## UNIT – I

## SOIL CLASSIFICATION AND COMPACTION

## PART A

1. **Draw the phase diagram for completely dry and fully saturated soil mass (May/June 14)**



2. **List various field compaction methods with its suitability. ( May/June 2014)**

| Type of soil | Type of equipment recommended |
|---|---|
| Cohesive soil | Sheepsfoot roller, rubber tired roller |
| Cohesionless soil | Rubber tired roller or vibratory roller, vibrofloatation. |
| All types of soil | Rammers or tampers |

3. **Differentiate between void ratio and porosity. (Nov/Dec 13) (Apr/May 11) (Nov/Dec10)**

| Property | Void ratio (e) | Porosity (n) |
|---|---|---|
| Definition | The relative volume of voids and solids is called void ratio | The relative volume of voids to the total volume is called porosity |
| Value range | 0.1 -2.5 | 9 – 70 % |

4. The most accurate method for the determination of water content in the laboratory is **oven dry method.** **( Nov/Dec 2013)**

5. **The dry density of a soil and its specific gravity of soils are respectively 18 kN/m³ and 2.7. Find the moisture content required to have 100% saturation of the soil. (May/June 2013).**

**Given**

$\gamma_d = 18$ kN/m$^3$ , G = 2.7

**Solution**

S=1 ( Since degree of saturation is 100%)

w =?

**To find 'e'**

**We know that**

$$\gamma_d = \frac{G\gamma_w}{1+e}$$

substituting the values of $\gamma w$ = 9.81 kN/m$^3$, $\gamma_d$ = 18 kN/m$^3$, G = 2.7
we get e = 0.47
We know that e.S = w.G
Substituting the values of e = 0.47, S= 1, G = 2.7
We get **w = 17.4%**

**6. If the liquidity index of a soil is zero. Find the consistency index (May/June 2013).**

Liquidity index

$$\boldsymbol{I_L = \frac{w - w_p}{I_p}}$$

Consistency index

$$\boldsymbol{I_c = \frac{w_L - w}{I_p}}$$

When liquidity index is zero

$$\boldsymbol{w = w_p}$$

**Substituting $\boldsymbol{w = w_p}$ *in consistency index***

$$\boldsymbol{I_c = \frac{w_L - w_p}{I_p}}$$

$\boldsymbol{I_c = \frac{I_p}{I_p}}$ **( Since $\boldsymbol{w_L = w_p}$)**

$$\boldsymbol{I_c = 1}$$

**Hence when the liquidity index of a soil is zero the consistency index is 1**

**7. Define sieve analysis and sedimentation analysis and what is the necessity of these two analysis? ( Nov/Dec 2012)**

**Sieve analysis :** Sieve analysis is a laboratory test that measures the grain size distribution of a soil by passing it through a series of sieves.

**Sedimentation analysis :** Sedimentation analysis is the most convenient method for determining the grain size distribution of the soil fraction finer than 75μ in size.

**8. Give the relationship between $\gamma_{sat}$, G, $\gamma_w$, and e. (May/June 2012).**

$$\gamma_{sat} = \frac{G+e}{1+e}\gamma_w$$

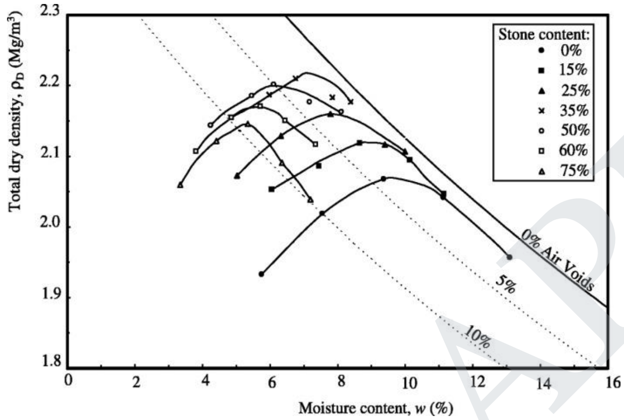
**9. Distinguish between Residual and Transported soil. (May/June 2012)**

The soils formed by weathering of rocks remain in position at the place of origin. These soils are called as residual soils.

The soil which gets transported from the place of origin by various agencies such as wind, water, ice etc is referred to as transported soil.

**10. What is zero air voids line? Draw a compaction curve and show the zero air voids line. (Nov/Dec 2011).**

Zero air voids line defines the edge of prohibited territory, which is the saturated moisture content for a particular density.




**11. Define the term degree of saturation. ( Nov/Dec 2011).**

Degree of saturation of a soil mass is defined as the ratio of the volume of water in the voids to the volume of voids. It is designated by S.

$$S = \frac{Vw}{Vv} x100\%$$

**12. What is water content in a given mass of soil? ( Apr/May 2011)**

Water content, w, also called the moisture content is defined as the ratio of the weight of water to the weight of solids in a given mass of soil. It is usually expressed in percentage.

$$w = \frac{W_w}{W_s} \text{ x } 100$$

**13. Define effective size of particle in sieve analysis. ( Nov/Dec 2010)**

Diameter $D_{10}$ corresponds to 10% of the sample finer in weight on the grain size distribution curve. The diameter $D_{10}$ is called the effective size.

**14. What are the methods available for sieve analysis?( April/May 2011)**

a) Dry sieve Analysis

b) Wet sieve analysis

**15. Define sensitivity and flow index (April/May 2011)**

**Sensitivity** of a clay is defined as the ratio of its unconfined compression strength in the natural or undisturbed state to that in the remoulded state, without change in the water content.

**Flow index** is the slope of the flow curve obtained between the number of blows and the water content in the Casagrande test for the determination of liquid limit.

$$I_f = \frac{w_1 - w_2}{log_{10}(N_2/N_1)}$$

**16. What are the factors affecting compaction? (April/ May 2011).**

- Moisture content
- Compactive effort
- Type of soil
- Method of compaction

**17. Define Atterberg Limits (April/May 2011) ( Nov/Dec 2010)**

**Liquid limit:** It is the water content at which the soil, changes from liquid to plastic state liquid.

**Plastic limit:** The maximum water content at which, soil changes from plastic to semi-solid state.

**Shrinkage limit:** The limit of water content at which the soil tends to pass from the semi solid-to-solid state.

**18. The natural water content of a saturated soil is 30%. If the specific gravity of solids of the soil is 2.7. find its porosity (Nov /Dec 2010).**

**Given**

w = 30%

G = 2.7

Porosity = ?

To find e

Given the soil is saturated. Assume S = 1

**We know that e.S = w.G**

Substituting the values of w,G,S in the above equation

ex1 = 0.3x 2.7

e = 0.81

**n =** $\frac{e}{e+1}$

substituting e in the above equation we get

**n = 44.70%**

**19. Define specific gravity and degree of saturation ( Nov / Dec 2010)**

**Specific gravity** of solids is defined as the ratio of the density of solids to the density of water.

$$G_s = \frac{M_s}{V_s\, \rho_w}$$

**Degree of saturation (S)** is the percentage of voids filled with water

$$S = \frac{Vw}{Vv} x100\%$$

**20. State different methods of analysis for finding various sizes of particles in a soil sample. (Nov/Dec 2010).**

For particles larger than 75mm in diameter sieve analysis is used for finding the various sizes of particles.

For silt and clay hydrometer analysis is used for finding the sizes of particles.

**21. What do you understand by consistency of soil? (Nov /Dec 2010)**

The consistency of a fine-grained soil is the physical state in which it exists. It is used to denote the degree of firmness of the soil. Consistency of a soil is indicated by terms such as soft, firm or hard.

**22. Differentiate between density and unit weight of soil? (Nov /Dec 2010)**

**Density –** Density is defined as the ratio of mass of the soil to its volume. It is denoted as ρ.

**Unit weight –** It is the ratio of weight of the soil to its volume. It is denoted by γ.

**23. List various soil classification systems (Nov/Dec2010) (May/ June 2010)**

- Particle size classification
- Textural classification
- AASHTO classification
- Unified soil classification

**24. Define Compaction .(May/ June 2010)**

Compaction is defined as the process by which the soil particles get rearranged and packed together by mechanical means, so that the porosity decreases and the dry density increases.

**25. Sketch the phase diagram for a soil and indicate the volumes and weight of the phase on it. (May/ June 2010).**

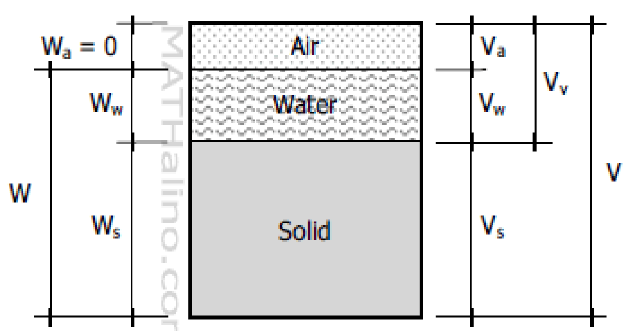



**Figure 1:** Phase Diagram of Soil

**26. A compacted soil sample of soil with a bulk unit weight of 19.62 kN/m$^3$ has a water content of 15%. What are its dry unit density, degree of saturation and air content? Assume G = 2.65. (Apr/May 2010).**

**Given**

$\gamma_b$ = 19.62 kN/m$^3$

w = 15%

$\gamma_d$ = ?

S = ?

**Solution**

**To find the dry unit weight**

$\gamma_d = \frac{\gamma}{1+w}$

$= \frac{19.62}{1+0.15}$

$\boldsymbol{\gamma_d}$ **= 17.06 kN/m$^3$**

**To find the degree of saturation**

Void ratio

$\mathbf{e = \frac{G\gamma w}{\gamma_d} - 1}$

substituting G = 2.65, $\gamma_d$ = 17.06 kN/m$^3$, $\gamma_w$ = 9.81 kN/m$^3$

e = 0.52

we know e.S = w.G

substituting the values of e=0.52, w = 0.15, G = 2.65

we get S = 0.76

Hence **S = 76%**

**To find the air content**

$\mathbf{a_c = \frac{V_a}{V_v}}$

$\mathbf{a_c}$ **= 24%**

**27. Two clays A and B have the following properties (Apr/May 2010)**

| | Clay A | Clay B |
|---|---|---|
| **Liquid limit** | **44%** | **55%** |
| **Plastic limit** | **29%** | **35%** |
| **Natural water content** | **30%** | **50%** |

**Which of the clays would experience larger settlements under identical loads? Why?**

**Clay A** Plasticity index = liquid limit – Plastic limit

= 44 – 29 = 15%

Water content = 30%

**Clay B** Plasticity index = liquid limit – Plastic limit

= 55 – 35 = 20%

Water content = 50%

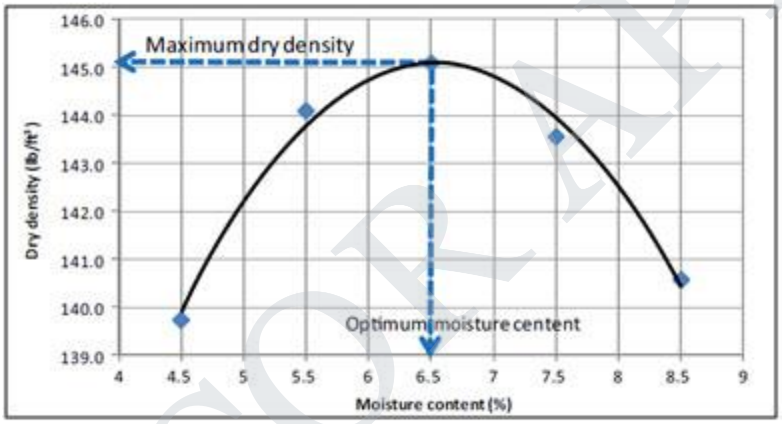
Clay B has more water content therefore larger settlement will occur in this clay.

**28. Name any four methods of determination of field density of soil (Apr/May 2010).**

- Sand replacement method
- Core cutter method
- Sand cone method
- Volumeter method

**29. What is optimum moisture content of soil? ( Apr/May 2010)**

Optimum moisture content of soil is the water content at which the dry density of the soil is maximum.




**30. Define sensitivity and activity of a clayey soil? (June 2009)**

Sensitivity is the ratio of undisturbed strength to the remoulded strength at the same water content.

Activity of soil is the ratio of the plasticity index and the percentage of clay fraction.

**PART B**

**1. A cubic meter of soil in its natural state weighs 17.75kN, after being dried it weighs 15.08kN. The specific gravity of the soil is 2.70. Determine the degree of saturation, void ratio, porosity and water content of the original soil sample. (May/June 14)(Nov/Dec12)**

**Given**

W = 17.75kN

$W_s$ = 15.08kN

G = 2.70

**To find**

i)Water content(w)

ii)Porosity(n)

iii)Void ratio(e)

iv)Degree of saturation(S)

**Solution**

**i)To determine the water content(w)**

$$w = \frac{W - W_s}{W_s}$$

**w = 17.7%**

**ii)To determine the porosity**

$$n = \frac{V_v}{V}$$

$W_w = W - Ws$ = 17.75 -15.08 = 2.67kN

$V_s = \frac{W_s}{G_s \gamma_w} = \frac{15.08}{2.70 x 9.81}$ = 0.569m$^3$

$V_w = \frac{W_w}{\gamma_w} = \frac{2.67}{9.81} = 0.272$m$^3$

$$V_v = V - V_s = 1 - 0.569 = 0.431 m^3$$

$$n = \frac{0.431}{1} = 0.431 \; or \; 43.1\%$$

**iii) To determine the void ratio**

$$e = \frac{V_v}{V_s}$$

$$e = \frac{0.431}{0.569} = 0.757$$

**iv)To determine the degree of saturation**

$e.S = w.G$

$$S = \frac{17.7x2.67}{0.757} = 62.42$$

**w = 17.7%**
**n = 43.1%**
**e = 0.757**
**S = 62.42%**

2. **Discuss the effect on compaction on engineering properties of soil. (May/June 2014)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 417 – 419

3. **Sandy soil in a borrow pit has unit weight of solids as 26.3kN/m³, water content equal to 11% and bulk unit weight equal to 16.4 kN/m³. How many cubic meter of compacted fill could be constructed of 3500m³ of sand excavated from the borrow pit, if the required value of porosity in the compacted fill is 30%. Also compute the change in degree of saturation. (Nov/Dec 2013) (Nov/Dec 2012)**

**Solution**

Let us use suffix 1 for the borrow pit soil and 2 for the compacted soil. Assuming that weight and water content do not change during construction, the change in the volume can be calculated from the change in the unit weight.

$$\frac{V_1}{V_2} = \frac{W/\gamma_1}{W/\gamma_2} = \frac{\gamma_2}{\gamma_1} = \frac{1+e_1}{1+e_2}$$

Hence $V_2 = V_1\left(\frac{1+e_2}{1+e_1}\right) = V_1\left(\frac{1-n1}{1-n2}\right)$

$$e = \frac{G\gamma_w}{\gamma_d} - 1 = \frac{\gamma_s}{\gamma/(1+w)} - 1 = \frac{\gamma_s(1+w)}{\gamma} - 1$$

$$e_1 = \frac{\gamma_s(1+w)}{\gamma_1} = \frac{2.63(1+0.11)}{16.4} - 1 = 0.780$$

$$e_2 = \frac{n_2}{1-n_2} = \frac{0.3}{1-0.3} = 0.429$$

$$V_2 = V_1\left(\frac{1+e_2}{1+e_1}\right)$$

$$V_2 = 3500\left(\frac{1+0.429}{1+0.780}\right) = 2810m^3$$

$$S_1 = \frac{w\gamma_s}{e_1\gamma_w} = \frac{0.11x26.3}{0.78x9.81} = 0.378$$

$$S_2 = \frac{w\gamma_s}{e_2\gamma_w} = \frac{0.11x26.3}{0.429x9.81} = 0.687$$

Thus, the degree of saturation will be considerably increased in the compacted fill.

4. **Discuss various methods available for field compaction ( Nov/Dec 2013)**

   Refer “Soil Mechanics and Foundations” by B.C Punmia Pg 412 – 413

5. **In a compaction test on a soil, the mass of wet soil when compacted in the mould was 18.55N. The water content of the soil was 16%. If the volume of the mould was 0.945 liters, determine the dry density, void ratio, degree of saturation and percentage air voids. Take G= 2.68 ( Nov/Dec 2013)**

**Solution**

$$Bulk\ density\ \rho = \frac{1.855}{0.945x10^{-3}} = 1962.96kg/m^3$$

$$\rho_d = \frac{\rho}{1+w} = \frac{1962.96}{1+0.16} = 1692.21kg/m^3$$

$1 + e = \frac{2.68x1000}{1692.21} = 1.584$

e =0.584

$$S = \frac{wG}{e} = \frac{0.16x2.68}{0.584} = 0.7342 = 73.42\%$$

$$\rho_d = \frac{(1-na)G.\rho_w}{1+wG}$$

$$(1-na) = \frac{1692.21x(1+0.16x2.68)}{2.68x1000} = 0.9022$$

$$na = 0.0978(9.78\%)$$

6. **A fine grained soil has liquid limit of 60%, plastic limit of 26%. Classify the soil as per IS classification system( May/June 2013)**

**Solution**

$W_L$ = 60%

$W_p$ = 26%

**$I_p = W_L - W_p$ = 60-26 = 34%**

**Refer to the plasticity chart**
**From the plasticity chart it is noted that the soil falls in CH category**
**CH –** Inorganic clays of high plasticity

7. **Write down a neat procedure for determining water content and specific gravity of a given soil in the laboratory by using a pycnometer.( Nov/Dec 2012)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 39 - 40, 41- 42

8. **The mass of wet soil when compacted in a mould was 19.55kN.The water content of the soil was 16%. If the volume of the mould was 0.95m$^3$. determine (i) Dry unit weight (ii) void ratio (iii) degree of saturation (iv) percent air voids. Take G = 2.68(May/June 2012)**

**Solution**
**i)Dry unit weight**

$$\gamma = \frac{M_{wet}}{V} = \frac{19.55}{0.95} = 20.57\ kN/m^3$$

$$\gamma_d = \frac{\gamma}{1+w} = \frac{20.57}{1+0.16} = 17.74 kN/m^3$$

**ii)Void ratio**

$$\gamma_d = \frac{G\gamma_w}{1+e}$$

$$17.74 = \frac{2.68x9.81}{1+e}$$

$$1 + e = 1.48$$

$$e = 0.48$$

**iii)Degree of saturation**

$$S = \frac{0.16x2.68}{0.48} = 0.893\ (or 89.3\%$$

**iv)Percent air voids**

$$n_a = \frac{e(1-S)}{1+e} = \frac{0.48(1-0.89)}{1+0.48} = 0.035$$

9. **In a hydrometer the corrected hydrometer reading in a 1000ml uniform soil suspension at the start of sedimentation was 28. After a lapse of 30 minutes,the corrected hydrometer reading was 12 and the corresponding effective depth 10.5cm. The specific gravity of the solids was 2.68. Assuming the viscosity and unit weight of water at the temperature of the test as 0.001Ns/m$^2$ and 9.81kN/m$^2$ respectively. Determine the weight of the solids mixed in the suspension, the effective diameter corresponding to the 30 minutes reading and the percentage of particle finer than this size. (May/June 2012)**

**Solution**

$$Corrected\ hydrometer\ reading\ initially\ R_{hi} = 28$$

$\gamma_i$= 0.01028N/cm$^3$

$$\gamma_i = \gamma_w + \left[\frac{G-1}{G}\right]\frac{W}{V} = 0.01028 = 0.01 + \left[\frac{2.7-1}{2.7}\right]\frac{W}{1000}$$

$$W = \frac{0.028x2.7}{17} = 0.445N$$

$$The\ weight\ of\ solid\ mixed\ in\ suspension\ is\ 0.445N$$

$$D = k\sqrt{\frac{H}{t}}$$

$$k = \sqrt{\frac{3\ \mu_w}{\gamma_w(G-1)}} = \sqrt{\frac{3.0.001}{9.81x(2.7-1)}} = 0.01342mm\frac{\sqrt{min}}{\sqrt{cm}}$$

$$D = 0.01342\sqrt{\frac{10.5}{39}} = 0.00794mm = 0.008mm$$

$$The\ effective\ diameter\ corresponding\ to\ the\ 30minute\ reading = 0.008mm$$

$$Therefore\ N = \frac{G\gamma_w}{G-1}.\frac{V}{W}.\frac{R_h}{10}$$

$$N = \frac{2.7}{1.7}x0.01x\frac{1000}{0.445}x\frac{12}{10} = 42.83$$

The percentage of finer than 0.008mm is 43%

**10. A soil has a bulk unit weight of 20.11 kN/m$^3$ and water content of 15%. Calculate the water content if the soil partially dries to a unit weight of 19.42 kN/m$^3$ and the void ratio remains unchanged.( Apr/May 2011).**

**Solution**

$$Bulk\ unit\ weight\ \gamma = 20.1KN/m^3$$
$$Water\ content\ w = 15\%$$
$$Dry\ unit\ weight\ \gamma_d = \frac{\gamma}{1+w} = \frac{20.1}{(1+0.15)} = 17.5kN/m^3$$

$$\gamma_d = \frac{G\gamma_w}{(1+e)} If\ the\ void\ ratio\ remains\ unchanged\ while\ drying\ takes\ place, the\ dry\ unit\ weightalso\ remians\ unc$$

$$New\ value\ of\ \gamma = 19.4\ kN/m^3$$

$\gamma = \gamma_d(1+w)$
$19.4 = 17.5(1+w)$

$$(1+w) = \frac{19.4}{17.5} = 1.1086$$
$$w = 0.1086$$
$$Hence\ the\ void\ ratio\ after\ drying = 10.86\%$$

**11. With necessary sketch, explain the modified Proctor compaction test.(Apr/May 2011)**

Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 410

**12. The undisturbed soil at a borrow pit has a water content of 18%, void ratio of 0.66 and specific gravity of 2.69. The above soil is to be used for an embankment of compacted volume 53000m$^3$ with water content of 19% and dry unit weight of 1.80g/cc. Calculate the quantity of soil to be excavated from the borrow pit. What would be the weight of excavated soil and compacted soil in the embankment? (Apr/May 2011)**

**Solution**

$$Dry\ unit\ weight\ of\ the\ embankment\ soil = \frac{W_s}{V} = 1.80 g/cc\ \ or\ 1.80 t/m^3$$
$$W_s = 1.80t$$
$$Hence\ for\ V = 53000cum, Ws\ required\ is\ 53000x1.80 = 95400t$$
$$Dry\ unit\ weight\ of\ the\ soil\ in\ the\ borrow\ pit = \gamma_d = \frac{G_s}{1+e}\gamma_w = \frac{2.69}{1+0.66}.1.0 = 1.620t/m^3\gamma_d$$
$$= \frac{W_s}{V} = 1.620t/m^3$$

$$For\ Ws = 95400t, the\ volume\ of\ soil\ that\ has\ to\ be\ taken\ out\ from\ the\ borrow\ pit$$

$$V = \frac{W_s}{\gamma_d} = \frac{95400}{1.620} = 58888cum$$

$The\ weight\ of\ soil (W) that\ has\ to\ be\ taken\ out\ from\ the\ borrow\ pit\ which\ has\ a\ natural\ moisture\ content\ of$ 18% given by W = $W_s$(1+w) = 95400(1+0.18) = 112572t

The weight of soil in the embankment, which has a moisture content of 19%, will be

W= 95400(1+0.19) = 113526t

**13. The following data on consistency limits are available for two soils A and B.**

| | **Soil A** | **Soil B** |
|---|---|---|
| **(i)Plastic limit** | **16%** | **19%** |
| **(ii)Liquid limit** | **30%** | **52%** |
| **(iii)Flow index** | **11** | **6** |
| **(iv)Natural water content** | **32%** | **40%** |

**Find which soil is**

1. **More plastic**
2. **Better foundation material on remoulding**
3. **Better shear strength as function of water content**

4. **Better shear strength at plastic limit**

**Classify the soil as per I.S classification system. Do those soils have organic matter? (Apr/May 2010)**

**Solution**

(i)**Plasticity index**

$$Plasticity\ chart\ I_p for\ soil\ A = 30 - 16 = 24$$

$$Plasticity\ chart\ I_p for\ soil\ B = 52 - 19 = 33$$

$$Since, plasticity\ index\ of\ soil\ B\ is\ greater, Soil\ B\ is\ more\ plastic$$

(ii)**Find which soil is better foundation material on remoulding?**

$$Consistency\ index\ I_c\ for\ soil\ A = \frac{W_L - w}{I_p}$$

$$Consistency\ index\ I_c\ for\ soil\ A = \frac{30 - 32}{24} = -0.083$$

$$Consistency\ index\ I_c\ for\ soil\ B = \frac{52 - 40}{31} = 0.387$$

The consistency index for soil A is negative, hence it turns into a slurry when remoulded. Hence soil A is not suitable for foundations. However soil B is suitable.

(iii)**Find which soil has better shear strength as function of water content**

$$Flow\ index I_f\ for\ soil\ A = 11$$

$$Flow\ index I_f\ for\ soil\ B = 6$$

Since flow index of soil B is lesser than soil A, soil B has better shear strength as function of water content.

(iv) **Find which soil has better shear strength at plastic limit**

$$Toughness\ index I_T\ for\ soil\ A = {}^{I_p}\!/_{I_f} = \frac{24}{11} = 2.18$$

$$Toughness\ index I_T\ for\ soil\ B = {}^{I_p}\!/_{I_f} = \frac{33}{6} = 5.5$$

Since Toughness index for soil B is greater than that of A, soil B has better shear strength at plastic limit.

**Classification**

When plasticity index and liquid limit are plotted on the plasticity chart, soils A and B fall in the zones of CL and CH respectively. Thus soil A is inorganic clay for low plasticity and soil B is inorganic clay of high plasticity. Hence these soils donot have organic matter.

**14. Show that**

$\gamma_b = \left(\frac{G+Se}{1+e}\right)\gamma_w$ **(Nov/Dec 2010)(Apr/May 2010)**

Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 19

**15. Give a detailed account on the soil classification as per Indian Standard classification system(ISCS)(Nov/Dec 2010)**

Refer “Soil Mechanics and Foundations” by B.C Punmia Pg 120

**16. Explain standard proctor compaction test with neat sketches(Nov/Dec 2010)**

Refer “Soil Mechanics and Foundations” by B.C Punmia Pg 410

**17. Soil is to be excavated from a borrow pit which has a density of 17.66 kN/m$^3$ and water content of 12%. The specific gravity of soil particle is 2.7. The soil is compacted so that water content is 18% and dry density is 16.2kN/m$^3$. For 1000cum of soil in fill, estimate**

**(i)The quantity of soil to be excavated from the pit in cum**

**(ii)The amount of water to be added. Also determine the void ratio of the soil in borrow pit and fill (Nov/Dec 2010)**

**Given**

$\gamma$ = 17.66 kN/m$^3$

w = 12%

G = 2.7

After compaction $\gamma_d$ = 16.2kN/m$^3$ w=18%

**Solution**

Let us use suffix 1 for borrow pit and 2 for the fill.

For the borrow pit

$$\rho = \frac{G\rho_w(1+w)}{1+e}$$

$$or\ e_1 = \frac{G\rho_w(1+w)}{\rho} - 1 = \frac{2.7x(1+0.12)}{1.75} - 1 = 0.728$$

For the fill

$$\rho_d = \frac{G\rho_w}{1+e}$$

$$or\ e_2 = \frac{G\rho_w}{\rho_d} - 1 = \frac{2.7x1}{1.65} - 1 = 0.6364$$

Since the volume of solids remains constant.

$$V_s = \frac{V_1}{1+e_1} = \frac{V_2}{1+e_2} = \frac{1000}{1+0.6364} = 611.1m^3$$

$$V_1 = 611.1(1+0.724) = 1056m^3 Again\ in\ general, w = \frac{M_w}{M_d}\ \ But\ Md = Ms = mass\ of\ solids$$

$$= V_s G\rho_w = 611.1x2.7x1 = 1649.97t$$

$$M_{w1} = Mdw_1 = 1649.97x0.12 = 197.996m^3$$

$$M_{w2} = Mdw_2 = 1649.97x0.18 = 296.995m^3$$

$$Water\ to\ be\ added = M_{w2} - M_{w1} = 296.995 - 197.996 = 99m^3$$

**18. The mass of soil specimen coated with thin layer of paraffin wax is 690.6g and the mass of soil alone is 683g. When the paraffin coated specimen is immersed in water, it displaces 350cc of water. The specific gravity of solids of the soil is 2.7 and that of wax is 0.89. Find the void ratio and degree of saturation if it has got water content of 17%. (Apr/May 2010)**

**Solution**

Mass of wax = 690.6-683 = 7.6gm

$$Volume\ of\ wax = \frac{7.60}{0.89x1} = 8.54ml$$

$$Volume\ of\ soil = 350 - 8.54 = 341.46ml$$

$$Bulk\ density\ \gamma = \frac{683}{341.46} = 2.00g/ml$$

$$\gamma_d = \frac{\gamma}{1+w} = \frac{2.00}{1+0.17} = 1.70g/ml$$

$$We\ know\ that\ \gamma_d = \frac{G\gamma_w}{1+e}$$

$$1+e = \frac{G\gamma_w}{\gamma_d}$$

$$e = 0.58$$

$$e.S = w.G$$

$$S = \frac{wG}{e} = \frac{0.17x2.7}{0.58} = 79.1\%$$

**19. A natural soil sample has bulk density of 19.5kN/m$^3$ with 6.5% water content. Calculate the amount of water required to be added to 1cum of soil to raise the water content of 15% while the void ratio remains constant. What is then the degree of saturation? Take G= 2.67.(Apr/May 2010)**

**Given**

$$\gamma = 19.5kN/m^3$$

$$w = 6.5\%$$

**Solution**

$$\gamma_d = \frac{\gamma}{1+w} = \frac{19.5}{1+0.065} = 18.30\frac{kN}{m^3}$$

$$when\ w = 6.5\%$$

$$w = \frac{W_w}{W_d}$$

$$W_d = \gamma_d.V = 18.30x1 = 18.30kN$$

$$W_w = W_d x w = 18.30x0.065 = 1.18kN$$

$$V_w = \frac{W_w}{\gamma_w} = \frac{1.18}{9.81} = 0.121m^3$$

$when\ w = 15\%$

$W_w = W_d x w = 18.30x0.15 = 2.74kN$

$V_w = \frac{W_w}{\gamma_w} = \frac{2.74}{9.81} = 0.279m^3$

Additional water required to raise the water content from 6.5% to 15%

= 0.279-0.121= 0.158 (158 litres)

**Void ratio (e)**

$\mathbf{e = \frac{G\gamma w}{\gamma_d} - 1}$

e = 0.431

**Degree of saturation**

$$S = \frac{wG}{e}$$

$$S = 92.9\%$$

## UNIT – II

## EFFECTIVE STRESS AND PERMEABILITY

## PART A

1. **State Darcy's law along with its limitations.(May/June 14)( Nov/Dec 10)(Apr/May 10)**

   Darcy performed experimental studies of the flow of water through sand and developed the following relationship, known as *Darcy's law.*

$$Q = kiA$$

   Where:
   Q = Flow rate
   k = Hydraulic conductivity (Also called coefficient of permeability)
   i = hydraulic gradient
   A = area perpendicular to the flow direction.

2. **Differentiate seepage velocity from discharge velocity (May/June 2014)(Apr/May 2010).**
   **Seepage velocity:** Seepage velocity is the rate of movement of an element of water through a soil.
   **Discharge velocity:** Discharge velocity is the quantity of flow that flows through a unit cross sectional area of the soil in a unit time.

3. **What is the importance of effective stress ( Nov/Dec 2013)**
   Effective stress is the pressure transmitted from particle through their point of contact through the soil mass. It is also termed as inter granular pressure. It is effective in reducing the void ratio of the soil mass and in mobilizing shear strength.

4. **What is quick sand? ( Nov/Dec 2013)(Nov – Dec 2011)**
   Quick sand condition occurs in sandy soils when upward seepage produces an effective stress close to zero. Cohesion also is zero, these soils have no shear strength and behave as a heavy fluid.

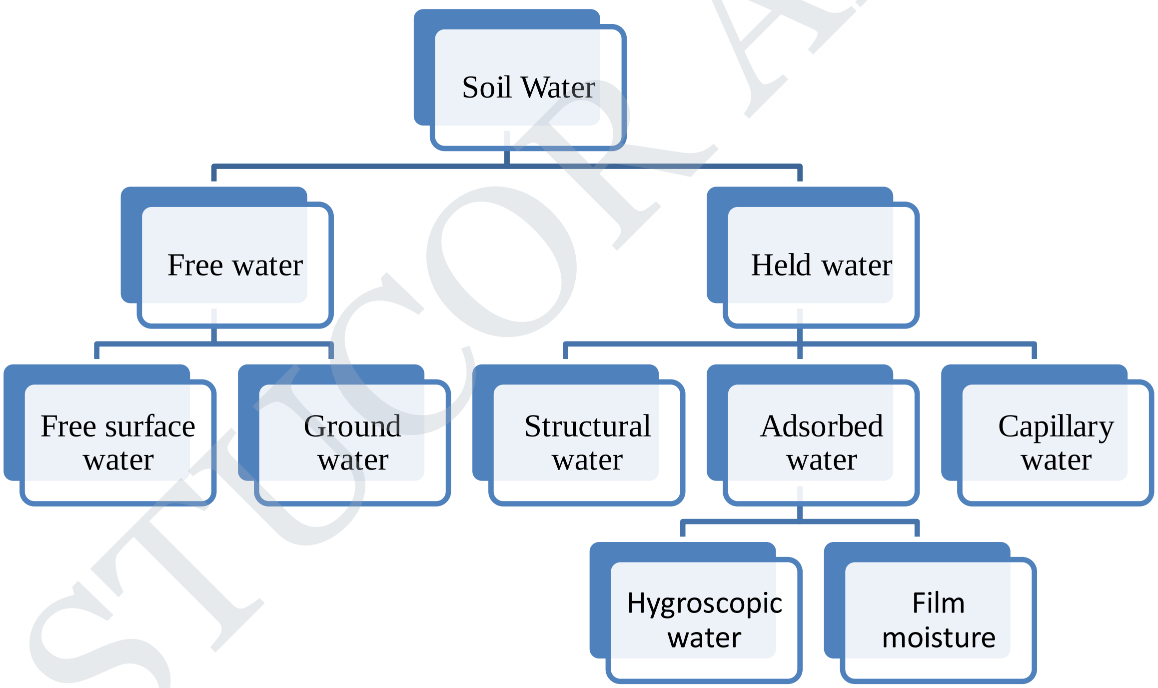
5. **In a laboratory permeability test on a clayey sample, the diameter of the standpipe is 2cm and the diameter of the permeameter is 120cm. The height of the mould is 130cm. Determine the time taken for the head of water in the standpipe to drop from 190cm to 150cm. ( May/June 2013)**

   **Given**
   d = 2cm
   D = 120cm
   L = 130cm

t = ?
$h_1$ = 190cm
$h_2$ = 150cm

**Solution**
Coefficient of permeability by falling head method is given by
k = 2.303 $\log_{10}(\frac{h_1}{h_2})\frac{aL}{At}$
substituting the values in the above equation, assuming k = $1\text{x}10^{-4}$ cm/sec
$1\text{x}10^{-4}$ = 2.303 $\log_{10}(\frac{190}{150})\frac{130x\pi}{11309.7xt}$
We get **t = 85.3 sec**

6. **What are the different types of soil water? ( May/June 2013)( May/June 2012) (Nov/Dec 2010)**




7. **What is total stress, neutral stress and effective stress?(Nov/Dec 12)(Nov/Dec 2010)**
**Total stress:** Sum of the stresses carried by the two phases (solid and water) is called total stress.
**Neutral stress:** Neutral stress or pore water pressure is the portion of stress carried by the pore water
**Effective stress:** Effective stress is the portion of stress carried by the solid particles.

8. **What is meant by capillary rise in soil? ( Nov/Dec 2012)( Apr/May 2011)**

Capillary rise is the upward movement of a liquid into the vadose zone, which is above the level of zero hydrostatic pressure. This upward movement occurs in porous media or in very small tubes.

**9. List out the methods of drawing flownet. ( May/June 2012)**

- Analytical method
- Electrical flow analogy
- Capillary flow analogy
- Sand model
- Graphical method

**10. Define cation exchange capacity. ( Nov/Dec 2011)**

The ability of a clay particle to absorb ions on its surface or edges is called its base or cation exchange capacity. It is a function of the mineral structure of clay and the size of particles.

**11. What are the major uses of flownet? ( Apr/May 2011)( Nov/Dec 2010)**

Once a flownet is constructed, its graphical properties can be used to obtain solutions for many seepage problems, such as:

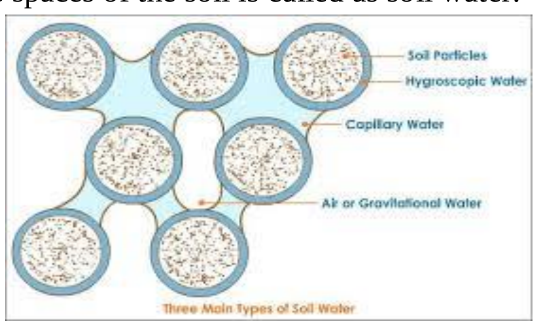
1. Estimation of seepage losses from the reservoirs
2. Determination of seepage pressures
3. Uplift pressure below dams
4. To check against the possibility of piping.

**12. What is surface tension? ( Apr/May 2011)**

**Surface tension** is a contractive tendency of the surface of a liquid that allows it to resist an external force.

**13. Define soil water ( Apr/May 2011)**

Water that is present in the pore spaces of the soil is called as soil water.




**14. The discharge and seepage velocities of a soil are $1\times10^{-3}$ cm/sec and $2\times10^{-3}$ cm/sec. Find the void ratio of the soil. ( Nov/Dec 2010)**

**Given**

$v_s = 2x10^{-3}$ cm/sec
$v = 1x10^{-3}$ cm/sec
Since, $v_s = \frac{v}{n}$
$n = \frac{1x10^{-3}}{2x\,10^{-3}}$

n = 0.5

we know that

$$e = \frac{n}{1-n}$$

substituting n = 0.5 in the above equation we get e = 1
Hence void ratio of the soil is 1.

**15. Differentiate laminar and turbulent flow. ( Nov/Dec 2010)**

**Laminar flow:** Flow is said to be laminar if a fluid particle follows a definite path and does not cross the path of other particle.

**Turbulent flow:** Flow is turbulent when random velocity fluctuations result in a zig-zag and criss crossing path of fluid particles.

**16. State the factors which cause swelling of soil.( Nov/Dec 2010)**

- ❖ Compressive forces between the solid particles
- ❖ Attraction of dipolar molecules of water to negatively charged soil particles
- ❖ Mutual repulsion of clay particles and adsorbed layers
- ❖ Expansion of entrapped air

**17. Write different methods for determining the coefficient of permeability (Nov/Dec 2010)**

**Laboratory methods:**
Constant head test
Falling head test
**Field methods**
Pumping in test
Pumping out test
**Other methods of computation**
From consolidation test data
From particle size

**18. List any four assumptions made in the construction of flownet. ( Nov/Dec 2010)**

- ❖ The curves should be roughly elliptical or parabolic in shape
- ❖ All transitions should be smooth
- ❖ The flow lines and equipotential lines should be orthogonal and form appropriate squares.
- ❖ Three to five flow channels are sufficient.

**19. What is seepage pressure? ( Nov/Dec 2010)**

By virtue of the viscous friction exerted on water flowing through the soil pores an energy transfer is effected between the water and the soil. The force corresponding to this energy transfer is called the seepage force or seepage pressure.

**20. The critical hydraulic gradient of a sandy soil having specific gravity of solids of 2.7 is 0.1. Find its porosity. ( Apr/May 2010)**

**Given**

$i_c = 1$

G = 2.7

**Solution**

$$ic = \frac{G-1}{1+e}$$

Substituting $i_c = 1$, G = 2.7 in the above equation we get

e = 0.7

To find porosity 'n'

$$n = \frac{e}{1+e}$$

$$n = \frac{0.7}{1+0.7}$$

$\boldsymbol{n}$ **= 0.41**

**21. Name the methods of determining permeability of soil and write down the formula for any one method. ( Apr/May 2010)**

**Laboratory methods:**

Constant head test

Falling head test

Formula for falling head method:

$k = 2.303 \log_{10}(\frac{h_1}{h_2}) \frac{aL}{At}$

where

k = permeability in cm/sec

$h_1$ = Initial height

$h_2$ = Final height

a = area of the stand pipe

L = Height of the

A = Cross sectional area of the soil sample
t = Time elapsed for the head to drop from $h_1$ to $h_2$

**22. Find the critical hydraulic gradient of a saturated sand with moisture content of 34% and specific gravity of 2.64. ( Apr/May 2010)**

**Given**

G = 2.64
w = 34%
$i_c$ = ?

**Solution**

$$ic = \frac{G-1}{1+e}$$

We know e.S = w.G
Soil is saturated S = 1, w = 0.34, G = 2.64
Hence e = 0.89
Critical hydraulic gradient

$$ic = \frac{2.64-1}{1+0.89}$$

**$i_c$ = 0.86**

**23. State the difference between unconfined and confined aquifer. (May/June 2010).**

**Unconfined aquifer:** Aquifer, in which a free water surface (water table) exists is called as unconfined aquifer.

**Confined aquifer:** Aquifer, which is confined between two impervious zones, is called as confined aquifer.

**24. Why is there more likelihood of quick sand condition in sands than in clays? (Nov/Dec 2009)**

For sand shear strength S = σ + tanφ
For clay shear strength S = c + σ + tanφ
Quick sand condition occurs when effective stress is reduced. In clay, even if the effective stress becomes zero there is some strength equal to cohesion intercept, hence cohesive soils are less prone to quick sand condition.

**25. A stratum consisting of fine sand is 2m thick. Under what head of water, lowing in an upward direction, will a quick sand condition develop. Take specific gravity of solids and void ratio as 2.68 and 0.6 respectively. ( Nov/Dec 2009)**

**Condition for quick sand**

$$i = \frac{\gamma'}{\gamma_w}$$

$\gamma' = \frac{G-1}{1+e}\gamma_w$

Substituting the values of G = 2.68, e = 0.6, $\gamma_w$ = 9.81kN/m$^3$ in the above equation we get

$\gamma'$= 10.3 kN/ m$^3$

Therefore

$$i = \frac{10.3}{9.81}$$

$i$ = 1.05

We know that

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

***Therefore h* = 2.1m**

**26. What is permeability of soil? ( June 2009)**

The property of soil by which it permits water to flow through it, is called as permeability (or) It is the ease with which water can flow through soil.

**27. Find the critical hydraulic gradient of a saturated soil mass with moisture content of 40% and specific gravity of solids 2.7 ( May 2009).**

**Given**

G = 2.7

w = 40%

$i_c$ = ?

**Solution**

$$ic = \frac{G-1}{1+e}$$

We know e.S = w.G

Soil is saturated S = 1, w = 0.40, G = 2.7

Hence e = 1.08

Critical hydraulic gradient

$$ic = \frac{2.7-1}{1+1.08}$$

**$i_c$ = 0.8**

**28. A loose uniform sand with rounded grains has an effective size $D_{10}$ equal to 0.3mm. Estimate the coefficient of permeability. ( May 2009)**

**Solution**

Effective size $D_{10}$ = 0.3mm

$k = C\ D_{10}^2$ [Allen Hazen's equation]
$k = 100(0.3)^2$
**k = 9 mm/sec**

**29. List the factors that affect coefficient of permeability. ( Nov/Dec 2009)**

- Particle size
- Structure of soil mass
- Shape of particles
- Void ratio
- Properties of water
- Degree of saturation
- Adsorbed water
- Impurities in water

**30. What is critical hydraulic gradient? ( June 2009)**

The hydraulic gradient at which the effective stress becomes zero is called as critical hydraulic gradient.

**31. What is adsorbed water? ( June 2009)**

The water held by electro-chemical forces existing on the soil surface is known as adsorbed water.

## PART B

1. **The falling head permeability test was conducted on a soil sample of 4cm diameter and 18cm length. The head fell from 1.0m to 0.40m in 20 minutes. If the cross sectional area of the stand pipe was 1 $cm^2$, determine the coefficient of permeability. (Apr/May 2014)**

**Given**

**Soil sample properties**

Diameter $D = 4cm$, Length $= 18cm$

Area of the soil sample $= \frac{\pi}{4} xD^2 = 12.56cm^2$

Initial height $h_1 = 1.0m = 100cm$

Final height $h_2 = 0.4m = 40cm$

Area of the stand pipe $= 1cm^2$

**To find the permeability k**

**Solution**

Permeability by variable head method is given by

$$k = 2.303 \frac{aL}{At} \log_{10} \left( {}^{h_1}/_{h_2} \right)$$

$$k = 2.303 \frac{1x18}{12.56x20} \log_{10} \left( {}^{100}/_{40} \right)$$

$$\mathbf{k = 0.065 cm/min}$$

2. **Explain in detail various uses of flownet. ( Apr/May 2014)(Apr/May 2011)(Nov/Dec 2010)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 234 – 236

3. **What is a flownet? Describe the method used to construct the flownet (Nov/Dec 2013)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 232 - 234

4. **In a falling head permeameter test, the initial head is 40cm. The head drops by 5cm in 10 minutes. Calculate the time required to run the test for the final head to be 20cm. If the sample is 6cm height and 50$cm^2$ in cross sectional area, calculate the coefficient of permeability, take area of stand pipe is 0.5 $cm^2$.( Nov/Dec 2013)**

**Given**

$h_1 = 40cm$

$h_1 = 35cm$

$t = 10$ min

$L = 6cm$

$A = 50cm^2$

a =0.5 cm$^2$

**To find (t for final head of 20cm)**
**Solution**

$$k = 2.303\frac{aL}{At}\log_{10}\left({}^{h_1}/{}_{h_2}\right)$$

$$k = 2.303\frac{0.5x6}{50x10}\log_{10}\left({}^{40}/{}_{35}\right)$$

$$\mathbf{k = 8.01x10^{-4}cm/min}$$

**To find the time required for the head to fall to 20cm**

$$8.01x10^{-4} = 2.303\frac{0.5x6}{50xt}\log_{10}\left({}^{40}/{}_{20}\right)$$

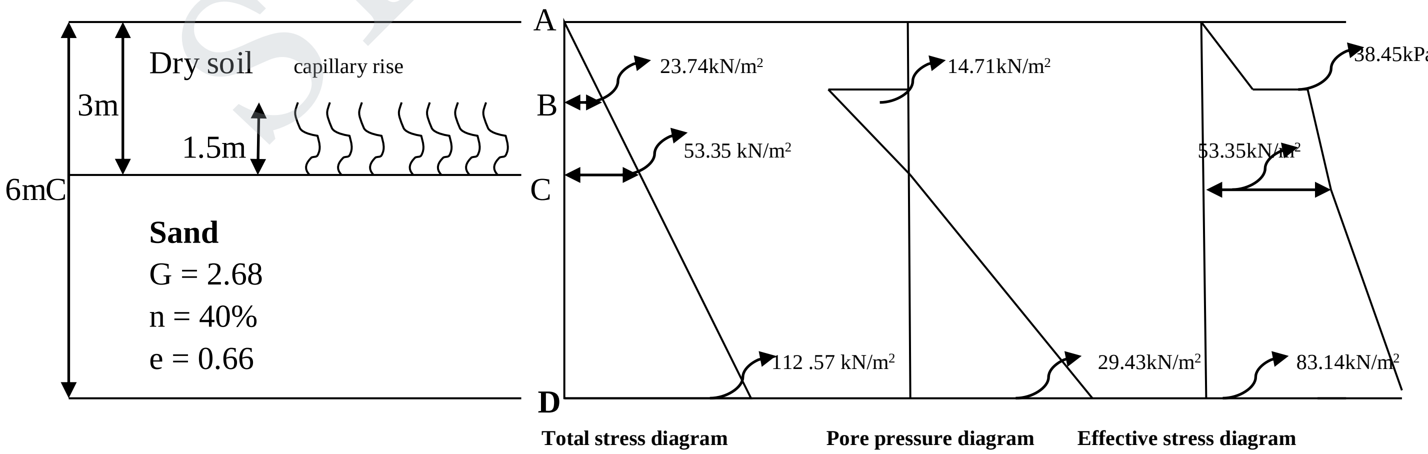
$$\mathbf{t = 51.9\ min}$$

5. **Derive an equation to determine the coefficient of permeability in an unconfined aquifer. (May/June 2013)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 207 – 209

6. **Write down the procedure for determination of permeability by constant head test in the laboratory. (Nov/Dec 2012)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 188 – 189

7. **Explain the falling head permeability test.( Apr/May 2011)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 189

8. **In a deposit of fine sand the water table is 3m below the ground level. The capillary rise is 1.50m above the water table. The specific gravity of sand is 2.68 with a porosity of 40%. Calculate the effective stress at a depth of 6m with and without considering capillary rise. (Apr/May 2011)**



**With capillary rise**

$$\gamma_d = \frac{G\gamma_w}{1+e} = \frac{2.68x9.81}{1+0.66} = 15.83kN/m^3$$

$$\gamma_{sat} = \frac{G+e}{1+e}\gamma_w = 19.74kN/m^3$$

**Total stress distribution**

At A $\sigma = 0$

At B $\sigma = \gamma_d Z = 15.83x1.5 = 23.74kN/m^2$

At C $\sigma = \gamma_d Z + \gamma_{sat} Z = 15.83x1.5 + 19.74x1.5 = 53.35kN/m^2$

At D $\sigma = \gamma_d Z + \gamma_{sat} Z + \gamma_{sat} Z = 15.83x1.5 + 19.74x1.5 + 19.74x3 = 112.57kN/m^2$

**Pore pressure distribution**

At A u = 0

At B u = -Z$\gamma_w$ = -1.5x9.81 = -14.714 kN/m$^2$

At C u = 0, At D u = 3x9.81 = 29.43kN/m$^2$

**Effective stress distribution**

At A σ' = σ – u = 0

At B σ' = 23.74 – (- 14.714) = 38.45 kN/m$^2$

At C σ' = 53.53 – 0 = 53.35 kN/m$^2$

At D σ' = 112.57 – 29.43 = 83.14 kN/m$^2$

**Without capillary rise**

**Total stress distribution**

At A $\sigma = 0$

At B $\sigma = \gamma_d Z = 15.83x3 = 47.49kN/m^2$

At C $\sigma = \gamma_d Z + \gamma_{sat} Z = 15.83x3 + 19.74x3 = 106.71kN/m^2$

**Pore pressure distribution**

At A u = 0

At B u = 0

At C u = 3x9.81 = 29.43kN/m$^2$

**Effective stress distribution**

At A σ' = σ – u = 0

At B σ' = 47.49 – 0 = 47.49 kN/m$^2$

At C σ' = 106.71 – 29.43 = 77.28 kN/m$^2$

**9. In a falling head permeameter, the sample was 18cm long and having a cross sectional area of 22 cm$^2$. Calculate the time required for the drop of head from 25cm to 10cm, if the cross sectional area of the stand pipe was 2cm$^2$. The sample of soil was homogeneous having coefficient of permeability of 3x10$^{-4}$ cm/sec for the first 6cm, 4x10$^{-4}$ cm/sec for the second 6cm and 6x10$^{-4}$ cm/sec for the last 6cm thickness. Assume the flow taking place perpendicular to the bedding planes.(Nov/Dec 2010)**

**Given**

L = 18cm
A = 22cm$^2$
t = ?
$h_1$ = 25cm, $h_2$ = 10cm
a = 2cm$^2$

**Solution**
When flow is perpendicular

$$k = \frac{h_1 + h_2 + h_3}{\frac{h_1}{k_1} + \frac{h_2}{k_2} + \frac{h_3}{k_3}}$$

$$k = \frac{6 + 6 + 6}{\frac{6}{3x10^{-4}} + \frac{6}{4x10^{-4}} + \frac{6}{6x10^{-4}}}$$

$$\mathbf{k = 4x10^{-4} cm/sec}$$

**To determine t**

$$k = 2.303 \frac{aL}{At} \log_{10} \left({}^{h_1}/_{h_2}\right)$$

$$t = 2.303 \frac{aL}{Ak} \log_{10} \left({}^{h_1}/_{h_2}\right)$$

$$t = 2.303 \frac{2x18}{22x4x10^{-4}} \log_{10} \left({}^{25}/_{10}\right)$$

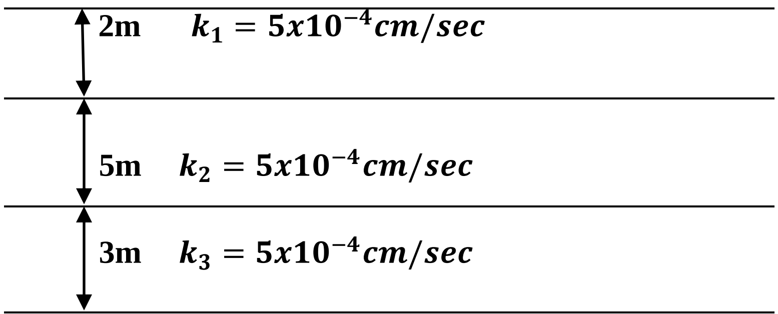
$$\mathbf{t = 62.4\ min}$$

**10. List the factors affecting permeability and explain them in detail(Nov/Dec 2010)**

Refer “Soil Mechanics and Foundations” by B.C Punmia Pg 183 - 184

**11. A stratified soil deposit is shown in the fig. along with the coefficient of permeability of the individual strata. Determine the ratio of $K_H$ and $K_V$. Assuming an average hydraulic gradient of 0.3 in both horizontal and vertical seepage, find**

**(i)Discharge value and discharge velocities in each layer for horizontal flow and**
**(ii)Hydraulic gradient and loss in head in each layer for vertical flow. (Nov/Dec 2010)**




**Solution**

Average coefficient of permeability for horizontal flow,

$$k_H = \frac{k_1 H_1 + k_2 H_2 + k_3 H_3}{H} = \frac{200x5x10^{-4} + 500x5x10^{-4} + 300x5x10^{-4}}{1000}$$

$$k_H = 5x10^{-4} \ cm/sec$$

Average coefficient of permeability for vertical flow,

$$k_v = \frac{H}{\frac{H_1}{k_1} + \frac{H_2}{k_2} + \frac{H_3}{k_3}} = \frac{1000}{\frac{200}{5x10^{-4}} + \frac{500}{5x10^{-4}} + \frac{300}{5x10^{-4}}} = 5x10^{-4} \ cm/sec$$

Therefore, $\frac{k_H}{k_v} = \frac{5x10^{-4} \ cm/sec}{5x10^{-4} \ cm/sec} = 1$

1) Horizontal flow

q = $k_H$ i A = $5x10^{-4}$ x0.3x10x$10^2$ = 0.15 cc/s/cm width

$$v_1 = k_1 i = 5x10^{-4} x0.3 = 1.5x10^{-4} cm/sec$$

$$v_1 = k_2 i = 5x10^{-4} x0.3 = 1.5x10^{-4} cm/sec$$

$$v_1 = k_3 i = 5x10^{-4} x0.3 = 1.5x10^{-4} cm/sec$$

For horizontal flow the gradient flow is the same but the velocity of flow is different for different layers

$$v = k_v i = v_1 = k_1 i_1 = v_2 = k_2 i_2 = v_3 = k_3 i_3$$

For vertical flow, velocity of flow is the same because of continuity of flow, but gradients are different for different layers

$v = 5x10^{-4}\ x\ 0.3 = 1.5x10^{-4} cm/sec$

$i_1 = \frac{1.5x10^{-4}}{5x10^{-4}} = 0.3 \qquad i_2 = \frac{1.5x10^{-4}}{5x10^{-4}} = 0.3 \qquad i_1 = \frac{1.5x10^{-4}}{5x10^{-4}} = 0.3$

**Loss in head in each layer of flow**

$h_1 = i_1 H_1 = 0.3x200 = 60cm$

$h_2 = i_2 H_2 = 0.3x500 = 150cm$

$h_3 = i_3 H_3 = 0.3x300 = 90cm$

Check total head loss = 60+150+90 = 300cm = 0.3(i) x 1000(H)

**12. A constant head permeability test was carried out on a sandy soil sample 160mm in length and 6000mm$^2$ in cross sectional area. Porosity was 40%. Under a constant head of 300mm a discharge was found to be 45x10$^3$ mm$^3$ in 18 seconds. Calculate the coefficient of permeability. Also evaluate the discharge velocity and seepage velocity during the test. Estimate the permeability of the sandy soil for a porosity of 30%. (Apr/May 2010)**

**Given**

L = 160mm
A = 6000mm$^2$
n = 40%
h = 300mm
t = 18sec
Q = 45x10$^3$ mm$^3$

**To find**

Permeability k
Discharge velocity V
Superficial velocity $V_s$

**Solution**

By constant head method

$k = \frac{QL}{Aht} = \frac{45x10^3x160}{6000x300x18} = 0.22mm/sec$

**Discharge velocity**

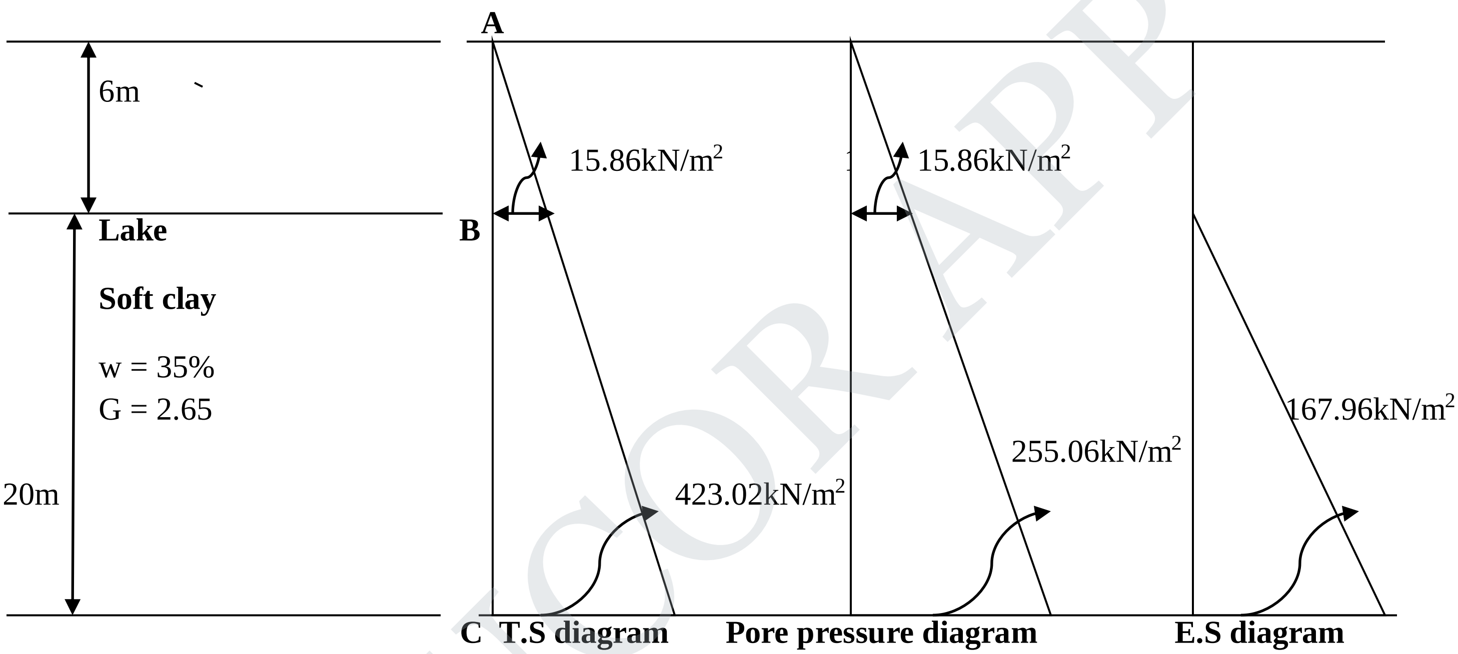
$V = \frac{Q}{At} = \frac{45x10^3}{6000x18} = 0.41mm/sec$

**Superficial velocity**

$V_s = \frac{V}{n} = \frac{0.41}{0.30} = 1.38mm/sec$

**13. Compute the total, effective and pore water pressure at a depth of 20m below the bottom of a lake 6m deep. The bottom of the lake consists of soft clay with a thickness of more than 20m. The average water content of the clay is 35% and specific gravity of the soil may be assumed 2.65. ( Apr/May 2010)**

**Solution**




**For the clay soil**

We know that $Se = W_{sat}G$

Void ratio $e = W_{sat}G$ (Since $S = 1$)

$e = 0.35x2.65 = 0.9275$

$\gamma_{sat} = \frac{\gamma_w(G+e)}{1+e} = \frac{9.81(2.65+0.9275)}{1+0.9275} = 18.208kN/m^3$

**i) Total stress(σ)diagram**

At A, $\sigma = 0$

At B, $\sigma = 9.81x6 = 58.86\ kN/m^2$

At C, $\sigma = 9.81x6 + (18.208x20) = 423.02\ kN/m^2$

**ii)Pore pressure diagram(u)**

At A, $u = 0$

At B, $u = 9.81x6 = 58.86\ kN/m^2$

At C, $u = 9.81x6 + (9.81x20) = 255.06\ kN/m^2$

**iii) Effective stress diagram** $(\sigma' = \sigma - u)$

At A, $\sigma' = 0$

At B, $\sigma' = 58.86 - 58.86 = 0$

At C, $\sigma' = 423.02 - 255.06 = 167.96\ kN/m^2$

**14. What will be the ratio of average permeability in horizontal direction to that in the vertical direction for a soil deposit consisting of three horizontal layers, if the thickness and permeability of the second layer are twice of those of the first and those of the third layer twice those of the second(Apr/May 2010)**

**Solution**

Let $K_1$ and $Z_1$ stand for first layer ,

For second layer $K_2 = 2K_1$ and $Z_2 = 2Z_1$

For third layer $K_3 = 2K_2 = 4K_1$ and $Z_3 = 2Z_2 = 4Z_1$

Total $Z = Z_1 + 2Z_1 + 4Z_1 = 7Z_1$

Average permeability of the soil deposit, $K_H = \dfrac{K_1Z_1 + K_2Z_2 + \cdots K_nZ_n}{Z}$

$$= \frac{K_1Z_1 + 2K_1 2Z_1 + 4K_1 4Z_1}{7Z_1} = \frac{21K_1}{7}$$

Average permeability perpendicular to the bedding plane, $K_v = \dfrac{Z}{\frac{Z_1}{K_1} + \frac{Z_2}{K_2} + \cdots \frac{Z_n}{K_n}}$

$$= \frac{7Z_1}{\frac{Z_1}{K_1} + \frac{2Z_2}{2K_1} + \frac{4Z_1}{4K_1}} = \frac{7K_1}{3}$$

The ratio of average permeability in the horizontal direction to that in the vertical direction

$$\frac{K_H}{K_v} = \frac{\frac{21K_1}{7}}{\frac{7K_1}{3}} = 1.286$$

## UNIT – III

## STRESS DISTRIBUTION AND SETTLEMENT

## PART A

**1. Compare Boussinesque's and Westergaard's analysis (May/June 2014)( Nov/Dec 2010)**

| Sl.No | Boussinesq's theory | Westergaard's theory |
|---|---|---|
| 1 | Boussinesq's theory assumes soil deposit is isotropic | The theory assumes that there are thin sheets of materials sandwiched in homogeneous soil mass. |
| 2 | There is both horizontal and vertical displacement of soil. | They permit only downward displacement of soil mass without any lateral displacement |

**2. Define coefficient of compressibility.( Nov/Dec 2013)**

Coefficient of compressibility is defined as the decrease in void ratio per unit increase in effective stress.

$$a_v = \frac{-\Delta e}{\Delta \sigma}$$

**3. What is an influence diagram? ( Nov/Dec 2013)(Nov/Dec 2011)**

The influence chart or influence diagram suggested by Newmark consists of a number of concentric circles divided into area units by radiating lines such that vertical stress at a given depth below the center of circles, due to load on each area unit is same.

**4. Define secondary consolidation. ( May/June 2013)**

The primary consolidation under a pressure increment ceases when the excess pore pressure caused by the applied pressure increment is fully dissipated, but some compression is observed even after the primary consolidation has ceased. This is referred to as secondary consolidation.

**5. Write down Boussinesque equation for finding out the vertical stress under a single concentrated load. ( Nov/Dec 2012) ( Apr/May 2011)**

$$\boldsymbol{\tau_z = \frac{3Q}{2\pi Z^2}\left\{\frac{1}{1+\left(\frac{r}{z}\right)^2}\right\}^{5/2}}$$

Where $\boldsymbol{\tau_z}$ = vertical stress at point P inside the soil massQ = point load acting on the surface

r = radial distance of point P from the axis of load
Z = depth of point below the surface of soil mass

6. **Define NC clays and OC clays. ( Nov/Dec 12)(Nov/Dec 10)(Apr/May 11)**
   A soil deposit is said to be normally consolidated if it has never been subjected to a pressure greater than the present existing pressure and has been fully consolidated under the presently acting pressure.
   A soil is said to be over consolidated if it has in the past been fully consolidated under a pressure greater than the present overburden pressure acting on the soil.

7. **Differentiate between compaction and consolidation. ( May/June 2012)**

| Sl.No | Compaction | Consolidation |
|---|---|---|
| 1 | This process involves the expulsion of air from the voids | This process involves the expulsion of water from the voids |
| 2 | Soil involved is partially saturated | Soil involved is completely saturated |
| 3 | Compaction occurs when dynamic load is applied on the soil | Consolidation occurs when static load is applied on the soil |
| 4 | It is a quick process | It is a slow process |

8. **What are the uses of newmark's influence chart? ( May/June 2012)**
   To use the chart for finding vertical stress at a depth z below a given point, due to a loaded area.
   Vertical ``````````stress at any point P is given by

$$\sigma_z = N_A I_f q$$

   Where,
   $N_A$ = Number of area units enclosed within the plan of loaded area
   $I_f$ = Influence value of Newmark$'$chart
   $q$ = intensity of load on given area

9. **What are isochrones? ( Nov/Dec 2011)**
   The curves which represent the excess pore pressure distribution along the depth of clay layer at different instances of time $t = t_1, t_2$……. are known as isochrones.

10. **What are the usual loading intensities released on soil sample when consolidation test is conducted?**
    Initial seating pressure – 5.0kN/m$^2$
    First increment of load gives pressure of 10kN/m$^2$
    Successive pressure applied are 20,40,80,160,320,640kN/m$^2$

11. **What are isobars? ( Apr/May 2011)( Nov/Dec 2011)**
    An isobar is a line or contour joining points inside soil mass at which the vertical stress have the same value. It is a contour of equal stress.





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**12. When a soil mass is said to be homogeneous? ( Apr/May 2011)**

A soil is said to be homogeneous if the elastic properties of the soil are the same at all points in identical directions.

**13. Write any four assumptions derived by Boussinesq's theory.( Nov/Dec 2010)**

- ❖ The soil mass is an elastic medium
- ❖ The modulus of elasticity E is a constant
- ❖ The soil mass is homogeneous
- ❖ The soil mass is isotropic
- ❖ The soil mass is semi in-finite

**14. Define the term consolidation ( Nov/Dec 2010)**

Consolidation is defined as the process in which gradual reduction in volume of soil mass occurs under sustained loading and is primarily due to expulsion of pore water.

**15. What are the factors that cause compression of clays? ( Nov/Dec 2010)**

The factors that cause compression of clays are:

- ❖ Rate of compression of solid particles and water in the voids
- ❖ Compression and expulsion of air in the voids.
- ❖ Expulsion of water present in the voids.

**16. What do you mean by under consolidated clay? ( Nov/Dec 2010)**

An underconsolidated soil deposit is one which is still not fully consolidated under the existing overburden pressure. This occurs in areas of recent landfill.

**17. State the assumptions made in Terzaghi's theory of one dimensional consolidation. (May/June 2010)**

- ❖ The soil is homogeneous and isotropic
- ❖ The soil is fully saturated
- ❖ The solid particles and water in voids are incompressible.
- ❖ Darcy's law is valid
- ❖ Soil is laterally confined.

**18. List the components of settlement in soil. ( Nov/Dec 2010)**

The various components of settlement are

- ❖ Initial settlement
- ❖ Primary or consolidation settlement
- ❖ Secondary consolidation settlement

**19. Define settlement.( May/June 2010)**

Settlement of a structure is its vertical downward movement due to a volume decrease of the soil on which it is built.

**20. What is contact pressure? How does it depend on the type of the structure and type of soil? ( May/June 2010)**

The upward pressure due to soil on the underside of the footing is termed as contact pressure.

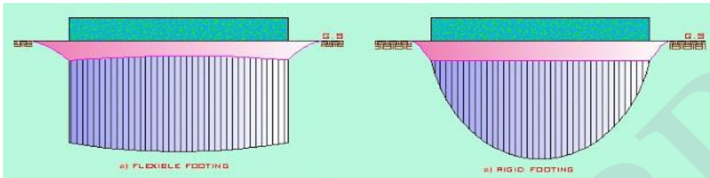



FIG. 2 CONTACT PRESSURE ON SAND.

**21. List different vertical pressure distribution diagrams that can be prepared by means of Boussinesq's theory. ( Nov/Dec 2010)**

- ❖ Vertical stress under a point load
- ❖ Vertical stress distribution on horizontal plane, vertical plane.
- ❖ Vertical stress under uniformly loaded circular area
- ❖ Vertical stress due to line load, strip load
- ❖ Vertical stress under a uniformly loaded rectangular area

**22. A circular area of diameter 5m is subjected to uniformly distributed load. Find the depth of the point along the central line of the loaded area that has vertical stress equal to 30% of the applied loading intensity.( Nov/Dec 2009)**

**Solution**

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

$$0.30q = q\left[1 - \left\{\frac{1}{1 + \left(\frac{5}{z}\right)^2}\right\}^{3/2}\right]$$

$$0.30 = \left[1 - \left\{\frac{1}{1 + \left(\frac{5}{z}\right)^2}\right\}^{3/2}\right]$$

$$0.70 = \left\{\frac{z^2}{z^2 + 25}\right\}^{3/2}$$

**z = 9.64m**

## PART B

1. **Discuss Terzaghi's theory of one dimensional consolidation, stating the carious assumptions and their validity. ( May/June 2014),( Nov/Dec 2013),(May/June 2013),( Nov/Dec 2012),(May/June 2012),(Apr/May 2010)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 346 -348

2. **A clay layer 4m thick is subjected to a pressure of 55 kN/m². If the layer has a double drainage and undergoes 50% consolidation in one year, determine the coefficient of consolidation. Take time factor as 0.196. If the coefficient of permeability is 0.020m/yr, determine the settlement in one year. ( May/June 2014)**

**Solution**

(a)We have,

$$c_v = \frac{d^2 T_v}{t} = \frac{0.196x\left(\frac{4}{2}\right)^2}{1} = 0.784\ m^2/year$$

Also, $m_v = \frac{k}{c_v \gamma_w} = \frac{0.020}{9.81X1.231} = 1.65X10^{-3} m^2/kN$

Final settlement $\rho_f = m_v \Delta\sigma' H = 1.65X10^{-3} x55x4 = 0.364m$

Settlement after 1 year = $0.5\rho_f$ = 0.5x0.364 = **0.182m**

(b)For U<60%, U is proportional to $\sqrt{t}$; hence settlement $(\rho)$is also proportional to $\sqrt{t}$ i.e $\rho = \sqrt{t}$ or $\rho^2 = t$

Let t = $C\rho^2$, where C is a constant

t = 1 year, $\rho = 0.182m$

C = $\frac{t}{\rho^2} = \frac{1}{(0.182)^2} = 30.18$

t = $30.18\rho^2$

or

$$\frac{d\rho}{dt} = \frac{1}{2x30.18x\rho} = \frac{0.0165}{\rho}$$

Since $\rho$ = 0.182 in 1 year $\frac{d\rho}{dt} = \frac{0.0165}{0.182} = \mathbf{0.090 m/year}$

(c) Discharge per unit area per face = 0.090/2 = **0.045 m³/yr/m²**

**3. A concentrated load of 10kN acts on the surface of the soil mass. Using Boussinesq's analysis find the vertical stress at points i) 3m below the surface on the axis of loading and ii) at radial distance of 2m from the axis of loading but at the same depth of 3m. ( May/June 2014)**

**Solution**

According to Boussinesq's equation

$$\boldsymbol{\tau_z = \frac{3Q}{2\pi Z^2}\left\{\frac{1}{1+\left(\frac{r}{z}\right)^2}\right\}^{5/2}}$$

**Condition 1: Directly under the load**

r = 0, z = 3m

Q= 10kN

$$\tau_z = \frac{3x10}{2\pi(3x3)}\left\{\frac{1}{1+\left(\frac{0}{3}\right)^2}\right\}^{5/2}$$

$$\boldsymbol{\tau_z = 53.05\mathrm{kN/m^2}}$$

**Condition2: At radial d/s of 2m and depth 3m**

r = 2m,z = 3m

Q=10kN

$$\tau_z = \frac{3x10}{2\pi(3x3)}\left\{\frac{1}{1+\left(\frac{2}{3}\right)^2}\right\}^{5/2}$$

$$\boldsymbol{\tau_z = 21.15\mathrm{kN/m^2}}$$

**4. A 6m thick bed of clay is overlain by 9m thick layer of sand with water table at 4m below ground surface. The initial void ratio of the clay layer is 1.08 and the compression index is 0.315. For the sand layer the bulk unit weights above and below water table are 18kN/m$^3$ and 20kN/m$^3$ respectively. Calculate the settlement of a building constructed on sand layer if it causes an increase in effective vertical stress of 100kN/m$^2$ at the middle of the clay layer. (May/June 2014).**

**Given**

For the sand layer $\gamma$ = 18kN/m$^3$ above the water table

$\gamma'$ = 20-9.81 = 10.19kN/m$^3$ below the water table

For clay layer
$e_0 = 1.08$
Assume G = 2.7

**Solution**
For the clay layer

$$\gamma' = \frac{(G-1)\gamma_w}{1+e} = \frac{(2.7-1)9.81}{1+1.08} = 8.02 kN/m^3$$

At the middle of the clay layer
$\sigma'_0 = 4x18+5x10.19+3x8.02 = 147.01 kN/m^2$

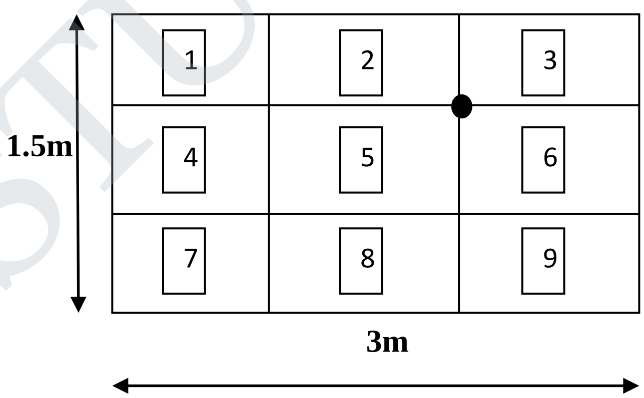
For the clay layer $C_c = 0.315$(Given)

Settlement $\rho = \frac{H}{1+e_0} C_c \log_{10} \frac{\sigma'_0 + \Delta\sigma'}{\sigma'_0}$

$$\rho = \frac{6}{1+1.08} x0.315 \log_{10} \frac{147.01+100}{147.01}$$

$\boldsymbol{\rho = 0.204 m}$ **or 204mm**

5. **A rectangular foundation 3.0mx1.5m carries a uniform load of 40kN/m². Determine the vertical stress at P which is 3m below the ground surface (Refer the fig). Use equivalent point load method. (Nov/Dec 2013)**




**Solution**
a = 0.5m
b = 2m
$m = \frac{a}{z} = \frac{0.5}{3} = 0.167$

$n = \frac{b}{z} = \frac{2}{3} = 0.667$

$$k_B = \frac{(0.0474 - 0.0242)}{(0.2 - 0.1)}(0.167 - 0.1) + 0.0242$$

$$k_B = \frac{0.0232}{0.1} 0.067 + 0.0242$$

$$k_B = 0.0397$$

Vertical stress P = $qk_B$

P = 40x0.0397

**P = 1.588kN/m$^2$**

6. **With neat sketches explain the procedure of determination of effective stress by Newmark chart method ( May/June 2013)( Apr/May 2011)**

   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 312 – 314

7. **A concentrated point load of 200 kN acts at the ground surface. Find the intensity of vertical pressure at a depth of 10m below the ground surface, and situated on the axis of loading. What will be the vertical pressure at a point at a depth of 5m and at a radial distance of 2m from the axis of loading? Use Boussinesq's equation.(Nov/Dec 2012)**

**Solution**

According to Boussinesq's equation

$$\boldsymbol{\tau_z = \frac{3Q}{2\pi Z^2}\left\{\frac{1}{1 + \left(\frac{r}{z}\right)^2}\right\}^{5/2}}$$

**Condition 1: Directly under the load at depth 10m**

r = 0, z = 10m

Q= 200kN

$$\tau_z = \frac{3x200}{2\pi(10x10)}\left\{\frac{1}{1 + \left(\frac{0}{3}\right)^2}\right\}^{5/2}$$

$$\boldsymbol{\tau_z = 95.49 kN/m^2}$$

**Condition2: At radial d/s of 2m and depth 5m**

r = 2m,z = 5m

Q=200kN

$$\tau_z = \frac{3x200}{2\pi(5x5)}\left\{\frac{1}{1+\left(\frac{2}{5}\right)^2}\right\}^{5/2}$$

$$\boldsymbol{\tau_z = 263.5kN/m^2}$$

**8. The load from a continuous footing of width 2m, which may be considered to be strip load of considerable length is 200kN/m$^2$. Determine the maximum principal stress at 1.5m depth below the footing if the point lies i) directly below the center of the footing ii) directly below the edge of the footing iii) 0.8m away from the edge of the footing. (May/June 2012)**

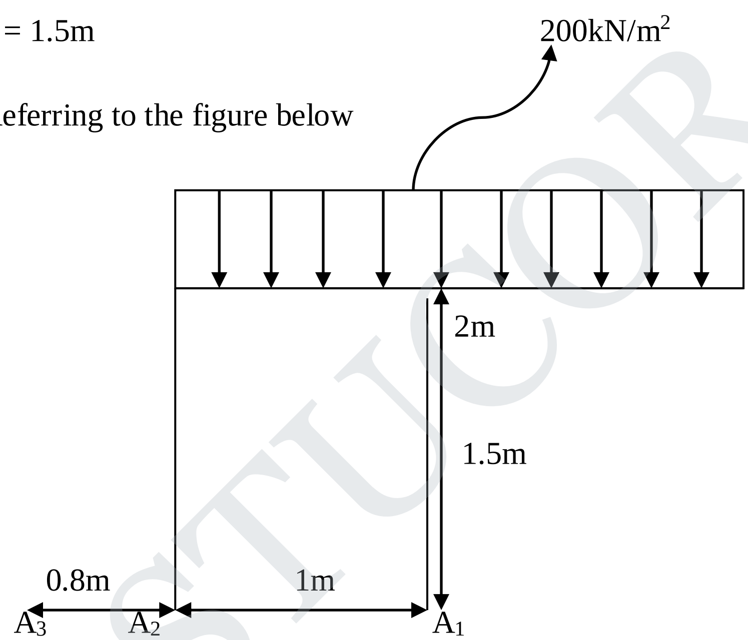
**Solution**

B = 2b = 2m

q = 200kN/m$^2$

z = 1.5m

Referring to the figure below




(i)For point $A_1$,

$$\frac{\theta_0}{2} = \tan^{-1}\frac{1}{1.5} = 33.69 = 0.588\text{rad}$$

$$\theta_0 = 1.176 \text{ rad}$$

Maximum principal stress

$$\sigma_1 = \left(\frac{q}{\pi}\right)(\theta_0 + \sin\theta_0) = \left(\frac{200}{\pi}\right)(1.176 + 0.923) = \mathbf{133.63kN/m^2}$$

(ii)For point $A_2$

$$\theta_o = \tan^{-1}\frac{2}{1.5} = 53.13 = 0.927\text{rad}$$

$$\sigma_1 = \left(\frac{q}{\pi}\right)(\theta_0 + \sin\theta_0) = \left(\frac{200}{\pi}\right)(0.927 + 0.799) = \mathbf{109.9 kN/m^2}$$

(iii)For point $A_3$

$$\theta_1 = \tan^{-1}\left(\frac{0.8}{1.5}\right) = 28.07 = 0.48 \text{ rad}$$

$$\theta_2 = \tan^{-1}\left(\frac{2.8}{1.5}\right) = 61.80 = 1.078 \text{ rad}$$

$$\theta_0 = \theta_2 - \theta_1 = 0.598 \text{ rad}$$

$$\sigma_1 = \left(\frac{q}{\pi}\right)(\theta_0 + \sin\theta_0) = \left(\frac{200}{\pi}\right)(0.598 + 0.562) = \mathbf{73.919 kN/m^2}$$

**9. How will you determine the coefficient of compression index from an oedometer test?( Apr/May 2011)( Nov/Dec 2010)**

Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 354 - 355

**10. How will you determine preconsolidation pressure? (Apr/May 2011)**

Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 346

**11. Derive Boussinesq's equation to find the intensity of vertical pressure and tangential stress when a concentrated load is acting on the soil. ( Nov/Dec 2010)**

Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 329 - 330

**12. An undrained soil sample 30cm thick got 50% consolidation in 20 minutes with drainage allowed at the top and bottom in the laboratory. If the clay layer from which the sample was obtained is 3m thick in field condition, estimate the time it will take to consolidate 50% with double surface drainage and in both cases, consolidation pressure is uniform ( Nov/Dec 2010)**

**Solution**

For the same degree of consolidation, $T_v$ is the same.

Hence $t \alpha \frac{d^2}{c_v}$, Also since both the soils are the same, $t \alpha d^2$

**(a) For the same case of double drainage**

$$\left(\frac{t_2}{t_1}\right) = \left(\frac{d_2}{d_1}\right)^2$$

$d_2 =$ drainage path in the field $= \frac{3}{2}\text{m} = 150\text{cm}$

$d_1 =$ drainage path in the laboratory specimen $= \frac{3}{2}\text{cm} = 1.5\text{cm}$

$t_1$ = Time for 50% consolidation in the laboratory = 20 min.

Therefore,

$$t_2 = t_1 \left(\frac{d_2}{d_1}\right)^2 = 20\left(\frac{150}{1.5}\right)^2 \text{ minutes} = \mathbf{385\ days}$$

**(b) For the case of double drainage**

$d_2$ = 3.5m = 350cm

$$T_2 = 20\left(\frac{350}{1.5}\right)^2 \text{ minutes} = \mathbf{756\ days}$$

**13. There is a layer of soft clay 4m thick under a newly constructed building. The overburden pressure over the center of the clay layer is 300kN/m$^2$. Compute the settlement if there is an increase in pressure of 100kN/m$^2$ due to construction. Assume Cc = 0.50, Gs = 2.70. the water content of the deposit was found to be 50% (Apr/May 2010)**

**Given**

Initial pressure $\sigma_o$ = 300kN/m$^2$

Incremental pressure = 100kN/m$^2$

Thickness of the soft clay = 4m

Compression index Cc = 0.50

w = 50%

Gs = 2.70

**Solution**

To compute the settlement

$$\mathbf{S = \frac{HC_c}{(1+e_o)}\log_{10}\left(\frac{\sigma_o + \Delta\sigma}{\sigma_o}\right)}$$

To compute $e_o$

We know

$e.S = w.G$

Since the soil is saturated S =1

Therefore e = 0.50x2.70

e = 1.35 = $e_o$

$$\mathbf{S = \frac{4x0.50}{(1+1.35)}\log_{10}\left(\frac{300+100}{300}\right)}$$

**S = 0.109m**

**14. The unit weight of soil in a uniform deposit of loose sand (Ko = 0.5) is 16.5 kN/m$^3$. Determine the geostatic stresses at a depth of 2m. Also determine the vertical stress at a point P which is 3m below the ground level and at a radial distance of 3m from the vertical load of 200kN. Use Boussinesq's equation (Apr/may 2010)**

Refer Soil mechanics and foundation Engineering By Dr.K.R Arora Example 11.4,11.5 Pg 250

**15. A water tank is supported by a ring foundation having outer diameter of 10m and inner diameter of 7.5m. The ring foundation transmits uniform load intensity of 160kN/m$^2$. Compute the vertical stress induced at depth of 4m, below the center of the ring foundation, using**

**Boussinesq's equation (Apr/May 2010)**

**Solution**

**a)Boussinesq's analysis**

Inner radius, $R_i = 7.5/2 = 3.75$m

Outer radius $R_0 = 10/2 = 5.0$m

$R_i/Z = 3.75/4 = 0.9375$

$R_0/Z = 5/4 = 1.25$

**For uniformly distributed load over circular area**

$$\sigma_Z = q\left[1 - \left\{\frac{1}{1+\left(\frac{q}{Z}\right)^2}\right\}^{3/2}\right]$$

$$\sigma_Z = 160\left[1 - \left\{\frac{1}{1+\left(\frac{5}{4}\right)^2}\right\}^{3/2}\right]$$

(-)

$$160\left[1 - \left\{\frac{1}{1+\left(\frac{3.75}{4}\right)^2}\right\}^{3/2}\right]$$

= 120.99 – 97.88 = **23.11 kN/m$^2$ =$\sigma_Z$**

**16. A stratum of clay with an average liquid limit of 45% is 6m thick. Its surface is located at a depth of 8m below the ground surface. The natural water content of the clay is 40% and the specific gravity is 2.7. Between ground surface and clay, the subsoil consists of fine sand. The water table is located at a depth of 4m below the ground surface. The average submerged unit weight of sand is 10.5 kN/m$^3$ and unit weight of sand above the water table**

**is 17.0 kN/m³. The weight of the building that will be constructed on the sand above the clay increases the overburden pressure on the clay by 40kN/m². Estimate the settlement of the building.( Apr/May 2010)**

**Solution**

**For clay**

$e = w_{sat}.G = 0.4x2.7 = 1.08$

$$\gamma'_{clay} = \frac{G-1}{1+e}\gamma_w = \frac{2.7-1}{1+1.08}x9.81 = 8.02kN/m^3$$

Now, effective stress at the center of the clay layer

$\sigma' = (17.0x4) + (10.5x4) + (8.02x3)$

$= 134.06kN/m^2$

$\Delta\sigma' = 40kN/m^2$

$H$ = Depth of clay layer = 6m

$e_0$ = void ratio of clay layer = 1.08

$C_c = 0.009(w_L - 10\%) = 0.009(45 - 10) = 0.315$

**Settlement of the building**

$$\Delta H = \frac{C_c H}{1+e_o}\log\frac{\sigma' + \Delta\sigma'}{\sigma'}$$

$$\Delta H = \frac{0.315x6}{1+1.08}\log\frac{134.06+40}{134.06} = 0.102m$$

Settlement of the building

$\mathbf{\Delta H = 0.102m = 102mm}$

# UNIT – IV

# SHEAR STRENGTH

## PART A

**1. What are the different types of shear test based on drainage conditions? (May/June 2014)(Nov/Dec 2011)(Nov/Dec 2010)(Apr/May 2010)**

- Unconsolidated Undrained test or simply Undrained test ( UU test)
- Consolidated Undrained test (CU test)
- Consolidated Drained test or simply Drained test ( CD test)

**2. List out the merits of triaxial test ( Nov/Dec 2013)**

- The specimen is free to fail along the weakest plane.
- The stress distribution on the failure plane is uniform.
- There is complete control of drainage conditions.
- Precise measurements of pore pressure and volume change are possible during test.
- The stresses induced on any plane within the specimen at any stage of the test can be determined.

**3. Write whether the following statement is true or false. On the failure plane , the shear stress is maximum ( Nov/Dec 2013)**

The given statement is false because the shear stress developed at failure is less than the maximum shear stress. Thus the failure plane does not carry the maximum shear stress.

**4. List out the demerits of triaxial test. ( Nov/Dec 2013)**

- The apparatus is elaborate, bulky and costly.
- The drained test takes place a longer period in comparison with a direct shear test.
- It is not possible to determine the cross sectional area of the specimen at larger strains, as the assumption that the specimen remains cylindrical does not hold good.
- The strain conditions in the specimen are not uniform due to frictional restraint produced by the loading cap and the pedestal disc. This leads to the formation of the dead zones at each end of the specimen.
- The consolidation of the specimen in the test is isotropic, whereas in the field, the consolidation is generally anisotropic.

**5. Write down the advantages of direct shear test. ( May/June 2013)**

- The test is very simple to perform.
- The thickness of the sample is very small and hence quick drainage and rapid dissipation of pore pressure is possible.

**6. Write down the expression to determine the shear strength of soil by vane shear test. (May/June 2013).**

Case 1: When both top and bottom of the vane takes part in shearing

$$T_f = \pi d^2 \tau_f \left[\frac{H}{2} + \frac{d}{6}\right]$$

Case 2: When only the bottom of the vane takes part in shearing

$$T_f = \pi d^2 \tau_f \left[\frac{H}{2} + \frac{d}{12}\right]$$

Where

$T_f$ = Torque at failure

H = Height of vanes

d = diameter across vanes

$\tau_f$ = shear strength of soil

**7. Write down the Mohr's Coulomb failure envelope equation. ( Nov/Dec 2012).**

$$\boldsymbol{\tau_f = c + \sigma tan\varphi}$$

Where c is the intercept of the strength envelope on the τ axis and tanφ the slope of the strength envelope.

**8. Why triaxial shear test is considered better than direct shear test? ( Nov/Dec 2012)**

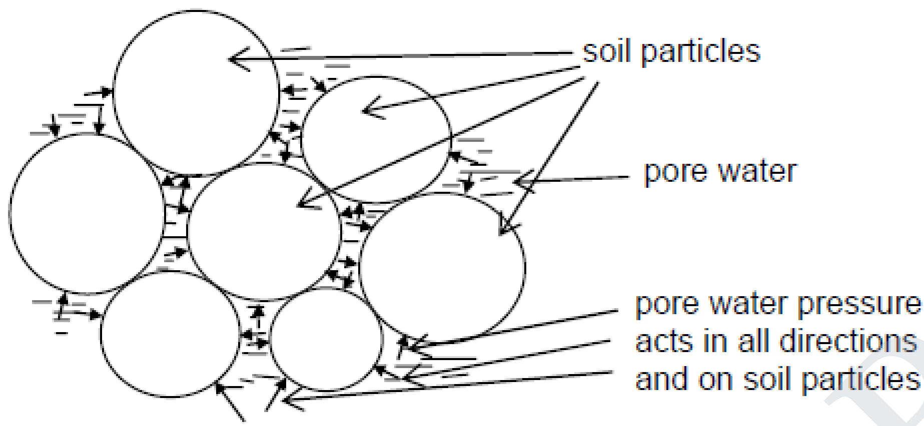
- The specimen is free to fail along the weakest plane unlike in direct shear test in which the specimen is forced to fail along a predetermined plane.
- The stress is mobilized uniformly at all points on the failure plane, unlike in direct shear test in which progressive failure takes place.
- There is complete control of drainage conditions, which enables better simulation of field drainage conditions as compared with direct shear test.

**9. State the principle of Direct shear test.( May/June 2012)**

A normal stress σ is applied on the specimen and it is kept constant throughout the test. The shear stress τ is caused by the application of shear force, and is transmitted to the top half of the shear box which bears against shear force measuring device, through the soil specimen.

**10. What is the effect of pore pressure on shear strength of soil. ( May/June 2012)**

The strength of a soil comes from friction between the soil particles. The greater the normal stress between the particles, the greater is the friction and greater shear stress $\tau$ can be supported by the soil. When pore water is present in the pores (or voids) of a soil, the pore water pressure $u$ pushes the soil particles apart and reduces the stress between the particles. Hence as the pore water pressure increases the shear strength of the soil decreases.




**11. How will you find the shear strength of cohesionless soil? ( Nov/Dec 2011)**

$$\tau_f = \sigma tan\varphi$$

The above equation gives the shear strength of cohesionless soil since c = 0 for cohesionless soils

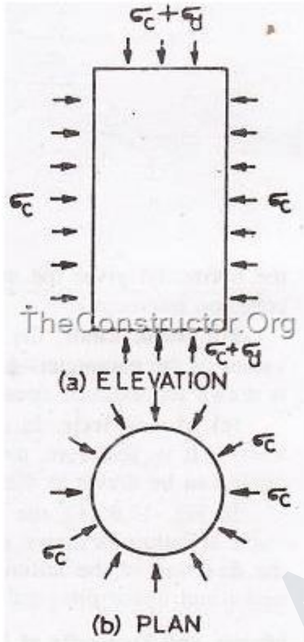
**12. What is shear strength of soil? ( Apr/May 2011)**

Shear strength is the maximum shearing resistance that is mobilized on the potential failure plane and is equal to the ultimate shear stress in the limiting equilibrium condition.

**13. What are the demerits of direct shear test? ( Apr/May 2011)**

- The shear strength is not uniformly distributed being more at the edge than at the center.
- The failure plane is predetermined. Therefore the specimen is not allowed to fail along its weakest plane.
- Shear displacements causes reduction in area under shear.
- The side walls of the shear box can cause lateral restraint on the edges of the specimen.
- Measurement of pore pressure is not possible.

**14. Draw a diagram showing the stresses acting on the soil sample in triaxial shear chamber. ( Apr/May 2011)**




**15. What are the shear strength parameters? ( Nov/Dec 2010)**

Shear strength parameters are:

- The frictional resistance between the particles at their points of contact
- Cohesion or force of attraction between particles.
- The structural resistance to displacement because of interlocking of particles and adhesion between particles

**16. Write the essential points of Mohr's strength theory. ( Nov/Dec 2010)**

- Material fails essentially by shear
- The ultimate shear stress depends on the normal stress on the potential failure plane and the properties of the material.
- In a three dimensional stress system the failure criterion is independent of intermediate principal stress.

**17. List three basic stress paths that are in use. ( Nov/Dec 2010)**

The three possible stress paths are:

- Effective stress path ( ESP)
- Total stress path (TSP)
- Stress path of total stress minus static pore water pressure (TSSP)

**18. How will you find the shear strength of cohesive soil? ( Nov/Dec 2010)**

Shear strength of cohesive soil is determined by the equation

$$S = c + \sigma tan\varphi$$

**19. What are the factors influencing the shear strength of soil? ( Apr/May 2010)**

The factors that influence the shear strength of the soil are

- ❖ Magnitude and manner of application of the loads.
- ❖ Previous stress history of the soil

**20. When the field and laboratory vane shear tests are performed? ( Apr/May 2010)**

The laboratory Vane Shear Test measures the shear strength of cohesive soils and it is useful for soils of low shear strength for which triaxial or unconfined test cannot be performed.

**21. Explain the Mohr-Coulomb failure theory. ( Apr/May 2010)**

The shear strength of a soil, defined in terms of effective stress is

$$S = c + \sigma tan\varphi$$

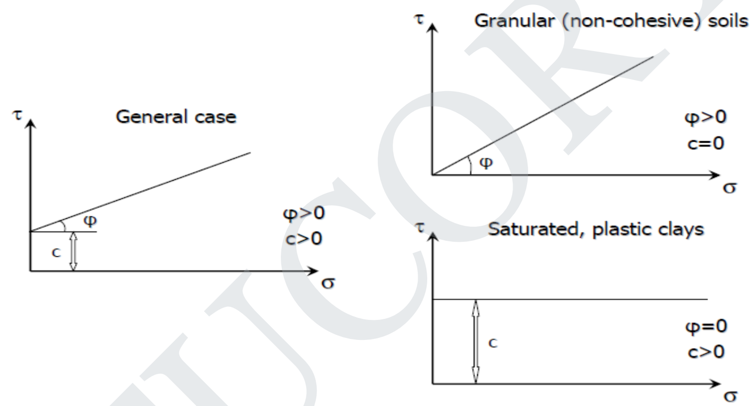
Where,

$\sigma$ = effective normal stress on the plane of shearing

c = cohesion or apparent cohesion

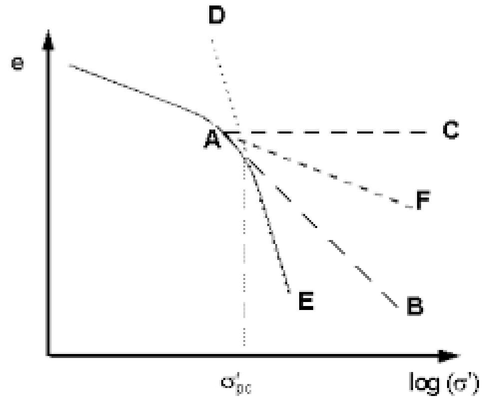
$\varphi$ = effective stress angle of friction

The above equation is referred to as Mohr-Coulomb failure criterion.




**22. What is meant by preconsolidation pressure?( Nov/Dec 2009)**

Preconsolidation pressure is the greatest effective stress to which the soil has been subjected to in the past and underwhich it has undergone full consolidation.




**23. Define angle of internal friction of soil.( May/June 2009)**

Internal Friction angle (φ), is the measure of the shear strength of soils due to friction.

**24. Define principal stresses.( June 2009)**

Principal stresses may be defined as ***" The extreme values of the normal stresses possible in the material."*** These are the maximum normal stress and the minimum normal stress. Maximum normal stress is called major principal stress while minimum normal stress is called minor principal stress.

**PART B**

**The results of three consolidated undrained tests on identical specimens of a particular soil are as follows. Determine the value of shear strength parameters. (May/June 2014)**

| **Test No** | **1** | **2** | **3** |
|---|---|---|---|
| **Confining stress** | **200** | **400** | **600** |
| **Deviatoric stress** | **118** | **240** | **352** |
| **Pore water pressure** | **110** | **220** | **320** |

**Solution**

| $\sigma_3$ | $\sigma_d$ | u | $\sigma_1 = \sigma_3 + \sigma_d$ | $\sigma'_1 = \sigma_1 - u$ | $\sigma'_3 = \sigma_3 - u$ |
|---|---|---|---|---|---|
| 200 | 118 | 110 | 318 | 208 | 90 |
| 400 | 240 | 220 | 640 | 420 | 180 |
| 600 | 352 | 320 | 952 | 632 | 280 |

Plot the graph between Normal stress (on x axis) and shear stress (on y axis)
From the plot
Total shear strength parameters from the plot
c = 0 and $\varphi = 14^0$
Effective shear strength parameters are

$$c' = 0 \text{ and } \varphi' = 24^0$$

**2. A direct shear test was performed on a 60mmx60mm sample of dry sand. The normal load was 360N. The failure occurred at a shear load of 180N. Plot the Mohr strength envelope, and determine φ. Assume c=0. Also determine principal stresses at failure (May/June 2014)**

**3. The stress on a failure plane in a drained test on a cohesionless soil are as under:**
**Normal stress(σ) = 100 kN/m$^2$**
**Shear stress(τ) = 40 kN/m$^2$**
**(i)Determine the angle of shearing resistance and the angle which the failure plane makes with the major principal plane.**
**(ii)Find the major and minor principal stresses. (Nov/Dec 2013)**

**4. What is Mohr's strength theory for soil? Derive the expression relating major and minor principal stresses and shear strength parameters of soil.(Nov/Dec 2013)**
Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 427 – 430

**5. Derive the equations for Skempton pore pressure parameters(May/June 2013)**
Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 452 - 455

6. **Write a detailed note on triaxial shear test with neat sketches along with merits and demerits of this test.(May/June 2013)(Nov/Dec 2011) (Apr/May 2011)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 436 - 441

7. **Write down a step by step procedure for determination of cohesion of a given clayey soil by conducting unconfined compression test. (Nov/Dec 2012)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 442 - 443

8. **A saturated specimen of cohesionless sand was tested in triaxial compression and the sample failed at a deviator stress of 482kN/m$^2$, when the cell pressure was 100kN/m$^2$ under the drained conditions. Find the effective angle of shearing resistance of sand. What would be the deviator stress and the major principal stress at failure for another identical specimen of sand, if it is tested under cell pressure of 200kN/m$^2$. Use either Mohr's circle method or analytical method.(Nov/Dec 2012)**

   **Given**
   $\sigma_d = 482\text{kN/m}^2$
   $\sigma_3 = 100\text{kN/m}^2$
   c = 0

   **Solution**
   $\sigma_1 = \sigma_3 + \sigma_d = 100 + 482 = 582 \text{ kN/m}^2$
   Now,$\sigma_1 = \sigma_3 \tan^2\alpha_f + 2c\tan\alpha_f = \sigma_3\tan^2\alpha_f$
   $\tan^2\alpha_f = \frac{\sigma_1}{\sigma_3} = \frac{582}{100} = 5.82$ From which $\alpha_f = 67.485 = 45^0 + \varphi/2$
   $\varphi = 2(67.485^0 - 45^0) = \mathbf{44.97^0}$
   **For another specimen**
   $\sigma_3 = 200 \text{ kN/m}^2$
   Now,$\sigma_1 = \sigma_3\tan^2\alpha_f = 200\text{x}5.82 = \mathbf{1164kN/m^2}$
   $\sigma_d = \sigma_1 - \sigma_3 = 1164 - 200 = \mathbf{964kN/m^2}$

9. **Explain with neat sketches the procedure of conducting Direct shear test. Give its advantages over other methods of finding shear strength of soil.(May/June 2012)(Apr/May 2011)(Nov/Dec 2010)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 434 - 436

10. **Write a brief note on Unconfined Compression test(May/June 2012)(Apr/May 2011)**
    Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 442 – 443

11. **What are the advantages and disadvantages of Triaxial Compression test?(May/June 2012)**
    Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 441

**12. A vane 10cm long and 8cm in diameter, was pressed into soft clay at the bottom of the borehole. Torque was applied and gradually increased to 15Nm when failure took place. Subsequently the vane rotated rapidly so as to completely remould the soil. The remoulded soil was sheared at a torque of 18N-m. calculate the cohesion of the clay in the natural and remoulded states and also the value of sensitivity.(Nov/Dec 2011)**

**Solution**

Shear strength $S = \frac{T}{\pi\left(\frac{D^2H}{2}+\frac{D^3}{6}\right)} = S = \frac{15x10^{-3}}{\pi\left(\frac{0.08^2 0.10}{2}+\frac{0.08^3}{6}\right)}$ = **37.0kN/m²**

Shear strength in the remoulded state

$S = \frac{T}{\pi\left(\frac{D^2H}{2}+\frac{D^3}{6}\right)} = S = \frac{18x10^{-3}}{\pi\left(\frac{0.08^2 0.10}{2}+\frac{0.08^3}{6}\right)}$ = **14.13kN/m²**

**13. A cylindrical specimen of dry sand was tested in a triaxial test. Failure occurred under a cell pressure of 1.2kg/cm² and at a deviator stress of 4kg/cm².Find**
**i)Angle of shearing resistance of the soil**
**ii)Normal and shear stresses on the failure plane**
**iii)The angle made by the plane with the major principal plane**
**iv)The maximum shear stress on any plane in the specimen at the instant of failure. (Nov/Dec 2010)**

**Given**

$\sigma_3 = 1.2\text{kg/cm}^2$

$\sigma_d = 4.0\text{kg/cm}^2$

$\sigma_1 = \sigma_3 + \sigma_d = 1.2 + 4 = 5.2\text{kg/cm}^2$

$\sigma_1 = \sigma_3\tan^2\alpha + 2c\tan\alpha$

Since c =0

$\sigma_1 = \sigma_3\tan^2\alpha$

Therefore, $\tan\alpha = \sqrt{\sigma_1/\sigma_3} = \sqrt{5.2/1.2} = 2.082$

$\alpha = 64.34^0 = 45^0 + \frac{\varphi}{2}$ or $\varphi = 38.7^0$

(1) Hence angle of shearing resistance = $\mathbf{38.7^0}$

(2) Shear stress $\tau = \frac{\sigma_1-\sigma_3}{2}\sin 2\alpha = \frac{4}{2}\sin(2x64.34^0)$ = **1.56 kg/cm²**

Normal stress $\sigma = \frac{\sigma_1+\sigma_3}{2} + \frac{\sigma_1-\sigma_3}{2}\cos 2\alpha$

$$\sigma = \frac{5.2+1.2}{2} + \frac{5.2-1.2}{2}\cos(2x64.34^0) = \mathbf{1.95kg/cm^2}$$

(3) Angle made by the failure plane with the major principal plane $\alpha_f = 64.34^0$

Angle made by the failure plane with the minor principal plane = 90 – $\alpha$ = $90 - 64.34^0 =$ $\mathbf{25.66^0}$

(4) Maximum shear stress, $\tau = \frac{\sigma_1 - \sigma_3}{2} = \frac{5.2-1.2}{2} = \boldsymbol{2kg/cm^2}$

**14. Two identical soil specimen were tested in a triaxial apparatus. First specimen failed at a deviator stress of 770kN/m$^2$ when the cell pressure was 2000kN/m$^2$. Second specimen failed at a deviator stress of 1370kN/m$^2$ under a cell pressure of 400kN/m$^2$. Determine the value of c and φ analytically. If the same soil is tested in a direct shear apparatus with a normal stress of 600kN/m$^2$, estimate the shear stress at failure. (Apr/May 2010)**

**Solution**

First test: $\sigma_3$= 200kN/m$^2$; $\sigma_d$= 770kN/m$^2$; $\sigma_1$= 200+770 = 970kN/m$^2$

970 = $200\tan^2\alpha + 2c\tan\alpha$ --------- (1)

Second test: $\sigma_3$= 400kN/m$^2$; $\sigma_d$= 1370kN/m$^2$; $\sigma_1$= 400+1370 = 1770kN/m$^2$

1770 = $400\tan^2\alpha + 2c\tan\alpha$ --------- (2)

From 1 and 2 equations

$200\tan^2\alpha$ = 800 from which $\tan\alpha = 2$,

$\alpha = 63.43^0 = 45^0 + \frac{\varphi}{2}$ or $\boldsymbol{\varphi = 36.87^0}$

From 1 970 = $200 \text{x} 2^2 + 2c(2)$, From which **c = 42.5 kN/m$^2$**

**For shear box test**

$\tau = c + \sigma\tan\varphi$

$\tau = 42.5 + 600\tan 36.87^0 = \boldsymbol{492.50 kN/m^2}$

# UNIT – V

# SLOPE STABILITY

## PART A

1. **Differentiate finite slope and infinite slope. ( May/June 2014)( Nov/Dec 2012) (Apr/May 2011)(Nov/Dec 2010)**
   Infinite slope: If a slope represents the boundary surface of a semi-infinite soil mass and the soil properties for all identical depths below the surface are constant, it is called infinite slope.
   Finite slope: If the slope is of limited extent, it is called a finite slope.

2. **What is stability number? ( May/June 2014)**
   Taylor stability number is a dimensionless quantity denoted by $S_n$ and defined as

$$S_n = \frac{C_m}{\gamma H}$$

$C_m$ = mobilised cohesion on slip surface
$\gamma$ = unit weight of soil , H- Height of the slope

**3. What are the different factor of safety used in the stability of slope?( Nov/Dec 2013) (Nov/Dec 2011)**

1. Factor of safety with respect to cohesion assuming cohesion to be fully mobilized

$$F = \frac{c}{c_m}$$

2. Factor of safety with respect to friction assuming cohesion to be fully mobilized.

$$F_\varphi = \frac{\varphi}{\varphi_m}$$

3. Factor of safety with respect to shear strength

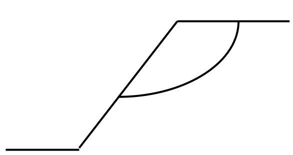
$$F = \frac{\tau_f}{\tau}$$

4. Factor of safety with respect to height

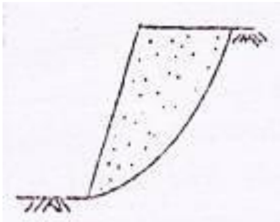
$$F_H = \frac{H_c}{H}$$

**4. List out the types of slope failure ( Nov/Dec 2013)( May/June 2013)( Apr/May 2011)(Nov/Dec 2010)( Apr/May 2010)**

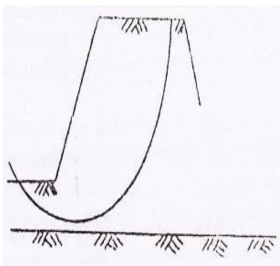
1. Face failure



2. Toe failure



3. Base failure



**5. List out any two-slope protection measures. ( Nov/Dec 2012)( Apr/May 2011)**

Slopes have been protected by adopting some successful techniques. In general, the corrective or protective measures involve:

(i) Reducing the mass or loading which contributes to sliding

(ii) Improving the shearing strength along the anticipated zone of failure, and

(iii) Providing certain materials which will provide resistance to movement.

**6. What do you mean by tension crack? ( May/June 2012)**

A tension crack at the head of a slide suggests strongly that instability is imminent. Tension cracks are sometimes used in slope stability calculations, and sometimes they are considered full of water. If this is the case, then hydrostatic forces develop. The maximum depth of tension crack is given by the equation

$$z_0 = \frac{2c_u}{\gamma}$$

**7. Define critical surface of failure. ( May/June 2012)**

There are three types of failure surfaces – Planar, Circular, Non-circular. However in most cases actual failure surfaces are curved. Circular arcs are close approximation of actual slip surface in homogeneous and isotropic soil conditions. Hence circular failure surfaces are the critical ones.

**8. What are the uses of stability charts? ( Nov/Dec 2011)( Nov/Dec 2010)**

In undrained homogeneous soil for a slope of simple profile we use Taylor's charts, using the soil properties $c_u$ ,$\varphi_u$ and $\gamma$, and slope dimensions i and H. A number of slopes of various heights and slope angles are analysed and a stability number $S_n$ is determined, which is used for evaluating the factor of safety.

**9. What is a slide? ( Apr/May 2011)**

The failure of a mass of soil located beneath a slope a called a slide.

**10. What is a finite slope? ( Nov/Dec 2010)**

If the slope is of limited extent it is called Finite Slope

**11. What is the maximum depth of vertical cut that can be made in a purely cohesive soil of unconfined compressive strength 32kPa and unit weight 16kN/m³. Taylor's stability number for this case is 0.261.( Nov/Dec 2010)( Apr/May 2010)**

Where, c = 32/2 = 16kPa

$\gamma = 16 kN/m^3$

$$H = \frac{c}{\gamma S_n F_c}$$

Taking F.O.S 1

$$\mathbf{H = 3.83m}$$

**12. State reasons for failure of slopes.( Nov/Dec 2010)**

- The action of gravitational force (loss of shear strength)
- Seepage forces within the soil
- Excavation or undercutting of its foot or due to gradual disintegration of the structure of the soil.

**13. Write down the expression for factor of safety of an infinite slope in case of cohesionless soils.**

$$F = \frac{\tau_c}{\tau} = \frac{\tan \varphi}{\tan i}$$

For submerged slope

$$F = \frac{\gamma' \tan \varphi}{\gamma_{sat} \tan i}$$

**14. The factor of safety of an infinite slope made of sandy soil is independent of the height of the embankment. Justify your answer. ( Apr/May 2010)**

$$F = \frac{\tau_c}{\tau} = \frac{\tan \varphi}{\tan i}$$

For submerged slope

$$F = \frac{\gamma' \tan \varphi}{\gamma_{sat} \tan i}$$

The above equations are independent of the height of the embankment

## PART B

1. **Discuss the friction circle method of stability analysis (May/June 14)(Nov/Dec 13)(Nov/Dec 12)(Apr/May 11)(Nov/Dec 10)(Apr/May 10)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 619 - 621

2. **An embankment of height 10m high is inclined at $35^0$ to the horizontal. A stability analysis by method of slices gave the following forces: Total normal force = 900kN, Total tangential force=420kN, Total neutral force = 200kN. If the length of the failure arc is 23m, find the factor of safety with respect to shear strength. The soil has $c=20kN/m^2$ and $\varphi = 15^0$ (May/June 2014)(Nov/Dec 2011)**

   **Solution**

   **(a) Factor of safety with respect to shearing strength**

$$F_s = \frac{c' r\theta + \{\sum(N-U)\}\tan\varphi'}{\sum T}$$

$$F_s = \frac{20x23 + \{900-200\}\tan 15}{420} = \mathbf{1.54}$$

   **(b) Factor of safety with respect to cohesion**

$$F_c = \frac{c' r\Theta}{\sum T} = \frac{20x23}{420} = \mathbf{1.09}$$

3. **Discuss the slope protection measures that can be adopted to improve the stability of slopes (May/June 2014)(May/June 2013)(Nov/Dec 2010)**
   Refer "Soil Mechanics and Foundations" by Donald Coduto Pg 553-557

4. **A slope is to be constructed at an inclination of $30^0$ with the horizontal. Determine the safe height of the slope at factor of safety of 1.5. The soil has the following properties.**
   **$c = 15kN/m^2$, $\varphi = 22.5^0$, $\gamma = 20kN/m^2$(Sn = 0.046) (Nov/Dec 2013)**

   **Given**

   $c = 15kN/m^2$, $\varphi = 22.5^0$, $\gamma = 20kN/m^2$, Sn = 0.046
   F.O.S = 1.5
   $i = 30^0$

   **Solution**

   Factor of safety with respect to cohesion

$$F_c = \frac{c}{c_m}$$

$$c_m = \frac{c}{F_c} = \frac{15}{1.5} = 10\text{kN/m}^2$$

Given stability number $S_n = 0.046$

$$Sn = \frac{c_m}{\gamma H}$$

$$0.046 = \frac{10}{20xH}$$

$$H = \frac{10}{0.046x20}$$

**H = 10.86m**

**5. Explain the Swedish circle method of analysis of slope stability with diagrams.(May/June 2013)(Apr/May 2011)(Nov/Dec2010)(Apr/May 2010).**

Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 611 - 614

**6. A new canal is excavated to a depth of 5m below ground level through a soil having the following characteristics; c=14kN/m², φ = 15⁰,e = 0.8 and G=2.70. The slope of banks is 1 in 1. Calculate the factor of safety with respect to cohesion when the canal runs full. If it is suddenly emptied, what will be the factor of safety? (Nov/Dec 2012)(May/June 2012)**

**Solution**

**i.Factor of safety when the canal is full**

$$\gamma_{sat} = \frac{G+Se}{1+e}\gamma_w = \frac{2.70+1x0.8}{1+0.8}9.81 = 19.08\text{kN/m}^3$$

$$\gamma' = \gamma_{sat} - \gamma_w = 19.08 - 9.81 = 9.27\text{kN/m}^3$$

**Given**

H=5m

$c = 14\text{kN/m}^2$

$i = 45^0 (\tan^{-1} 1 = 45)$

$\varphi = 15^0$

For $i = 45^0$ and $\varphi = 15^0$, from Taylor's stability chart Sn =0.083

$$\text{Factor of safety } F_c = \frac{C}{\gamma' H S_n} = \frac{14}{9.27x5x0.083} = \mathbf{3.64}$$

**(ii) When the canal is emptied completely**

$$\varphi_w = \frac{\gamma'}{\gamma_{sat}} = \frac{9.27}{19.08} = 7.3$$

For $i = 45^0$ and $\varphi = 7.3^0$, from Taylor's stability chart Sn =0.122

Factor of safety $F_c = \frac{C}{\gamma_{sat}\ HS_n} = \frac{14}{19.08x5x0.122} = \mathbf{1.20}$

7. **What are the different types of slope failures? (Nov/Dec 2011)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 608 - 609

8. **Explain Taylor's stability number and its applicability.(Apr/may 2011)(Apr/May 2010)**
   Refer "Soil Mechanics and Foundations" by B.C Punmia Pg 621 - 624

9. **A long natural slope of cohesionless soil is inclined at $15^0$ to the horizontal. Taking φ = $30^0$, determine the factor of safety of the slope. If the slope is completely submerged, what will be the change in the factor of safety? (Apr/May 2010)**

**Given**
$\varphi = 30^0$
$i = 15^0$

**Solution**

$$F = \frac{\tau_c}{\tau} = \frac{\tan\varphi}{\tan i}$$

$$F = \frac{\tan 30}{\tan 15} =$$

**Effect of submergence**

When the slope is submerged γ is replaced by γ'

$$F = \frac{\tau_c}{\tau} = \frac{(\gamma' z\cos^2 i)\tan\varphi}{\gamma' z\sin i\cos i} = \frac{\tan\varphi}{\tan i} = \frac{\tan 30}{\tan 15} =$$

Thus the factor of safety will remain the same, except that φ is to be determined under submerged condition.

10. **In order to find a factor of safety of a slope of an earth dam during steady seepage, the section of the dam was drawn to a scale of 1:4 and the following results were obtained on a trial slip circle.**
    **Area of N rectangle = $10cm^2$**
    **Area of T rectangle = $8cm^2$**
    **Area of U rectangle = $4.8cm^2$**
    **Length of the failure arc = 12cm**
    **The laboratory test on slope material produced c = $18kN/m^2$ and φ = $25^0$. Determine the factor of safety of slope of unit weight of soil is $20kN/m^3$.(Apr/May 2010)**
    **Given**
    Given scale 1cm = 4cm

$\gamma = 20kN/m^3$
$c=18kN/m^3$
$\varphi = 25^0$

**Solution**
Given scale 1cm = 4cm, Therefore x=4
Consider 1cm length of the dam

$$\sum N = A_N.x^2\gamma = 10.(4)^2.20 = 3200kN$$
$$\sum T = A_T.x^2\gamma = 8.(4)^2.20 = 2560kN$$
$$\sum U = A_U.x^2\gamma_w = 4.8.(4)^2.9.81 = 753.4kN$$

$\widehat{L} = 12x4 = 48m$; $c' = 18kN/m^2$

$$F = \frac{c'\widehat{L} + \tan\varphi' \sum(N-U)}{\sum T} = \frac{(18x48) + \tan25^o(3200 - 753.4)}{2560} = 0.78$$

**11. A cutting 8m deep is to be made in a saturated clay soil with $\gamma = 20kN/m^3$,Cu =20kN/m$^3$ and $\varphi = 0$. A hard stratum exists at a depth of 12m below the ground level. Determine the angle of the slope at which the failure would occur(Apr/May 2010)**

**Given**
$D_f H = 12m$
H =8m
Therefore $D_f = 1.5m$
Assume a factor of safety of 1.5

**Solution**

$$S_n = \frac{c}{F_c\gamma H}$$
$$S_n = \frac{20}{1.5x20x8} = 0.083$$

From Taylor's stability chart

For $S_n = 0.083$ and $D_f = 1.5$

We have **i = 8$^o$**

For a factor of safety of 1.5 the failure would occur at an angle of **8$^o$**

**12. A slope is to be constructed in a soil for which c=0 and $\varphi=36^0$. It is to be assumed that the water level may occasionally reach the surface of a slope, which seepage taking place**

**parallel to the slope. Determine the maximum slope angle for a factor of safety of 1.5, assuming a potential failure parallel to the slope. What would be the factor of safety of the slope, constructed at this angle, if the water table should be well below the surface? The saturated unit weight of the soil is 19kN/m³.(Apr/May 2010)**

**Solution**

**(a)Seepage parallel to the slope**

$$\sigma_z = \frac{W}{b} = \gamma_{sat} Z \cos i$$

$$\sigma = \sigma_z \cos i = \gamma_{sat} Z\cos^2 i$$

$$\tau = \sigma_z \sin i = \gamma_{sat}\, Z \cos i \sin i$$

$$u = \text{pore pressure} = \gamma_w Z\cos^2 i$$

$$F = \frac{\tau_f}{\tau} = \frac{(\sigma - u)\tan\varphi}{\tau} = \frac{\gamma' Z\cos^2 i \tan\varphi}{\gamma_{sat}\, Z \cos i \sin i} = \frac{\gamma' \tan\varphi}{\gamma_{sat} \tan i}$$

Here $\gamma_{sat}$ = 19kN/m$^3$

$\gamma'$ = 19-9.81 =9.19kN/m$^3$

Factor of safety, F =1.5(given) = $\frac{9.19}{19} \text{x} \frac{\tan 36^0}{\tan i}$

$$\tan i = \frac{9.19}{19} \text{x} \frac{\tan 36^0}{1.5} = 0.2343$$

**i = 13.19°**

**(b)No seepage: water table below the surface**

For no seepage u=0

$$F = \frac{\tau_f}{\tau} = \frac{\sigma \tan\varphi}{\tau} = \frac{\gamma_{sat} Z\cos^2 i \tan\varphi}{\gamma_{sat}\, Z \cos i \sin i} = \frac{\tan\varphi}{\tan i} = \frac{\tan 36}{\tan 13.19} = 3.10$$

Factor of safety **F = 3.10**