

UPPSC-AE

2021

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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Origin of Soil

1.1 Soil Mechanics

- It is the branch of science that deals with the study of physical properties of soil masses subjected to various types of forces.
- Terzaghi is known as the father of soil mechanics.
- According to Terzaghi (1948) soil mechanics is the application of civil engineering involving the study of soil, its behaviour and application as the engineering material.
- Apart from the testing and classification of various types of soil, in order to determine the physical properties, knowledge of soil mechanics is particularly helpful in following problems of civil engineering.
 1. Foundation design of construction
 2. Pavement design
 3. Design of underground structures and earth retaining structures.
 4. Design of embankment and excavation.
 5. Design of earth dams.

1.2 Soil

- It is defined as uncemented and unconsolidated aggregate of mineral grain and decayed organic matter (solid particles) with liquid and gas in the empty spaces between the solid particles.
- Soil consists of gravel, sands, silts and clay.

1.3 Origin of Soil

- The process of soil formation is called pedogenesis.
- The soil formation is cyclic which is called geological cycle.
- Stages in geological cycle of soil formation:

Weathering → Transportation → Deposition → Upheaval

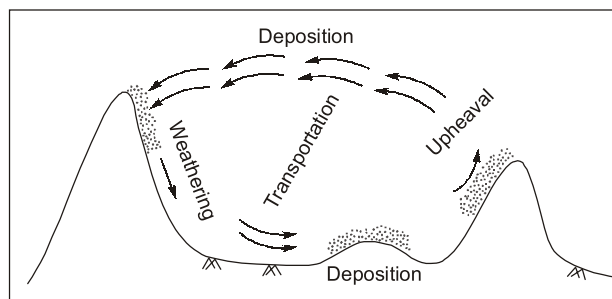


Fig. Stages of Geological Cycle in case of transported soil

1.3.1 Weathering

- Rock disintegration, also called weathering, is one of the important geological process.
- Formation of soil particles takes place by two process.
 - (a) Physical weathering
 - (b) Chemical weathering

Physical Weathering

- Physical weathering are:
 - (i) Erosion of rock by wind, water, glacier etc. and penetration of plant root.
 - (ii) Disintegration of rocks due to alternate freezing and thawing cycles.
- Soil so formed retain the minerals that were present in parent rock.
- Soil so formed are coarse grained soil (CGS) e.g sand and gravel.
- Their shape may be angular, sub angular, rounded.
- Soil so formed does not have bond between the particles and they are said to have single grained structure.

Chemical Weathering

- It occurs due to chemical action of acids and alkalies present in water, air and glacier. Chemical action leads to formation of crystalline particle of small size ($< 2\mu$) known as clay minerals.
- The identity of these minerals are different from that observed parent rock.
- Clay minerals have plate like structure having large specific surface. Thus surface bonding forces are more predominant in these soils.
- Presence of water in the soil so formed influences their engineering properties significantly.

1.3.2 Transportation/Deposition

- If the products of rock weathering are still located at the place where they originated, they are called residual soil while soil that are transported from their origin by wind, water, ice or any other agency and has been deposited is called transported soil.
- Characteristics of soil such as size of particle, shape and roundness, surface texture and degree of shortening are influenced by the agency of transportation.

NOTE: Residual soils have better engineering properties as compared to transported soil.

According to the transporting agent, soils are classified as:

Type of soil	Transporting agent	Remarks
1. Alluvial	Running water	River banks
2. Lacustrine	Fresh and still water	Lakes and ponds
3. Marine	Sea water	Sea shores
4. Colluvial soils (Talus)	Gravity	Mountain valley
5. Glacial soil (Till)	Ice	Glaciers
6. Aeolian (sand dunes)	Wind	Deserts
7. Loess	Wind blown silt	With increase in water content soil become soft and collapsible

1.4 Various type of Soils

- **Loess:** These are wind blown uniformly graded fine soil. Loess is formed in arid and semi-arid regions. Its colour is yellowish brown and deposits of this soil are found in Rajasthan and North Gujarat.
- **Caliche:** It is cemented soil rich in calcium carbonate consisting of gravel, sand and clays. These are also wind blown in semi-arid climate and later on cemented by the calcium carbonate left out from the evaporation of capillary water.
- **Loam:** It is a mixture of sand, silt and clay in definite proportion which in some cases may consist of organic matter.
- **Cumulose:** Peaty (organic) soils are also called cumulose soil or muck. These are formed due to accumulation of organic content under waterlogged condition. It is generally found in the areas having deficient sewerage facilities or found after overflowing of the rivers.
- **Gumbo:** These are highly sticky, plastic and dark coloured soil.
- **Marl:** These are fine grained calcium carbonated soil of marine origin. These are formed due to decomposition of cell mass and bones of aquatic life.
- **Humus:** Humus is a mixture of mud and dead plants. The tiny pieces of rock and humus joint to make various soils.
- **Peat:** It is highly organic soil containing almost decomposed vegetable matter.
- **Gravel:** Gravel is a type of coarse grain soil having particle size in the range of 4.75 mm to 80 mm.
- **Sand:** They are cohesionless aggregates of rounded, sub angular or angular sediment in the range of 0.075 mm to 4.75 mm.
- **Silt:** It is a fine-grained soil, with particle size between 0.002 mm and 0.075 mm.
- **Clay:** It is an aggregate of mineral particles of microscopic and submicroscopic range. Clay may be organic or inorganic.
- **Cobbles:** Cobbles are large size particles in the range of 80 mm to 300 mm.
- **Boulders:** Boulders are rock fragment of large size (more than 300 mm).
- **Tuff:** These are small grained slightly cemented volcanic ash that has been transported by wind or water.
- **Bentonite:** It is a clay formed by chemical weathering of volcanic ash which have high content of montmorillonite. Pulverized slurry of bentonite is highly plastic and is often used as a lubricant in drilling.
- **Kaolin (China Clay):** It is very pure form of white clay, which is extensively used in ceramic industry.
- **Hardpans:** Hardpans are types of soils that offer great resistance to the penetration of drilling tools during soil exploration. These are generally dense, well graded, cohesive aggregates of mineral particles.
- **Varved Clays:** These are sedimentary deposits consisting of alternate thin layer of silt and clay. These clays are the result of deposition in lakes during periods of alternate high and low waters.
- **Till:** It is formed by glaciers and iceberg and may contain mixture of gravel, sand, silt and clay. These soils are well graded.

1.4.1 Lateritic Soils

- Lateritic soils are formed by decomposition of rock, removal of bases and silica and accumulation of iron oxide and aluminium oxide.
- The presence of iron oxide gives these soils the characteristics red or pink colour.
- These are residual soils, formed from basalt.

1.4.2 Organic and Inorganic Soil

Soils can also be classified as organic or inorganic soil.

- Organic soil are formed by growth and subsequent decomposition of plant. For example peat and mosses.
- In general, organic soil is that transported soil obtained from rock weathering which contains decomposed vegetable matter.
- Inorganic soils referred to ordinary soil obtain from rock disintegration due to weathering.



Student's Assignment

Q.1 Bentonite clay is a material obtained due to the weathering of

- (a) Lime stone (b) Quartzite
(c) Volcanic ash (d) Shales

Q.2 Which of the following is transported by gravitational forces.

- (a) Loess (b) Talus
(c) Drift (d) Dune sand

Q.3 Match **List-I** with **List-II** and select the correct answer using the codes given below the lists:

- | List-I | List-II |
|-------------------------|---|
| A. Residual soil | 1. Soil transported by wind. |
| B. Loess | 2. Organic soil |
| C. Peat | 3. Deposition in lake during periods of high and low waters. |
| D. Varved clays | 4. Soil left in place after weathering of parent rock. |

Codes:

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

Q.4 Glaciers are formed by

- (a) Compaction and recrystallization of snow.
(b) Continuous freezing of water.

- (c) A sudden drop in temperature.
(d) None of the above.

Q.5 Identify the true statements:

- (a) A soil transported by gravitational forces is called talus.
(b) Laterite soil is category of organic soil.
(c) Water held firmly to the clay particles has the same properties as ordinary water.
(d) A clay deposits which exhibit no evidence of fissuring is described as intact.

Q.6 Geological cycle for the formation of soil is

- (a) upheaval → transportation → deposition → weathering
(b) weathering → upheaval → transportation → deposition
(c) weathering → transportation → deposition → upheaval
(d) Transportation → upheaval → weathering → deposition

Q.7 Lacustrine soil are soils

- (a) transported by rivers and streams
(b) transported by glaciers
(c) deposits in sea beds
(d) deposited in lake beds

Q.8 Which one of the following soils is the Aeolian?

- (a) Volcanic soil (b) Residual soil
(c) Weathered soil (d) Transported soil

Q.9 Match **List-I** (Type of soil) with **List-II** (Feature) and select the correct answer using the codes given below the lists:

List-I

- A. Lacustrine
- B. Alluvial
- C. Aeolian
- D. Marine

List-II

- 1. Transported by wind
- 2. Transported by running water
- 3. Deposited at the bottom of lakes
- 4. Deposited in sea water

Codes:

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

- Q.10** The collapsible soil is associated with
 (a) dune sands (b) laterite soils
 (c) loess (d) black cotton soils
- Q.11** Bentonite is a material obtained due to the weathering of
 (a) limestone (b) quartzite
 (c) volcanic ash (d) shales
- Q.12** Loess deposits are formed by:
 (a) Physical disintegration of rock.
 (b) Constant blowing of wind from the same direction.
 (c) Vertical deposition of glacial till.
 (d) Chemical weathering of residual deposits.
- Q.13** Wind blown silt having little or no stratification is called
 (a) Talus (b) Drift
 (c) Peat (d) Loess (UPPSC)
- Q.14** Soil deposit formed due to transportation by wind is termed as
 (a) Lacustrine deposit
 (b) Alluvial deposit
 (c) Estuarine deposit
 (d) Aeolian deposit

ANSWER KEY

**STUDENT'S
ASSIGNMENT**

- | | | | | |
|---------|---------|---------|---------|---------|
| 1. (c) | 2. (b) | 3. (c) | 4. (a) | 5. (a) |
| 6. (c) | 7. (d) | 8. (d) | 9. (b) | 10. (c) |
| 11. (c) | 12. (b) | 13. (d) | 14. (d) | |

HINTS & SOLUTIONS

**STUDENT'S
ASSIGNMENT**

5. (a)

Intact rock: The rock portion between two discontinuities is called intact rock. Intact rock has more strength than rock mass.

9. (b)

Lacustrine – Deposited at the bottom of lakes
 Alluvial – Transported by running water
 Aeolian – Transported by wind
 Marine – Deposited in sea water

11. (c)

Bentonite is decomposed volcanic ash containing high percentage of clay mineral-montmorillonite.

12. (b)

Loess are wind deposited soils. They are uniformly grained silt sized (0.01– 0.05 mm) soils.

13. (d)

Loess is a wind deposit soil (silt). It is generally of uniform gradation, with the particle size between 0.01-0.05 mm. Loess are compressible in nature when they are in wet form. For loess the permeability in vertical direction is generally much greater than that of horizontal direction.



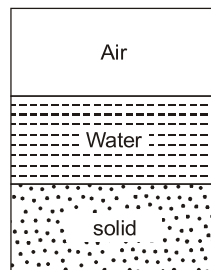
Properties of Soil

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).

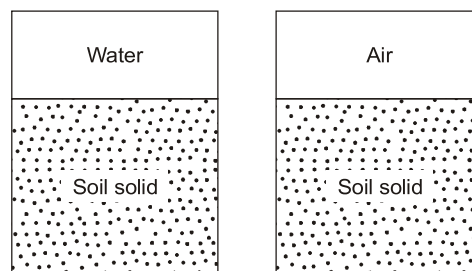
2.2 Phase Diagram

- 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:



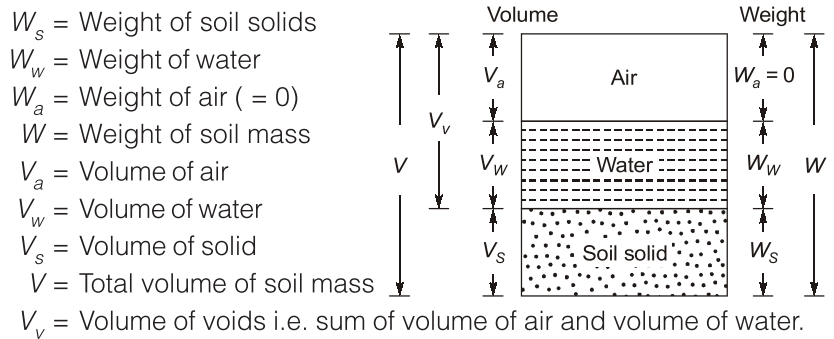
Saturated soil

Dry soil



Three phase solid water air system

2.3 Important Definitions



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 = volume of air

V = 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.

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

- 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.

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

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

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

(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 $\frac{\text{kN}}{\text{m}^3}$ or $\frac{\text{kgf}}{\text{cm}^3}$

(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 $\frac{\text{kN}}{\text{m}^3}$ or $\frac{\text{kgf}}{\text{cm}^3}$

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—

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

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

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

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

2.3.1 Some important Relationship (Soul of Soil):

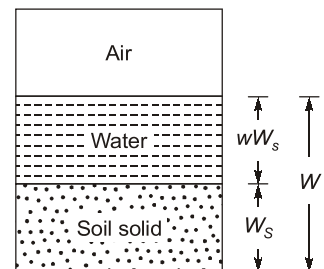
1. Relation between W_s , W , w :

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

$$W_w = w \cdot W_s$$

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

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



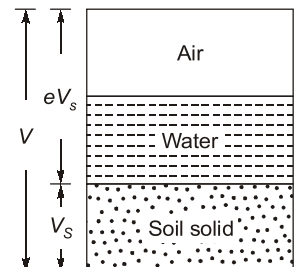
2. Relation between V_v , V , e :

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

$$V_v = e \cdot V_s$$

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

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



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

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

Also,

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

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

or

$$Se = w G$$

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

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

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

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

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

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

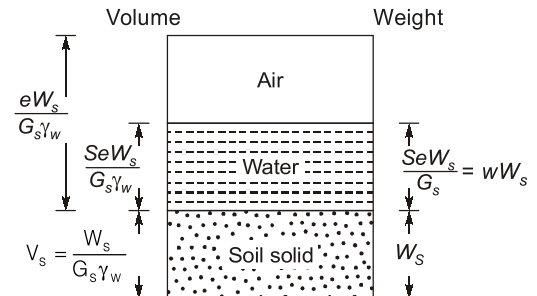
Special Case (a): If soil is saturated, then

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

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

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 :

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

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

$$\begin{aligned}\left(1 + \frac{wG_s}{S}\right) &= \frac{G_s \gamma_w}{\gamma_t}(1+w) \\ \frac{1}{G_s} \left(1 + \frac{wG_s}{S}\right) &= \frac{\gamma_w}{\gamma_t}(1+w) \\ \frac{1}{G_s} + \frac{w}{S} &= \frac{\gamma_w}{\gamma_t}(1+w)\end{aligned}$$

$$\text{or} \quad S = \frac{w}{\frac{\gamma_w}{\gamma_t}(1+w) - \frac{1}{G_s}}$$



NOTE

S.No.	Relationship in unit weight	Relationship in density
1.	$n = \frac{e}{1+e}$	$n = \frac{e}{1+e}$
2.	$e = \frac{n}{1-n}$	$e = \frac{n}{1-n}$
3.	$n_a = n a_c$	$n_a = n a_c$
4.	$\gamma = \frac{(G_s + Se)\gamma_w}{1+e}$	$\rho = \left(\frac{G_s + Se}{1+e} \right) \rho_w$
5.	$\gamma_d = \frac{G_s \gamma_w}{1+e}$	$\rho_d = \frac{G_s \rho_w}{1+e}$
6.	$\gamma_{\text{sat}} = \left(\frac{G_s + e}{1+e} \right) \gamma_w$	$\rho_{\text{sat}} = \left(\frac{G_s + e}{1+e} \right) \rho_w$
7.	$\gamma_{\text{sub}} = \left(\frac{G_s - 1}{1+e} \right) \gamma_w$	$\rho_{\text{sub}} = \left(\frac{G_s - 1}{1+e} \right) \rho_w$
8.	$\gamma_d = \frac{\gamma}{1+w}$	$\rho_d = \frac{\rho}{1+w}$
9.	$e = \frac{w G_s}{s}$	$e = \frac{w G_s}{s}$
10.	$\gamma_d = \frac{(1-n_a) G_s \gamma_w}{1+w G_s}$	$\rho_d = \frac{(1-n_a) G_s \rho_w}{1+w G_s}$

$\rho_w = 1000 \text{ kg/m}^3,$ $= 1.0 \text{ gm/cc} = 1 \text{ gm/ml}$	$\gamma_w = 9810 \text{ N/m}^3$ $= 9.81 \text{ kN/m}^3$
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- Some important points for numericals:
 - Mixing of two or more soils:
 - No change: W_s, V_s, W_w, V_w, W
 - Change: V_a, V_v, V



Example - 2.1 Soil sample *A* and *B* have void ratio of 0.5 and 0.7 respectively. If 1.5 m³ of sample *A* and 1.7 m³ of sample *B* are mixed to form sample *C* having a volume of 3.2 m³, which of the following correctly represents the porosity of sample *C*?

- (a) 50% (b) 37.5%
(c) 100% (d) 33.33%

Solution: (b)

Soil A(1)

$$e_1 = 0.5$$

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

Soil B(2)

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

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

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

$$\text{The solids in soil A,} \quad V_{s1} = \frac{V_1}{1 + e_1} = \frac{1.5}{1 + 0.5} = 1 \text{ m}^3$$

$$\text{The solids in soil B,} \quad V_{s2} = \frac{V_2}{1 + e_2} = \frac{1.7}{1 + 0.7} = 1 \text{ m}^3$$

$$\text{Total volume of solids in soil C,} \quad V_{s3} = V_{s1} + V_{s2} = 2 \text{ m}^3$$

$$\therefore \text{Volume of void in soil C,} \quad V_v = V_3 - V_{s3} = 3.2 - 2 = 1.2 \text{ m}^3$$

$$\therefore \text{Porosity,} \quad n = \frac{V_v}{V_3} = \frac{1.2}{3.2} = 0.375$$

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)

$$W_3 = W_1 + W_2$$

$$w_3 = ?$$

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

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

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

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

$$\text{Weight of solids in soil A,} \quad W_{sA} = \frac{1000}{1 + 1} = 500 \text{ g}$$

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

$$\text{Weight of solids in soil B,} \quad W_{sB} = \frac{1000}{(0.5 + 1)} = 666.7 \text{ g}$$

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

$$W_{s, \text{mix}} = W_{sA} + W_{sB} = 500 + 666.7 \text{ and } = 1166.7 \text{ g}$$

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

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

- (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,

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

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

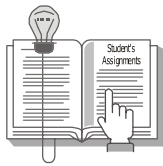
$$\Rightarrow (I_T)_B > (I_T)_A$$

$\therefore B$ 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

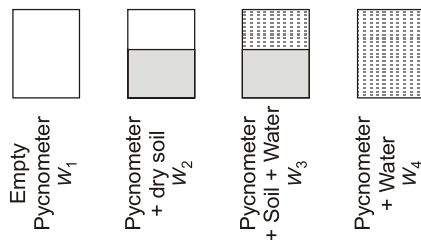
- Q.1** Which of one of the following gives the correct sequence of decreasing order of densities of a soil sample?
- saturated, submerged, wet, dry
 - saturated, wet, submerged, dry
 - saturated, wet, dry, submerged
 - wet, saturated, submerged, dry
- Q.2** Which of the following correctly defines the 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

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

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

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

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

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,

$$\gamma_{\text{sat}} > \gamma > \gamma_{\text{chy}} > \gamma_{\text{sub}}$$

2. (a)

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

Higher the plasticity index, higher is the activity.

3. (b)

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

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

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

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

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

 \Rightarrow

$$e_{\text{max}} = 0.1948 + 0.40$$

 \Rightarrow

$$e_{\text{max}} = 0.5998 \approx 0.6$$

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

$$ex1 = 0.4 G_s$$

 \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

$$G_s = 2.901$$