

UPPSC-AE

2023

Uttar Pradesh Public Service Commission

Combined State Engineering Services Examination
Assistant Engineer

Civil Engineering

Geotechnical Engineering and Foundation Engineering

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**



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Geotechnical Engg. & Foundation Engg.

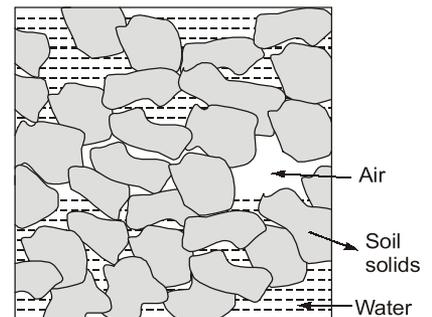
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2.1 Introduction

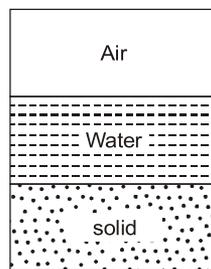
Soil is essentially made up of solid particles, with spaces or voids in between. The assemblage of particles in contact is usually referred to as the 'soil matrix' or the 'soil skeleton'. The intermittent void spaces are filled up by either air or water or both air and water. This means that an element of 'soil' may be considered as a three-phase material, comprising some solid (soil grains), some liquid (pore water) and some gas (pore air).



Three phase solid water air system

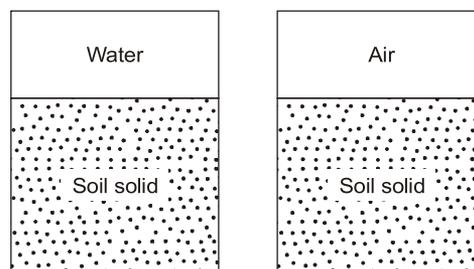
2.2 Phase Diagram

- The diagrammatic representation of the different phases in soil mass is called the 'Phase diagram'.
- Different phases present in soil mass cannot be separated, all three constituents are assumed to occupy separate spaces.
- Soil can be either two phase or three phase composition.
 - (a) Three phase system:



Partially saturated soil

- (b) Two phase system:



Saturated soil

Dry soil

2.3 Important Definitions

W_s = Weight of soil solids

W_w = Weight of water

W_a = Weight of air (= 0)

W = Weight of soil mass

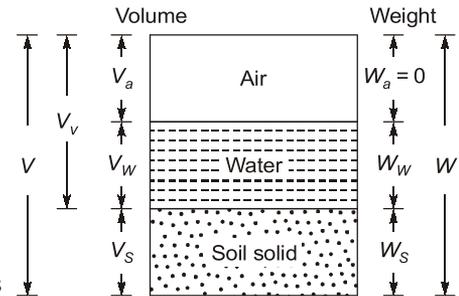
V_a = Volume of air

V_w = Volume of water

V_s = Volume of solid

V = Total volume of soil mass

V_v = Volume of voids i.e. sum of volume of air and volume of water.



1. Water Content (w)

- Water content (w) is also called moisture content. It is the ratio of weight of water to the weight of soil solids.

$$w = \frac{W_w}{W_s}; \quad w \geq 0$$

- This is represented as a percentage.
- The water content of a oven dry soil is zero but natural water content for most soils is around 60%.
- There is no upper limit for water content. It can be greater than 100%.



NOTE

- Fine-grained soils have higher values of natural moisture content as compared to coarse-grained soils.
- There are four possible forms of water present in soil:
 - Gravity water (free water):** Added due to rain or flooding
 - Capillary water:** Extracted through capillary action
 - Hygroscopic water:** Water absorbed by oven dried sample when it is placed in open atmosphere
 - Structural water:** Water bounded in crystalline structure of soil

On oven drying, gravity water, capillary water and hygroscopic water are removed but structural water remains present in soil mass.
- Water content in soil represents gravity water, capillary water and hygroscopic water, which can be removed on oven drying.

2. Degree of Saturation (S)

- Degree of saturation (S) of a soil is defined as the ratio of the volume of water to the volume of voids in the soil mass.

$$S = \frac{V_w}{V_v} \times 100$$

where,

V_w = volume of water

V_v = volume of voids

- It is expressed in percentage.
- For dry soil, $S = 0\%$ and for fully saturated soil $S = 100\%$, whereas for partially saturated soil $0 < S < 100\%$.

**NOTE**

If soil is partially saturated, then total volume of soil and volume of void remain constant during variation of moisture content. If soil is super saturated due to further addition of water, then volume of void and total volume increases. Hence void ratio will change but degree of saturation remains constant equal to 100%.

3. Void Ratio (e)

- The void ratio (e) of a soil is defined as the ratio of the total volume of voids to the volume of solids.

$$e = \frac{V_v}{V_s}; \quad e > 0$$

where,

V_v = volume of voids

V_s = volume of soil solids

- It is expressed in decimal.
- In general $e > 0$, i.e. no upper limit for void ratio.
- Void ratio of fine grained soils are generally higher than those of coarse grained soils. The individual void spaces in coarse grained soil are larger than fine grained soils; but the total void space is generally more in fine grained soils.

4. Porosity (n)

- The porosity (n) of a soil is defined as the ratio of volume of voids to the total volume of soil.

$$n = \frac{V_v}{V} \times 100\%$$

where,

V_v = volume of voids

V = Total volume of soil

- It is expressed in percentage.
- In porosity, total volume of soil is used which includes volume of voids.
- Hence porosity (n) of soil cannot exceed 100%.
- The range of porosity is $0 < n < 100\%$.

**NOTE**

Void ratio (e) and porosity (n) both have same significance but void ratio (e) is more widely adopted than porosity because volume of solid which is used in void ratio is more stable than total volume used in porosity.

5. Air Content (a_c)

- It is defined as the ratio of the volume of air to the total volume of voids present in soil.

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

where,

V_a = volume of air in voids

V_v = volume of voids

- It is expressed in percentage.

6. Percentage Air Voids (n_a)

- Percentage air voids (n_a) is defined as the ratio of volume of air to the total volume of soil mass.

$$n_a = \frac{V_a}{V} \times 100$$

where,

$$V_a = \text{volume of air}$$

$$V = \text{total volume of soil}$$

- It is expressed in percentage.

7. Unit Weights

(a) Bulk Unit Weight (γ_t)

- It is the ratio of total weight of soil to the total volume of soil mass.

$$\gamma_t = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w + V_s}$$

- It is expressed as $\frac{kN}{m^3}$ or $\frac{kgf}{cm^3}$



NOTE

- Bulk density is defined as the ratio of total soil mass to the total volume.

$$\rho_t = \frac{M}{V} = \frac{M_s + M_w}{V_s + V_w + V_s}$$

- It is expressed as $\frac{kg}{m^3}$

(b) Dry Unit Weight (γ_d)

- It is the ratio of total dry weight of soil to the total volume of soil mass.

$$\gamma_d = \frac{\text{Dry weight of soil}}{\text{Total volume}} = \frac{W_{dry}}{V}$$

- Dry unit weight is used as a measure of denseness of soil. More dry unit weight means more dense or compacted is the soil.



NOTE

Dry density is defined as the ratio of total dry mass to the total volume.

$$\rho_d = \frac{M}{V} = \frac{M_{dry}}{V}$$

(c) Saturated Unit Weight (γ_{sat})

- It is defined as the ratio of total saturated weight of soil to the total volume of soil mass

$$\gamma_{sat} = \frac{W_{sat}}{V}$$



NOTE

Saturated density is defined as the ratio of total saturated soil mass to the total volume of soil mass.

$$\rho_{sat} = \frac{M_{sat}}{V}$$

(d) Submerged Unit Weight or Buoyant Unit Weight (γ'_{sub} or γ')

- It is the ratio of buoyant weight of soil to the total volume of soil mass.

$$\gamma' = \frac{W_{sub}}{V}$$

- When soil is below water i.e. in submerged condition, a buoyant force acts on the soil solids which is equal in magnitude to the weight of water displaced by the soil solids. Hence the net weight of soil is reduced and reduced weight is known as buoyant weight or submerged weight.

$$\therefore \gamma' = \frac{W_{sub}}{V} = \gamma_{sat} - \gamma_w$$

- γ' is roughly $\frac{1}{2}$ of saturated unit weight (γ_{sat})

NOTE: Submerged density or buoyant density, $\rho' = \rho_{sat} - \rho_w$

(e) Unit Weight of Water (γ_w)

- It is the ratio of weight of water to the volume occupied by the water

$$\gamma_w = \frac{W_w}{V_w}$$

- Unit weight of water depends on its temperature. However, the unit weight of water is taken to be constant as 9.81 kN/m³ or 1g/cc.
- It is expressed in $\frac{kN}{m^3}$ or $\frac{kgf}{cm^3}$

(f) Unit Weight of Solids (γ_s)

- It is the ratio of weight of soil solids to the volume occupied by the soil solids.

$$\gamma_s = \frac{W_s}{V_s}$$

- It is expressed in $\frac{kN}{m^3}$ or $\frac{kgf}{cm^3}$

8. Specific Gravity (G)

- Specific gravity of soil solids (G) is the ratio of the weight of a given volume of solids to the weight of an equivalent volume of water at 4°C.

$$G = \frac{W_s}{V_s \gamma_w} = \frac{\gamma_s}{\gamma_w} \quad \left[\because \gamma_s = \frac{W_s}{V_s} \right]$$

- The specific gravity of most of the inorganic soils lies in the range of 2.65 to 2.80.
- For organics soils, it lies in the range of 1.2 to 1.40.

9. Apparent or Mass Specific Gravity (G_m)

- Mass specific gravity is defined as the ratio of the total weight of a given volume of soil to an equivalent volume of water.

- Mass specific gravity can be defined as the ratio of bulk unit weight of soil to unit weight of water.

$$G_m = \frac{W_t}{V\gamma_w} = \frac{\gamma_t}{\gamma_w}$$

If soil is in saturated state,

$$G_m = \frac{\gamma_{sat}}{\gamma_w}$$

If soil is in dry state,

$$G_m = \frac{\gamma_d}{\gamma_w}$$



NOTE

Generally, specific gravity is represented either at 27°C or at 20°C. If test temperature is different than the standard temperature, then correction has to be done as follows–

$$G = \frac{\gamma_s}{\gamma_w}$$

$$\therefore G \times \gamma_w = \text{constant}$$

$$\Rightarrow G_{27^\circ\text{C}} \times \gamma_{w27^\circ\text{C}} = G_{T^\circ\text{C}} \times \gamma_{w27^\circ\text{C}}$$

$$\therefore G_{27^\circ\text{C}} = G_{T^\circ\text{C}} \times \frac{\gamma_{wT^\circ\text{C}}}{\gamma_{w27^\circ\text{C}}}$$

2.3.1 Some important Relationship (Soul of Soil):

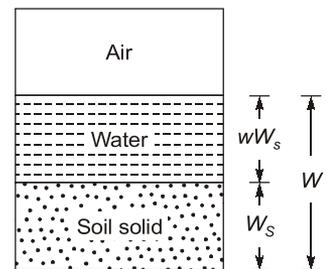
1. Relation between W_s , W , w :

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

$$W_w = w \cdot W_s$$

$$W = W_s + W_w = W_s + wW_s$$

$$W_s = \frac{W}{1+w}$$



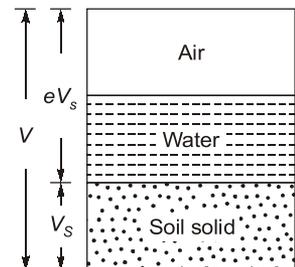
2. Relation between V_s , V , e :

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

$$V_v = e \cdot V_s$$

$$V = V_v + V_s = eV_s + V_s = V_s(1 + e)$$

$$V_s = \frac{V}{1+e}$$



3. Relation between e and n :

$$n = \frac{V_v}{V} = \frac{V_v}{V_v + V_s} = \frac{V_v / V_s}{\left(\frac{V_v}{V_s}\right) + 1} = \frac{e}{1+e}$$

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

Also

$$n + ne = e$$

$$e(1 - n) = n$$

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

4. Relation between S , e , w and G_s :

Method-1: By using phase diagram

From above phase diagram,

$$\frac{SeW_s}{G_s} = w \cdot W_s$$

$$\Rightarrow Se = w \cdot G_s$$

Method-2:

We know

$$\text{Void ratio, } e = \frac{V_v}{V_s}$$

$$\text{Also, } e = \frac{V_v}{V_s} = \frac{V_v}{V_w} \times \frac{V_w}{V_s} = \frac{V_v}{V_w} \times \frac{W_w / \gamma_w}{W_s / \gamma_s} = \frac{V_v}{V_w} \cdot \frac{W_w}{W_s} \cdot \frac{G_s \gamma_w}{\gamma_w} = \frac{1}{S} w G_s$$

$$e = \frac{w G_s}{S}$$

$$\text{or } Se = wG$$

5. Relation between γ_t , G_s , e , w and γ_w :

$$\gamma_t = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_v} = \frac{W_s \left(1 + \frac{W_w}{W_s} \right)}{V_s \left(1 + \frac{V_v}{V_s} \right)}$$

$$\text{But } \frac{W_w}{W_s} = w \quad \text{and} \quad \frac{W_s}{V_s} = \gamma_s = G_s \gamma_w$$

$$\therefore \gamma_t = \frac{G_s \gamma_w (1 + w)}{1 + e}$$

$$\text{But } w = \frac{Se}{G_s}$$

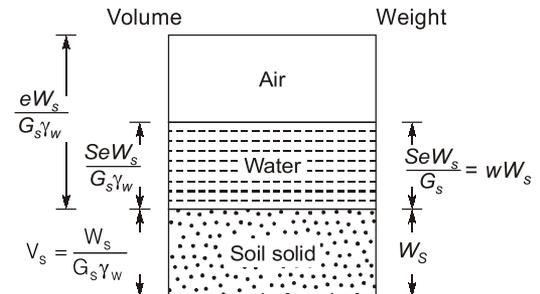
$$\therefore \gamma_t = \left(\frac{G_s + Se}{1 + e} \right) \gamma_w$$

Special Case (a): If soil is saturated, then

$$\gamma_t = \gamma_{\text{sat}} \quad \text{and} \quad S = 1$$

$$\text{Hence } \gamma_{\text{sat}} = \left(\frac{G_s + 1 \times e}{1 + e} \right) \gamma_w$$

$$\text{or } \gamma_{\text{sat}} = \left(\frac{G_s + e}{1 + e} \right) \gamma_w$$



Special Case (b): If soil is dry, then

$$\gamma_t = \gamma_d \quad \text{and} \quad s = 0$$

Hence

$$\gamma_d = \left(\frac{G_s + 0 \times e}{1 + e} \right) \gamma_w$$

or

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

Special Case (c): If soil is submerged, then

$$\gamma' = \gamma_{sat} - \gamma_w = \left(\frac{G_s + e}{1 + e} \right) \gamma_w - \gamma_w$$

$$\gamma' = \left(\frac{G_s - 1}{1 + e} \right) \gamma_w$$

6. Relation between γ_t , γ_d , w :

$$\gamma_t = \frac{W}{V} = \frac{W_s + W_w}{V}$$

$$\gamma_t = \frac{W_s(1 + W_w / W_s)}{V}$$

or

$$\gamma_d = \frac{\gamma_t}{1 + w} \quad \left(\because \gamma_d = \frac{W_s}{V} \right)$$

7. Relation between γ_d , G_s , w and n_a :

$$V = V_s + V_w + V_a$$

$$1 = \frac{V_s}{V} + \frac{V_w}{V} + \frac{V_a}{V} = \frac{V_s}{V} + \frac{V_w}{V} + n_a$$

or

$$1 - n_a = \frac{V_s}{V} + \frac{V_w}{V} = \frac{W_s / G_s \gamma_w}{V} + \frac{w W_s / \gamma_w}{V} \quad \left(\because V_w = \frac{w W_s}{\gamma_w} \right)$$

$$= \frac{\gamma_d}{G_s \gamma_w} + \frac{w W_s / \gamma_w}{V} = \frac{\gamma_d}{G_s \gamma_w} + \frac{w \gamma_d}{\gamma_w} = \frac{\gamma_d}{\gamma_w} \left(W + \frac{1}{G_s} \right)$$

or

$$\gamma_d = \frac{(1 - n_a) G_s \gamma_w}{1 + w G}$$

Special Case (a): When $n_a = 0$, then soil become fully saturated at a given water content

Hence

$$\gamma_d = \frac{G_s \gamma_w}{1 + w G}$$

or

$$\gamma_{sat} = \left(\frac{G_s + e}{1 + e} \right) \gamma_w$$

8. Relation between S , w , G_s , γ_t and γ_w :

$$\gamma_t = \left(\frac{G_s + S e}{1 + e} \right) \gamma_w$$

$$\frac{\gamma_t}{\gamma_w} = \left(\frac{G_s + S e}{1 + e} \right) = \left(\frac{G_s + w G_s}{1 + \frac{w G_s}{S}} \right)$$

Solution: (b)

Soil A(1)

$$e_1 = 0.5$$

$$V_1 = 1.5 \text{ m}^3$$

Soil B(2) Soil C(3)

$$e_2 = 0.7 \quad V_3 = 3.2 \text{ m}^3$$

$$V_2 = 1.7 \text{ m}^3$$

Even after mixing, volume of solids of each soil will be same in mixed sample

The solids in soil A,

$$V_{s1} = \frac{V_1}{1 + e_1} = \frac{1.5}{1 + 0.5} = 1 \text{ m}^3$$

The solids in soil B,

$$V_{s2} = \frac{V_2}{1 + e_2} = \frac{1.7}{1 + 0.7} = 1 \text{ m}^3$$

Total volume of solids in soil C,

$$V_{s3} = V_{s1} + V_{s2} = 2 \text{ m}^3$$

∴ Volume of void in soil C,

$$V_v = V_3 - V_{s3} = 3.2 - 2 = 1.2 \text{ m}^3$$

∴ Porosity,

$$n = \frac{V_v}{V_3} = \frac{1.2}{3.2} = 0.375$$

Hence, option (b) is correct.



Example - 2.2 Which one of the following is the water content of the mixed soil made from 1 kg of soil (say A) with water content of 100% and 1 kg of soil (say B) with water content of 50%?

(a) 66%

(b) 71%

(c) 75%

(d) 82%

Solution: (b)

Soil A(1)

$$W_1 = 1 \text{ kg}$$

$$w_1 = 100\%$$

Soil B(2)

$$W_2 = 1 \text{ kg}$$

$$w_2 = 50\%$$

Soil C(3)

$$W_3 = W_1 + W_2$$

$$w_3 = ?$$

Water content,

$$w = \frac{W_w}{W_s} \times 100$$

⇒

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

$$\frac{w}{100} + 1 = \frac{W_w + W_s}{W_s}$$

⇒

$$W = \left(\frac{w\%}{100} + 1 \right) W_s = (w + 1) W_s$$

Weight of solids in soil A,

$$W_{SA} = \frac{1000}{1 + 1} = 500 \text{ g}$$

$$W_{wA} = 1000 - 500 = 500 \text{ g}$$

Weight of solids in soil B,

$$W_{SB} = \frac{1000}{(0.5 + 1)} = 666.7 \text{ g}$$

$$W_{wB} = 1000 - 666.7 = 333.3 \text{ g}$$

$$W_{S, \text{mix}} = W_{SA} + W_{SB} = 500 + 666.7 \text{ and } = 1166.7 \text{ g}$$

$$W_{w, \text{mix}} = W_{wA} + W_{wB} = 500 + 333.3 \text{ g} = 833.3 \text{ g}$$

∴

$$w = \frac{W_{w, \text{mix}}}{W_{S, \text{mix}}} = \frac{833.3}{1166.7} \times 100 = 71\%$$

- (b) Stiffer the soil better would be shear strength. Hence, it would be more preferred as a foundation material.

More is (I_C) consistency index more is stiffness of soil at its natural moisture content,

$$(I_C)_A = \frac{w_L - w_n}{(I_P)_A} = \frac{35 - 30}{20} = \frac{5}{20} = \frac{1}{4} = 0.25$$

$$(I_C)_B = \frac{w_L - w_n}{(I_P)_B} = \frac{65 - 30}{45} = \frac{35}{45} = \frac{7}{9} = 0.77$$

$$\Rightarrow (I_C)_B > (I_C)_A$$

\therefore B is better foundation material.

- (c) Shear strength at plastic limit is checked w.r.t. toughness index (I_T) .

More is (I_T) more would be toughness of soil at plastic limit,

$$(I_T)_A = \frac{(I_P)_A}{(I_f)_A} = \frac{35 - 15}{8} = \frac{20}{8} = 2.5$$

$$(I_T)_B = \frac{(I_P)_B}{(I_f)_A} = \frac{45}{4} = 11.25$$

$$\Rightarrow (I_T)_B > (I_T)_A$$

\therefore B is having more shear strength at plastic limit (w_p).

- (d) Compressibility is the function of w_L (Liquid limit), more is the liquid limit more is the compressibility of soil,

$$(w_L)_B > (w_L)_A$$

Hence, compressibility of B is more than that of A.



Student's Assignment

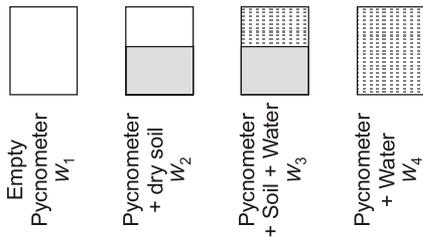
- Q.1** Which of one of the following gives the correct sequence of decreasing order of densities of a soil sample?
- saturated, submerged, wet, dry
 - saturated, wet, submerged, dry
 - saturated, wet, dry, submerged
 - wet, saturated, submerged, dry
- Q.2** Which of the following correctly defines the term activity of clay?
- Plasticity index / % of clay
 - Plastic limit / liquidity index
 - UCS/cohesion
 - Strength of remoulded sample unconfined compressive strength of undisturbed sample.
- Q.3** The difference between maximum void ratio and minimum void ratio of sand sample is 0.30. If the relative density of sample is 66.6% at the void ratio of 0.40, then the void ratio of the sample at its too rest state will be
- 0.40
 - 0.60
 - 0.50
 - 0.75
- Q.4** A sample has natural moisture content w , void ratio ' e ', specific gravity of solids ' G_s '. The bulk unit weight of soil ' γ ' is given by (γ_w is unit weight of water)
- $\frac{(1-w)G_s\gamma_w}{1-e}$
 - $\frac{(1+w)G_s\gamma_w}{1-e}$
 - $\frac{(1+w)G_s\gamma_w}{1+e}$
 - $\frac{(1-w)G_s\gamma_w}{1+e}$

- Q.5** If the specific gravity of the soil sample is represented by G_s and void ratio is 'e', the hydraulic gradient is expressed as
- (a) $\frac{G_s - 1}{1 + e}$ (b) $\frac{G_s + 1}{1 - e}$
 (c) $\frac{1 - G_s}{1 + e}$ (d) $\frac{1 + G_s}{1 + e}$
- Q.6** If the plasticity index of soil mass is zero, the soil is
- (a) Clay (b) Clayed silt
 (c) Sand (d) Silt
- Q.7** The moisture content of a soil, below which the soil volume becomes constant, is called
- (a) Liquid limit (b) Plastic limit
 (c) Shrinkage limit (d) None of the above
- Q.8** The value of porosity of soil sample in which the total volume of soil grains is equal to twice the total volume of void would be
- (a) 75% (b) 66.66%
 (c) 50% (d) 33.33%
- Q.9** The mass specific gravity of a fully saturated specimen of clay having a w/c of 40% is 1.88. On oven drying if mass specific gravity drops to 1.74 then the specific gravity of clay will be
- (a) 1.95 (b) 2.90
 (c) 2.67 (d) 2.85
- Q.10** Soil samples A and B have void ratios of 0.5 and 0.7 respectively. If 1.5 m^3 of soil sample A and 1.7 m^3 of soil sample B are mixed to form sample C having a volume of 3.2 m^3 , which one of the following correctly represents the porosity of sample C ?
- (a) 0.375 (b) 0.60
 (c) 1.66 (d) 2.66
- Q.11** In Casagrande's liquid limit device, the material of the test specimen is harder than the standard rubber. This hardness indicates that the liquid limit, plasticity index, flow index and toughness index, respectively, of the specimen, are
- (a) more, less more and same
 (b) same, less, same and more
 (c) less, less, same and less
 (d) less, same, less and more
- Q.12** Which one of the following is the water content of the mixed soil made from 1 kg of soil (say A) with water content of 100% and 1 kg of soil (say B) with water content of 50%?
- (a) 66 % (b) 71%
 (c) 75 % (d) 82 %
- Q.13** Given for a sample of a river sand :
 Void ratio at the densest state = 0.40
 Void ratio at the loosest state = 1.20
 Which one of the following correctly represents the relative density of a sample prepared with a void ratio of 1.0 ?
- (a) 12.5 % (b) 25 %
 (c) 75 % (d) 87.5 %
- Q.14** A saturated sand deposit have natural moisture content of 30%. It was noticed that the maximum and minimum void ratios are 0.95 and 0.40 respectively. Assume specific gravity of sand solids are 2.7, the sand deposit will be classified as
- (a) Medium (b) Dense
 (c) Loose (d) Very dense
- Q.15** Two soil samples A and B have porosities $n_A = 40\%$ and $n_B = 60\%$, respectively. What is the ratio of void ratio $e_A : e_B$?
- (a) 2:3 (b) 3:2
 (c) 4:9 (d) 9:4
- Q.16** A clay sample has a void ratio of 0.54 in dry state. The specific gravity of soil solids is 2.7. What is the shrinkage limit of the soil?
- (a) 8.5% (b) 10.0%
 (c) 17.0% (d) 20.0%
- Q.17** Consider the following properties of clay X and Y.
- | S. No. | Properties | Clay (X) | Clay (Y) |
|--------|----------------|----------|----------|
| 1. | LL(%) | 42 | 56 |
| 2. | PL(%) | 20 | 34 |
| 3. | Natural W/C(%) | 30 | 50 |
- Which of the days, X or Y experiences larger settlement under identical loads; is more plastic; and is softer in consistency?
- (a) X, Y and X (b) Y, X and X
 (c) Y, X and Y (d) X, X and Y

Q.18 The dry density of a soil is 1.5 g/cc. If the saturation water content were 50% then its saturated density and submerged density would, respectively, be

- (a) 1.5 g/cc and 1.0 g/cc
- (b) 2.0 g/cc and 1.0 g/cc
- (c) 2.25 g/cc and 1.25 g/cc
- (d) 2.50 g/cc and 1.50 g/cc

Q.19 The given figure indicate the weights of different pycnometers:



The specific gravity of the solids is given by

- (a) $\frac{W_2}{W_4 - W_2}$
- (b) $\frac{W_1 - W_2}{(W_3 - W_4) - (W_2 - W_1)}$
- (c) $\frac{W_2}{W_3 - W_4}$
- (d) $\frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)}$

Q.20 The liquid limit and plastic limit of sample are 65% and 29% respectively. The percentage of the soil fraction with grain size finer than 0.002 mm is 24. The activity ratio of the soil sample is

- (a) 0.50
- (b) 1.00
- (c) 1.50
- (d) 2.00

Q.21 In a wet soil mass, air occupies one-sixth of its volume and water occupies one-third of its volume. The void ratio of the soil is

- (a) 0.25
- (b) 0.5
- (c) 1.00
- (d) 1.50

Q.22 A soil has mass unit weight γ , water content 'w' (as ratio). The specific gravity of soil solids = G, unit weight of water = γ_w ; S the degree of saturation of the soil is given by

(a) $S = \frac{1+w}{\frac{\gamma_w}{\gamma}(1+w) - \frac{1}{G}}$

(b) $S = \frac{w}{\frac{\gamma_w}{\gamma}(1+w) - \frac{1}{G}}$

(c) $S = \frac{(1+w)}{\frac{\gamma_w}{\gamma}(1+w) - \frac{1}{G}}$

(d) $S = \frac{w}{\frac{\gamma_w}{\gamma}(1+w) - \frac{1}{wG}}$

Q.23 If a soil sample of weight 0.18 kg having a volume of 10^{-4} m^3 and dry unit weight of 1600 kg/m^3 is mixed with 0.02 kg of water then the water content in the sample will be

- (a) 30%
- (b) 25%
- (c) 20%
- (d) 15%

Q.24 Match **List-I** (Terms) with **List-II** (Formulae) and select the correct answer using the codes given below the lists:

List-I	List-II
A. Void Ratio	1. $\frac{V_V}{V}$
B. Porosity	2. $\frac{W_W}{W_S}$
C. Degree of saturation	3. $\frac{V_W}{V_V}$
D. Water content	4. $\frac{W}{V}$
	5. $\frac{V_V}{V_S}$

Codes:

	A	B	C	D
(a)	4	3	5	1
(b)	5	4	3	1
(c)	4	1	5	2
(d)	5	1	3	2

ANSWER KEY
**STUDENT'S
ASSIGNMENT**

- | | | | | |
|---------|---------|---------|---------|---------|
| 1. (c) | 2. (a) | 3. (b) | 4. (c) | 5. (a) |
| 6. (c) | 7. (c) | 8. (d) | 9. (b) | 10. (a) |
| 11. (c) | 12. (b) | 13. (b) | 14. (c) | 15. (c) |
| 16. (d) | 17. (c) | 18. (c) | 19. (d) | 20. (c) |
| 21. (c) | 22. (b) | 23. (b) | 24. (d) | 25. (c) |
| 26. (c) | 27. (a) | 28. (d) | 29. (d) | 30. (a) |
| 31. (c) | 32. (c) | 33. (a) | 34. (c) | 35. (b) |
| 36. (b) | 37. (b) | 38. (b) | 39. (b) | 40. (c) |
| 41. (d) | 42. (d) | 43. (d) | 44. (d) | 45. (c) |
| 46. (d) | 47. (b) | | | |

HINTS & SOLUTIONS
**STUDENT'S
ASSIGNMENT**
1. (c)

$$\gamma = \frac{G_s(1+w)}{1+e} \gamma_w$$

 For dry soil, $w = 0$

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

and for submerged condition

$$\begin{aligned} \gamma_{\text{sub}} &= \gamma_{\text{sat}} - \gamma_w \\ &= \frac{G_s - 1}{1+e} \gamma_w \end{aligned}$$

 Thus, $\gamma_{\text{sat}} > \gamma > \gamma_{\text{ch}} > \gamma_{\text{sub}}$
2. (a)

$$\text{Activity of clay} = \frac{I_P}{\% \text{ clay}}$$

Higher the plasticity index, higher is the activity.

3. (b)

$$\text{As we know, } R_D = \frac{e_{\text{max}} - e_{\text{nat}}}{e_{\text{max}} - e_{\text{min}}}$$

$$\text{Given, } e_{\text{max}} - e_{\text{min}} = 0.30$$

$$\text{and } R_D = 0.666$$

$$e_{\text{nat}} = 0.40$$

$$\text{Then, } 0.666 = \frac{e_{\text{max}} - 0.40}{0.30}$$

$$\begin{aligned} \Rightarrow e_{\text{max}} &= 0.1948 + 0.40 \\ \Rightarrow e_{\text{max}} &= 0.5998 \approx 0.6 \end{aligned}$$

4. (c)

$$g = \frac{(G_s - es)}{1+e} \gamma_w$$

and

$$es = w G_s$$

 \Rightarrow

$$g = \frac{G_s(1+w)}{1+e} \gamma_w$$

5. (a)

 Hydraulic gradient (i)

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

6. (c)

Plasticity index of sand is '0'.

7. (c)

Below the shrinkage limit of soil, there is no change in volume.

8. (d)

$$\text{Porosity} = \frac{\text{Volume of voids}}{\text{Total volume}}$$

$$\begin{aligned} n &= \frac{V_v}{V_s + V_v} = \frac{V_v}{2V_v + V_v} = \frac{1}{3} \\ &= 33.33\% \end{aligned}$$

9. (b)

$$w = 40\%$$

$$\gamma = 1.88$$

$$\gamma_{\text{dry}} = 1.74$$

Since soil is fully saturated,

 At $w = 40\%$

Thus,

$$es = w G_s$$

 \Rightarrow

$$e \times 1 = 0.4 G_s$$

 \Rightarrow

$$e = 0.4 G_s$$

and

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

and

$$\gamma = \frac{G_s + e_s}{1+e} \gamma_w$$

 \Rightarrow

$$1.88 = \frac{G_s + 0.4 G_s}{1 + 0.4 G_s} \times 1 \gamma_w$$

 \Rightarrow

$$1.88(1 + 0.4 G_s) = 1.4 G_s$$

 \Rightarrow

$$G_s = 2.901$$

10. (a)

The volume of solids $V_s = \frac{V}{1+e}$ will not change even after mixing.

The solids in soil A = $\frac{1.5}{1+0.5} = 1\text{m}^3$

The solids in soil B = $\frac{1.7}{1+0.7} = 1\text{m}^3$

porosity $n = \left(\frac{V_v}{V}\right)$

Soil	Solids	Void
A.	1	0.5
B.	1	0.7
Mix	2	1.2

Thus the porosity of mix = $\frac{3.2 - 1 - 1}{3.2}$
 $= \frac{3}{8} = 0.375$

11. (c)

If the test specimen is harder than the standard rubber less number of blows will fill the groove for a given water content. In other words 25 number of blows will be required at less water content. So liquid limit and thereby plasticity index will be less. There will be no effect on flow index (I_f)

Toughness index = $\frac{I_p}{I_f}$ will also be less.

12. (b)

Water content $w = \frac{W_w}{W_s} \times 100$

Total weight $W = \left(\frac{w}{100} + 1\right)W_s$

Weight of solids in soil A

$W_{SA} = \frac{1000}{1+1} = 500\text{ gm}$, $W_{WA} = 500\text{ gm}$

Weight of solid in solid B

$W_{WB} = \frac{1000}{1.5} = 666.7\text{ gm}$, $W_{WB} = 333.3\text{ gm}$

In mixed soil

$W_w = 8.33.3\text{ gm}$

$W_s = 1166.7\text{ gm}$

$W = \frac{833.3}{1166.7} \times 100 = 71\%$

Alternate Solution:

Since weight of solids will be same,

$W_s = \frac{w}{1+w}$

Thus, $W_{SA} = \frac{1}{1+1.0} = 0.5\text{ kg}$

$W_{SB} = \frac{1}{1+0.5} = \frac{2}{3}\text{ kg}$

Thus weight of water in mixed soil

$= 2 - \left(\frac{2}{3} + 0.5\right) = 0.833\text{ kg}$

Height of solids in mixed soil

$= \frac{2}{3} + 0.5 = 1.167\text{ kg}$

Thus, $W = \frac{W_w}{W_s} \times 100 = \frac{0.833}{1.167} \times 100 = 71\%$

13. (b)

Relative density $D_r = \frac{e_{\max} - e}{e_{\max} - e_{\min}} \times 100$

$= \frac{1.2 - 1.0}{1.2 - 0.4} \times 100 = 25\%$

14. (c)

Natural W/C = 0.30

$e_{\max} = 0.95$

$e_{\min} = 0.40$

$G_s = 2.7$

$R_D = \frac{e_{\max} - e_{nat}}{e_{\max} - e_{\min}} \times 100$

and

$e_s = wG_s$

$e \times L = 0.3 \times 2.7$

$e = 0.81$

Thus,
$$R_D = \frac{0.95 - 0.81}{0.95 - 0.40} \times 100$$

$$= 25.45\%$$

$I_D(\%)$	Classification
0 - 15	Very loose
15 - 35	Loose
35 - 65	Medium
65 - 85	Dense
85 - 100	Very dense

Since, $15 < R_D < 35$ (Loose sand)

15. (c)

Void ratio, $e = \frac{n}{1-n}$

$$\frac{e_A}{e_B} = \frac{n_A}{(1-n_A)} \times \frac{(1-n_B)}{n_B}$$

$$= \frac{0.4}{(1-0.4)} \times \frac{(1-0.6)}{0.6} = \frac{4}{9}$$

16. (d)

At shrinkage limit, soil is fully saturated ($s = 1$)
and $e_s = wG_s$
 $\Rightarrow 0.54 \times L = w \times 2.7$
 $\Rightarrow w = 0.2$ or 20%

17. (c)

For clay X, $I_p = 42 - 20 = 22\%$
 For clay Y, $I_p = 56 - 34 = 22\%$

and
$$\Delta H = \frac{C_c H_0}{1+e} \log \left(\frac{\bar{\sigma}_2}{\bar{\sigma}_1} \right)$$

$\Rightarrow \Delta H \propto C_c$

and $C_c = 0.009(LL - 10)$

where LL is liquid limit, Thus, $C_c \propto LL$
 Hence, as clay y has more liquid limit,

\therefore Settlement of y will be more and I_p for both the soil is same.

Consistency index, $I_C = \frac{LL - w}{LL - PL}$

For clay X, $I_C = \frac{42 - 30}{22} = 0.545$

For clay Y, $I_C = \frac{56 - 50}{22} = 0.273$

Thus, clay Y is of softer consistency. Thus from the options, (c) is the correct one.

18. (c)

$$\gamma_{\text{sat}} = \gamma_d(1+w) = 1.5 \times 1.5$$

$$= 2.25 \text{ g/cc}$$

$$\gamma_{\text{sub}} = \gamma_{\text{sat}} - \gamma_w = 2.25 - 1.0$$

$$= 1.25 \text{ g/cc}$$

19. (d)

Specific Gravity of solids is given by

$$G_s = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)}$$

20. (c)

Activity = $\frac{\text{Plasticity index}}{\text{Percent of clay particles finer than } 2\mu\text{m}}$

$$= \frac{65 - 29}{24} = \frac{36}{24}$$

$$= 1.5 > 1.25$$

\therefore The soil is active.

21. (c)

Void ratio,

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

$V_v =$ air void + water filled voids

$$= \frac{1}{6}V + \frac{1}{3}V = \frac{V}{2}$$

$$V_s = V - V_v = \frac{V}{2}$$

\therefore

$$e = \frac{V/2}{V/2} = 1.0$$

22. (b)

$$\gamma = \frac{G(1+w)}{1+e} \gamma_w$$

$$1+e = \frac{G(1+w)\gamma_w}{\gamma}$$

and

$$Gw = Se$$

$$\frac{Gw}{S} = \frac{G(1+w)\gamma_w}{\gamma} - 1$$

Dividing both sides by G, we get

$$\Rightarrow \frac{w}{S} = (1+w) \frac{\gamma_w}{\gamma} - \frac{1}{G}$$

$$S = \frac{w}{\frac{\gamma_w}{\gamma}(1+w) - \frac{1}{G}}$$