\frac{K_z}{K_x}}$



(A) Original section **(B) Transformed section**

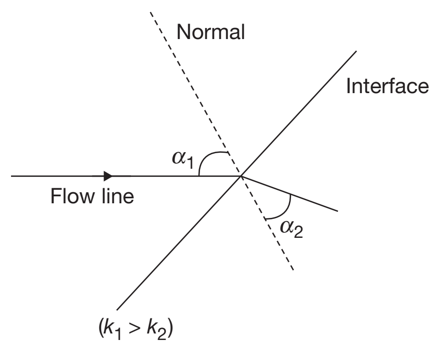
- Transformed section is obtained only by changing the 'x' value without change in any z-value.
- Laplace equation, in case of anisotropic soils, is given by:

$$\frac{\partial^2 h}{\partial x_t^2} + \frac{\partial^2 h}{\partial z^2} = 0$$

Flow Net in a Non-homogeneous Soil Mass

Let k_1 and k_2 be the coefficient of permeability of two soils.

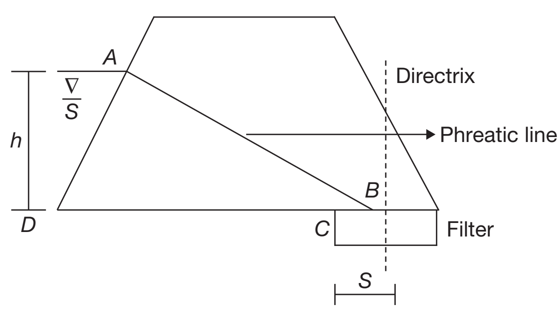
- In case of non-homogeneous soils, flow lines and equipotential lines get deflected at the interface.



Flow Net in a Non-homogeneous Soil

$$\boxed{\frac{k_1}{\tan\alpha_1} = \frac{k_2}{\tan\alpha_2}}$$

Flow Net in Earth Dams



- The line 'AB' is known as phreatic line or seepage line or top flow line.
- On phreatic line, pressure head is zero and total head is equal to the elevation head.
- Kozney's solution is used to find discharge through the body of earth dam.

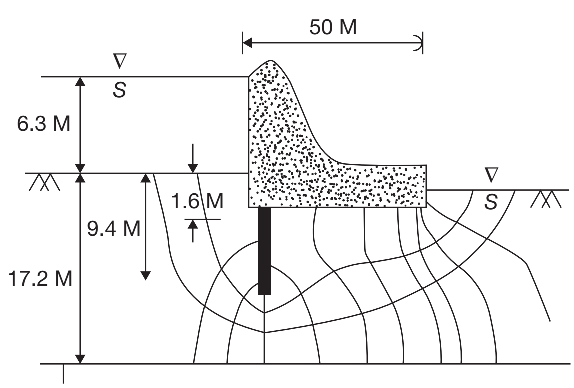
$$\boxed{q = k \cdot s}$$

Where, s is the distance between the focus and directory known as focal distance.

SOLVED EXAMPLES

Example 1

The flow net constructed for the dam is shown in the following figure. Taking the coefficient of permeability as 3.8 × 10^6 m/s, the quantity of flow (in cm^3/s) under the dam per metre of dam is:



Impermeable stratum

Solution

From the given figure:
Number of flow channel, $N_f = 3$
Number of equipotential drop, $N_d = 10$

Quantity of flow in cm^3/s = $q = \dfrac{K \cdot H \cdot N_f}{N_d}$

$$= 3.8 \times 10^{5m/s} \times 6.3 \times \frac{3}{10}$$

$$= 7.182 \times 10^{-6} \times 10^{6}\,\text{cm}^3/\text{s/n}$$

$$Q = 7182\ \text{cm}^3/\text{s/m}.$$

Stresses Due to Applied Loads

Boussinesq's Theory

1. Soil mass is an elastic continuum.
2. Soil is homogeneous, isotropic and semi-infinite.
3. Soil is weightless and free from residual stresses before the application of the load.
   - Vertical stress (σ_z) at point 'p' due to a point load 'Q' is given by:

$$\boxed{\sigma_z = \frac{3Q}{2\pi z^2}\left[\frac{1}{1+\left(\frac{r}{z}\right)^2}\right]^{\frac{5}{2}}}$$

z = Vertical distance of point below ground

r = Radial distance of point = $\sqrt{x^2 + y^2}$

$$\boxed{\sigma_z = I_B \frac{Q}{z^2}}$$

Where

$$\boxed{I_B = \frac{3}{2\pi\left[1+\left(\frac{r}{z}\right)^2\right]^{\frac{5}{2}}}}$$

The coefficient I_B is known as Boussinesq influence coefficient.

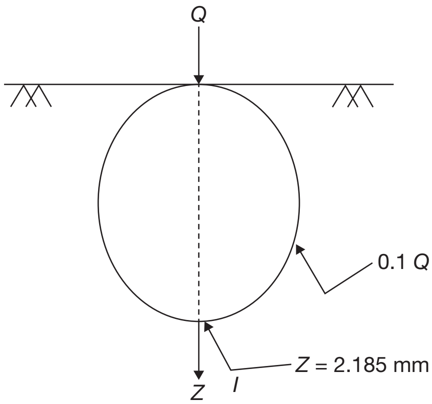
Important Points

1. σ_z does not depend on modulus of elasticity (E) and Poison's ratio (μ). Hence, these are applicable for every type of soils.
2. Applicable for shallow footings only.
3. The vertical stress decreases rapidly with an increase in $\left(\frac{r}{z}\right)$ ratio and becomes extremely small at $\frac{r}{z} = 5.0$ or more. Theoretically, σ_z is zero only at an infinite distance from the point load.
   - Radial shear stress $\boxed{\varsigma_{rz} = (\sigma_z)\frac{r}{z}}$

   At top, $z = 0$, $\zeta_{rz} = 0$.

Isobar Diagram

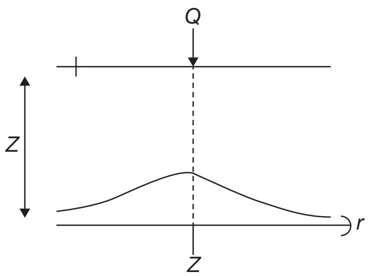
- An isobar is a curve joining the points of equal vertical stress intensity.
- An isobar is a spatial curved surface and has the shape of a lemniscate curve.
- It is symmetrical about the vertical axis passing through the load point.
- The zone within which stresses have significant effect on the settlement of structures is known as pressure bulb.
- The pressure inside an isobar is greater than the pressure present on that isobar.



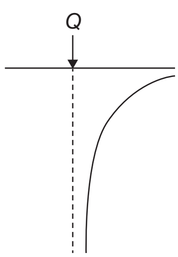
Isobar of 0.1Q

Stress Distribution

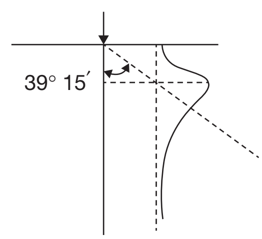
Vertical stress distribution on a horizontal plane:



Vertical stress distribution on a vertical plane:

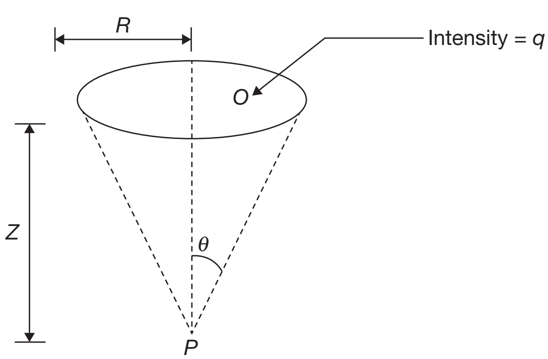


σ_z variation on vertical plane just below the load



σ_z variation on vertical at a distance '*r*' from load

Vertical Stress Under a Circular Loaded Area



Circular load

Vertical stress due to a circular loaded area is given by:

$$\boxed{\sigma_z = q\left[1-\left\{\frac{1}{1+\left(\frac{R}{z}\right)^2}\right\}^{\frac{3}{2}}\right]}$$

$$\sigma_z = q(1-\cos^3\theta)$$

Where

q = Intensity of load per unit area $\left(\frac{t}{m^2}\right)$.

R = Radius of loaded area.

Z = Vertical distance of the point below the centre of uniformly loaded circular area.

Newmark's Influence Charts

- To find the vertical stress, below the loaded are of any shape.
- The vertical stress at any point 'p' is given by:

$$\boxed{\sigma_z = Inq}$$

Where

I = Influence coefficient

n = Number of small area units covered by the plan

q = Intensity of load

- The point 'p' at which the vertical stress is required may be anywhere within or outside the loaded area.
- Newmark's influence chart is based on the Boussinesq theory.

Vertical Stress Under a Corner of Rectangular Area

- Vertical stress

$$\boxed{\sigma_z = I_N q}$$

Where, I_N = Newmark's influence coefficient

- I_N depends on m and n values.

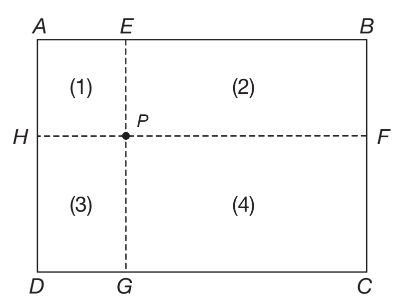
$$\boxed{m = \frac{L}{z};\quad n = \frac{B}{z}}$$

- Both m and n can be interchangeable.

NOTE

If a point 'p' is not at the corner of a rectangular area, make it as a corner and find the vertical stress.

For example, point 'p' is lying in the inner part of the rectangular area as shown in the figure.



The given rectangle is sub-divided into 4 small rectangles, each having one corner at point 'p'. The vertical stress of p is equal to that from four small rectangles.

$$\sigma_z = [(I_N)_1 + (I_N)_2 + (I_N)_3 + (I_N)_4]q$$

Westergaard's Theory

- Westergaard's solution assumes that soil mass consists of infinitely rigid thin sheet of materials sandwiched in a homogeneous soil mass.
- Westergaard's theory is applicable for sedimentary deposits.
- Vertical stress at a point 'p' below the concentrated load 'Q' is given by:

$$\boxed{\sigma_z = \frac{Q}{\pi z^2}\left[\frac{1}{1+2\left(\frac{r}{z}\right)^2}\right]^{\frac{3}{2}}}$$

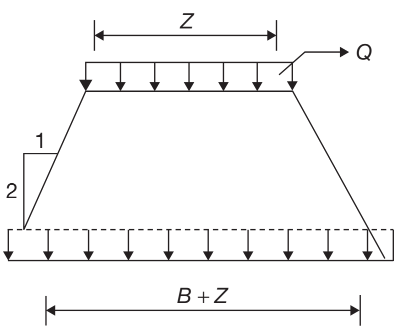
$$\boxed{\sigma_z = I_w \frac{Q}{Z^2}}$$

Where, I_w = Westergaard's influence coefficient

- Fenske's charts are based on Westergaard's solution.

Approximate Method

Two-to-one Load Distribution Method



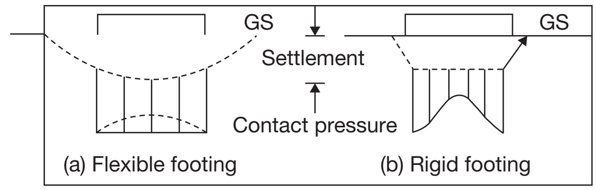
The average vertical stress (σ_z) depends upon the shape of loaded area are as follows:

1. Square Area $(B \times B), \sigma_z = \frac{qB^2}{(B+Z)^2}$
2. Rectangular area $(B \times L)$, σ_z $= \frac{q(B \times L)}{(B+Z)(L+Z)}$
3. Circular area (diameter, D), $\sigma_z = \frac{q \cdot D^2}{(D+Z)^2}$

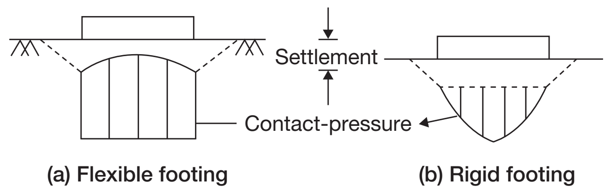
   The maximum stress is, generally, taken as 1.5 times the average stress.

Contact Pressure Distribution

- The upward pressure, due to soil on under side of the footing, is termed as contact pressure.
- Contact pressure depends on various factors, such as elastic properties of the footing, material and soil, the thickness of footing.



Contact pressure on saturated day



Contact pressure on sand

Example 2

A footing, 2 m × 1 m, exerts a uniform pressure, 150 kN/m^2, on the soil. Assuming that a load dispersion of 2 vertical to 1 horizontal, the average vertical stress (kN/m^2) at 1.0 m below the footing is

(A) 50 (B) 75
(C) 80 (D) 100

Solution

The given footing is rectangular.

∴Using the formula:

$$\sigma_z = \frac{Q}{(B+Z)(L+Z)} = \frac{150 \times (2 \times 1)}{(2+1)(1+1)}$$

$$\sigma_z = 50 \text{ kN/m}^2.$$

Compaction

- Compaction is compression of soil mass by mechanical methods.
- Compaction of a soil mass is done to improve its engineering properties.
- Due to compaction shear strength of soil increases, permeability and compressibility decrease.

Compaction Tests

- Compaction tests are done to assess the amount of compaction and the water content required in the field.
- Compaction test provide a relationship between water content and dry density.

Standard Proctor Test (IS Light Compaction Test)

- Mould is of 100 mm diameter, 127.3 mm height and 1000 ml capacity.
- Weight of rammer recommended is 2.6 kg and height of fall is 31 cm.
- Soil is compacted in 3 layers with each layer given by 25 hammer blows.
- Standard proctor test is recommended for the compaction of fills behind retaining wall and in highways and earth dams where light rollers are used.

Modified Proctor Test (IS Heavy Compaction Test)

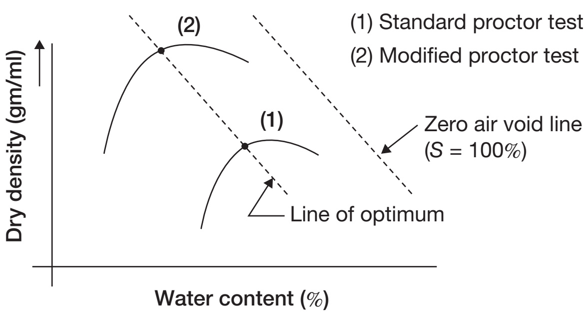
- Test is recommended in modern highways and runways where heavier compaction is required.
- Mould used is same as the standard proctor test.
- Weight of rammer recommended is 4.90 kg and height of fall is 45 cm.

NOTES

1. The compactive effort in the modified proctor test is about 4.55 times that in standard proctor test.
2. If the percentage of soil retained on 4.75 mm sieve is more than 20%, large mould of capacity 2250 ml is used. In this case, 56 blows are required for each layer.

Compaction Curve

- A compaction curve is a plot between the water content as abscissa and corresponding dry density as ordinate.



- The line of optimum shown in the figure joins the points indicating the maximum dry density. It is roughly parallel to the zero air void line. This line corresponds to air voids of about 5%.
- The line indicating the theoretical maximum dry density is known as zero air void line or 100% saturation line.
- Theoretical maximum dry density:

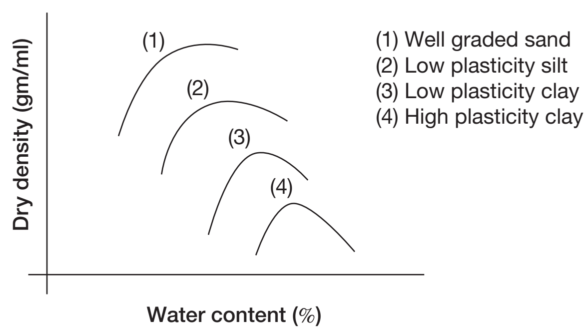
$$(\gamma_d)_{\text{theomax}} = \frac{G\gamma_w}{1 + w \cdot G}$$

- The lines for other degree of saturation, such as 90%, 80% are not identical with the lines for other percentages of air voids, such as 10%, 20%.
- For plotting air void line, the following equation is used.

$$\boxed{(\gamma_d) = \frac{(1-n_a)G\gamma_w}{1 + wG}}$$

Factors Affecting Compaction

1. **Water content:** As water content increases, the soil particles get lubricated and particles have closer packing. This leads to increase in dry density. As water content increases, dry density increases reaches to the maximum at optimum water content and, then decrease as the soil particles are replaced by water.
2. **Amount of compaction:** With increase in the amount of compaction there is an increase in dry density and decrease in optimum water content.
3. **Type of soil:** The maximum dry density and the optimum water content for different soils are shown in the following figure.



Compaction curves for different soils

From the given figure, it is inferred that the coarse-grained soil have less optimum water content and high dry density, whereas fine-grained soils have more optimum water content and less dry density because of more surface area.

4. **Admixtures:** The compaction characteristics of the soils are improved by adding admixtures. Commonly used admixtures are lime, cement and bitumen.

Effect of Compaction on the Properties of Soil

- Dry of optimum means, when the water content is less than the optimum standard. Wet of optimum means, when the water content is more than the optimum standard.
- Soil compacted to the dry of optimum has flocculated structure and has more swelling, more shear strength and less shrinkage characteristic.

- With increase in water content on dry side of optimum, permeability decrease and minimum permeability occurs at or slightly above water content.
- Soil compacted to the wet of optimum has dispersed structure and have low swelling, low shear strength and high shrinkage characteristics.

Methods of Compaction Used in Field

1. **Tampers:** Tampers are used to compact soils adjacent to existing structure or confined areas, such as trenches and behind the bridge abutments.
2. **Rollers:**
   (a) **Smooth wheel rollers:** Smooth wheel rollers are useful for finishing operations after compaction of fills and for compacting granular base course of highways. These are not effective for compaction of deep layers of soils. These rollers are, generally, used to seal the surface of the fill at the end work to provide a smooth surface to quickly drain off any rain water.
   (b) **Pneumatic tyred rollers:** The rollers of this type compacts the soil primarily by kneading action. These rollers are effective for compacting cohesive as well as cohesionless soils.
   (c) **Sheep foot rollers:** Sheep foot rollers are ideally suited for compaction of cohesive soils. The rollers compact the soil by a combination of tamping and kneading action.
3. **Vibratory compactors:** Suitable for compacting granular soils.

Placement Water Content

- Actual water content used in the field for compaction.
- To avoid large expansions and swelling pressure under pavements, floors and core of an earth dam, soil should be compaction on wet side of optimum.
- Soil should be compacted to dry of optimum in case of highway, embankments and in the outer shell of earth dam.

Relative Compaction

- It is defined as the ratio of the dry density in the field to the maximum dry density obtained in laboratory, is known as relative compaction.

$$\boxed{\begin{aligned}&\text{Relative compaction}\\&=\frac{\text{Dry density in the field}}{\text{Maximum dry density in the laboratory}}\times 100\end{aligned}}$$

Example 3

In a standard proctor test, 18 kg of moist soil was filling the mould (Volume = 944 cc) after compaction. A soil sample weighing 23 g was taken from the mould and oven dried for 24 hours at a temperature of 110°C. Weight of the dry sample was found to be 20 g. Specific gravity of soil solids is $G = 2.7$. The theoretical maximum volume of the dry unit weight of the soil at that water content is equal to

(A) 4.67 kN/m^3 (B) 11.5 kN/m^3
(C) 16.26 kN/m^3 (D) 18.85 kN/m^3

Solution

Theoretical maximum dry density,

$$(\gamma_d)_{\text{theomax}} = \frac{G\cdot\gamma_w}{1+w\cdot G}$$

$$\text{Water content, } w = \frac{W-W_d}{W_d}\times 100 = \frac{23-20}{20}\times 100 = 15\%$$

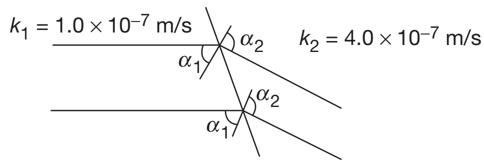
$$(\gamma_d)_{\text{theomax}} = \frac{2.7\times 9.81}{1+(0.15)(2.7)}$$

$$(\gamma_d)_{\text{theomax}} = 18.85 \text{ kN/m}^3.$$

Exercises

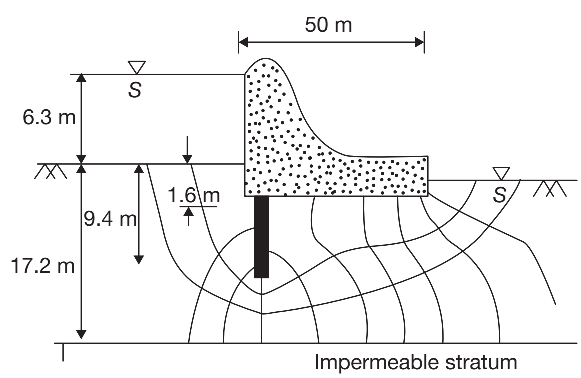
1. For an anisotropic soil, permeability in x and y direction are K_x and K_y respectively in a two dimensions flow. The effective permeability for the soil is given by
   (A) $K_x + K_y$ (B) $\frac{K_x}{K_y}$
   (C) $\left(K_x^2 + K_y^2\right)^{1/2}$ (D) $(K_x K_y)^{1/2}$
2. The coefficients of permeability of a soil in horizontal and vertical direction are 3.46 and 1.5 m/day respectively. The base length of a concrete dam resting in this soil is 100 m. When the flow net is developed for this soil with 1 : 25 scale factor in the vertical direction, the reduced base length of the dam will be
   (A) 2.63 m
   (B) 4.00 m
   (C) 6.08 m
   (D) 5.43 m

3. The following figure shows two flow lines for seepage across an interface between two soil media of different coefficient of permeability. If entrance angle $\alpha_1 = 30°$, the exit angle α_2 will be



(A) 7.50°
(B) 14.03°
(C) 66.59°
(D) 75.96°

4. The flow net constructed for the dam is shown in the figure. Taking the coefficient of permeability as 3.8×10^{-6} m/s, the quantity of flow (in cm^3/s) under the dam per metre of dam is ______.



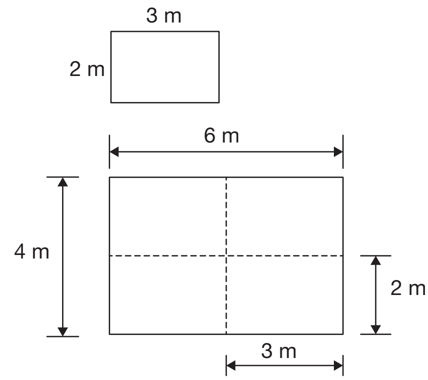
5. A 25 kN point load acts on the surface of an infinite elastic medium. The vertical pressure intensity in kN/m^2 at a point 6.0 m below and 4.0 m away from the load will be

(A) 132 (B) 13.2
(C) 1.32 (D) 0.132

6. There are two footings resting on the ground surface. One footing is square of dimension '*B*'. The other is strip footing of width '*B*' both of them are subjected to a loading intensity of q. The pressure intensity at any depth below the base of the footing along the center line would be

(A) equal in both footings.
(B) large for square footing and small for strip footing.
(C) large for strip footing and small for square footing.
(D) more for strip footing at shallow depth ($\leq B$) and more for square footing at large depth ($> B$).

7. The vertical stress at some depth below the corner of a 2 m × 3 m rectangular footing due to a certain load intensity is 100 kN/m^2. What will be the vertical stress in kN/m^2 below the centre of a 4 m × 6 m rectangular footing at the same depth and same load intensity?



(A) 25 (B) 100
(C) 200 (D) 400

8. For conducting a standard proctor compaction test, the weight of hammer (**P** in kg), the fail of hammer (**Q** in mm), the number of blows per layer (**R**) and the number of layers (**S**) required are respectively

	P	**Q**	**R**	**S**
(A)	5.89	550	50	3
(B)	4.89	450	25	3
(C)	3.60	310	35	4
(D)	2.60	310	25	3

9. **Assertion (A):** For a given soil, the optimum moisture content increases with the increase in compactive effort.

Reason (R): Higher the compactive effort, higher is the dry density at the same moisture content.

(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not a correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

10. An increase in compaction effort will lead to which of the following?

(A) Decrease in both the optimum moisture content (OMC) and maximum dry density.
(B) Decrease in the optimum moisture content (OMC) and increase in the maximum dry density.
(C) Increase in the optimum moisture content (OMC) and decreases in the maximum dry density.
(D) Increase in both the optimum moisture content (OMC) and maximum dry density.

11. A concentrated load of 50 *t* acts vertically at a point on the soil surface. If Boussinesq's equation is applied for computation of stress, then the ratio of vertical stresses at depths of 3 m and 5 m respectively vertically below the point of application of load will be

(A) 0.36
(B) 0.60
(C) 1.66
(D) 2.77

12. In the case of stratified soil layers, the best equation that can be adopted for computing the pressure distribution is

(A) Prandtl's (B) Skempton's
(C) Westergaard's (D) Boussinesq's

13. Westergaard's formula for vertical stress gives greater value of stress than that by the Boussinesq's formula, when r/z exceeds

(A) 1.5 (B) 2.5
(C) 3.5 (D) 4.0

14. A point load of 700 kN is applied on the surface of thick layer of saturated clay. Using Boussinesq elastic analysis, the estimated vertical stress (σ_v) at a depth of 2 m and a radial distance of 1.0 m from the point of application of load is

(A) 47.5 kPa (B) 47.6 kPa
(C) 47.7 kPa (D) 47.8 kPa

15. In a compaction test, as the compaction effort is increased, the optimum moisture content

(A) decreases.
(B) remains same.
(C) increases.
(D) increases first there after decreases.

16. A clayey soil has a maximum dry density of 16 kN/m^3 and optimum moisture content of 12%. A contractor during the construction of core of an earth dam obtained the dry density 15.2 kN/m^3 and water content 11%. This construction is acceptable because

(A) the density is less than the maximum dry density and water content is on dry side of optimum.
(B) the compaction density is very low and water content is less than 12%.
(C) the compaction is done on the dry side of the optimum.
(D) both the dry density and the water content of the compacted soil are within the desirable limits.

17. Compaction of an embankment is carried out in 500 mm thick layers. The rammer used for compaction has a foot area of 0.05 sq. m and the energy imparted in every drop of remmar is 400 Nm. Assuming 50% more energy in each pass over the compacted area due to overlap, the number of passes required to develop, compactive energy equivalent to Indian standard light compaction for eacllayer would be

(A) 10 (B) 16
(C) 20 (D) 26

18. In a standard proctor test, 1.8 kg of moist soil was filling the mould (volume = 944 cc) after compaction. A soil sample weighing 23 g was taken from the mould and oven dried for 24 hours at a temperature of 110°C. Weight of the dry sample was found to be 20 g. Specific gravity of soil solids is $G = 2.7$. The theoretical maximum volume of the dry unit weight of the soil at that water content is equal to

(A) 4.67 kN/m^3
(B) 11.5 kN/m^3
(C) 16.26 kN/m^3
(D) 18.85 kN/m^3

19. The intensity of radial shear stress at a point 8 m below vertically and 5 m horizontally below a point load of 3 tonnes is

(A) 1.438 t/m^2 (B) 1.583 t/m^2
(C) 1.875 t/m^2 (D) 2.013 t/m^2

20. The curves indicating the distribution of excess hydrostatic pressure in the soil are known as

(A) isobars (B) isochrones
(C) isotopes (D) isohyts

21. A 50 kN load acts on the surface of an infinite elastic medium the vertical pressure intensity in kN/m^2 at 10 m below and 4 m away from the load will be

(A) 0.048 kN/m^2
(B) 0.096 kN/m^2
(C) 0.049 kN/m^2
(D) 0.035 kN/m^2

22. For a given flow net, if number of flow channels and number of potential drops are found as 12 and 8; then what would be the shape factor of the flow net?

(A) 4 (B) 1.67
(C) 1.5 (D) 1.71

23. The seepage occuring through an earthen dam is represented by a flownet comprising of 12 equipotential drops and 24 flow channels. The coefficient of permeability is 4 mm/min and the head loss is 5 m. The rate of seepage (expressed in cm^3/s per m length of the dam) through the earthen dam is ______.

(A) 665 (B) 775
(C) 525 (D) 420

24. A 40 kN point load acts on the surface of an infinite elastic medium. The vertical pressure intensity in kN/m^2 at a point 4.0 m below and 3.0 m away from the load will be ______ kN/m^2.

(A) 0.10 (B) 0.20
(C) 0.30 (D) 0.40

25. A granular soil possess saturated density of 21 kN/m^3. Its effective angle of internal friction is 40 degrees. If the desired factor of safety is 1.5, the safe angle of slope for this soil, when seepage occurs at and parallel to the slope surface, will be (take γ_w: 10 kN/m^3)

(A) 25° (B) 20°
(C) 16° (D) 12°

26. Water is following in an upward direction through a stratum of sand, 5 m thick, under a total head difference of 2.5 m. The sand has a specific gravity of 2.65 and void ratio of 0.07. The factor of safety against quick sand condition will be

(A) 1.0 (B) 1.5
(C) 2.0 (D) 3.0

27. Westergaard's formula for vertical stress gives greater value of stress than that by the Bousinnesq's formula, when r/z exceeds,
(A) 1.5
(B) 2.5
(C) 3.5
(D) 4

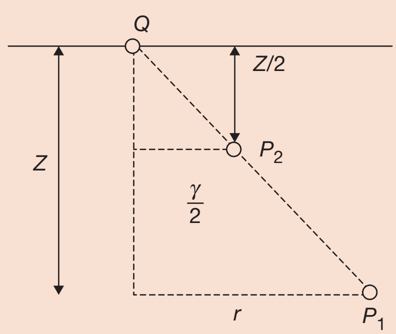
28. A point load of 700 kN is applied on the surface of thick layer of saturated clay. Using Boussinesq's elastic analysis, the estimated vertical stress (σ_v) at a depth of 2 m at a radial distance of 2 m from the point of application of the load is ______.
(A) 41.7 kPa (B) 21.7 kPa
(C) 14.7 kPa (D) 12.7 kPa

Previous Years' Questions

1. A footing of 2 m × 1 m exerts a uniform pressure of 150 kN/m^2 on the soil. Assuming a load dispersion of 2 vertical to 1 horizontal, the average vertical stress (kN/m^2) at 1.0 m below the footing is **[GATE, 2008]**
(A) 50 (B) 75
(C) 80 (D) 100

2. Compaction by vibratory roller is the best method of compaction in case of **[GATE, 2008]**
(A) moist silty sand.
(B) well graded dry sand.
(C) clay of medium compressibility.
(D) silt of high compressibility.

3. The vertical stress at point P_1 due to the point load Q on the ground surface as shown in the figure is σ_2. According to Boussinesq equation the vertical stress at a point P_2 shown in the figure will be **[GATE, 2010]**



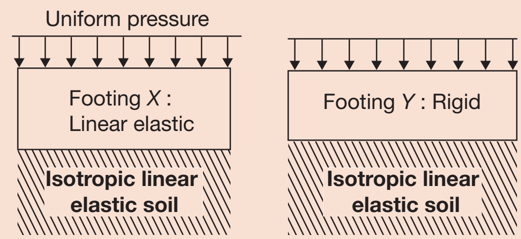
(A) $\frac{\sigma_z}{2}$ (B) σ_z
(C) $2\sigma_z$ (D) $4\sigma_z$

4. In a compaction test, G, w, S and e represent the specific gravity, water content, degree of saturation and void ratio of the soil sample, respectively. If γ_w represents the unit weight of water and γ_d represents the dry unit weight of the soil, the equation for zero air voids line is **[GATE, 2010]**

(A) $\gamma_d = \dfrac{G\gamma_w}{1+Se}$ (B) $\gamma_d = \dfrac{G\gamma_w}{1+Gw}$

(C) $\gamma_d = \dfrac{Gw}{1+\gamma_w S}$ (D) $\gamma_d = \dfrac{Gw}{1+Se}$

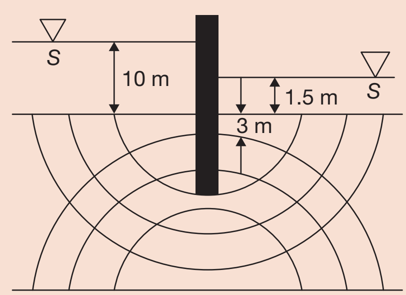
5. Two geometrically identical isolated footing, X (linear elastic) and Y (rigid), are loaded identically (shown in the figure). The soil reaction will **[GATE, 2011]**



(A) be uniformly distributed for Y but not for X.
(B) be uniformly distributed for X but not for Y.
(C) be uniformly distributed for both X and Y.
(D) not be uniform distributed for both X and Y.

Direction for questions 6 and 7:

The flow net around a sheet pile wall is shown in the figure. The properties of soil are: permeability coefficient = 0.09 m/day (isotopic) specific gravity = 2.70 and void ratio = 0.85. The sheet pile wall and the bottom of soil are impermeable. **[GATE, 2012]**



6. The seepage loss (in m^3 per day per unit length of the wall) of water is
(A) 0.33 (B) 0.38
(C) 0.43 (D) 0.54

7. The factor of safety against the occurrence of piping failure is
(A) 3.55 (B) 2.93
(C) 2.60 (D) 0.39

8. Two series of compaction tests were performed in the laboratory on an inorganic clayey soil employing two different levels of compaction energy per unit volume of soil. With regard to the above tests, the following two statements are made

[GATE, 2012]

I. The optimum moisture content is expected to be more for the tests with higher energy.

II. The maximum dry density is expected to be more for the tests with higher energy.

The correct option evaluating the above statements is

(A) Only I is true
(B) Only II is true
(C) Both I and II are true
(D) Neither I nor II is true

9. The ratio N_f/N_d is known as shape factor, where N_f is the number of flow channels and N_d is the number of equipotential drops. Flow net is always drawn with a constant b/a ratio, where b and a are distances between two consecutive flow lines and equipotential lines, respectively. Assuming that b/a ratio remain the same, the shape factor of a flow net will change if the **[GATE, 2013]**

(A) upstream and downstream heads are interchanged.
(B) soil in the flow space is changed.
(C) dimension of the flow space are changed.
(D) head difference causing the flow is changed.

10. The contact pressure for a rigid footing resting on clay at the centre and the edges are respectively **[GATE, 2014]**

(A) maximum and zero.
(B) zero and maximum.
(C) maximum and minimum.
(D) minimum and maximum.

11. The seepage occurring through an earthen dam is represented by a flownet comprising of 10 equipotential drops and 20 flow channels. The coefficient of permeability of the soil is 3 mm/min and the head loss is 5 m. The rate of seepage (expressed in cm^3/s per m length of the dam) through the earthen dam is _________. **[GATE, 2016]**

12. OMC-SP and MDD-SP denote the optimum moisture content and maximum dry density obtained from standard Proctor compaction test, respectively. OMC-MP and MDD-MP denote the optimum moisture content and maximum dry density obtained from the modified Proctor compaction test, respectively. Which one of the following is correct?

[GATE, 2016]

(A) OMC-SP < OMC-MP and MDD-SP < MDD-MP
(B) OMC-SP > OMC-MP and MDD-SP < MDD-MP
(C) OMC-SP < OMC-MP and MDD-SP > MDD-MP
(D) OMC-SP > OMC-MP and MDD-SP > MDD-MP

Answer Keys

Exercises

1. D	**2.** A	**3.** C	**4.** 7.18	**5.** D	**6.** C	**7.** D	**8.** D	**9.** D	**10.** B
11. D	**12.** C	**13.** A	**14.** D	**15.** A	**16.** D	**17.** D	**18.** D	**19.** C	**20.** B
21. D	**22.** C	**23.** A	**24.** D	**25.** C	**26.** D	**27.** A	**28.** C		

Previous Years' Questions

1. A	**2.** B	**3.** D	**4.** B	**5.** B	**6.** B	**7.** C	**8.** B	**9.** C	**10.** D
11. 500	**12.** B								