GATE MASTER'S ACADEMY

SINCE - 2007

GEO-TECHNICAL ENGINEERING

www.gatemastersacademy.com

Head Office:

HYDERABAD

GATE MASTER'S ACADEMY
3rd Floor, S.S. Towers, Beside Kamala Hospital,
Dilsukhnagar, Hyderabad.
Tel: 040-6662 3032
Mobile:+91 8125303032

GM Publications

Address : #303, 3rd Floor, SS Towers, Beside Kamala Hospital,
Dilsukh Nagar, Hyderabad - 60

Phone : 040-66623032

Mobile : +91 8125303032

e-mail : info.gmpublication@gmail.com

web : www.gatemasterspublication.com

Authors

Subject Experts of Gate Master's Academy, Hyderabad.

Editions:

First Edition - 2007

Fourth Edition - 2010

Ninth Edition - 2015

Fourteenth Edition - 2020

Fifteenth Edition - 2022

INDEX

SOIL MECHANICS

FOUNDATION ENGINEERING

TSPSC AEE SYLLABUS

Soil Mechanics and Foundation Engineering: Soil Mechanics: Physical properties of soils, Classification and identification,Permeability, Capillarity, Seepage, Compaction, Consolidation, Shear Strength, Mohr'scircle, Earth pressure, Slope stability; Foundation Engineering: Site investigations, stress distribution in soils, Bearing capacity,Settlement analysis, Types of Foundation, Pile foundations, Foundations on expansivesoils; swelling and its preventions; Coffer dams, Caissons, Dewatering, Bracing forexcavations, Newmark charts, machine foundations.Engineering Geology: Mineralogy, Structural Geology, Groundwater Explorationmethods; Engineering Geology applications for Tunnels, Dams and Reservoirs;Geological hazards and preventive measures.

APPSC AEE SYLLABUS

Properties and classification of soil, Compaction, Permeability and Seepage, Flow nets, Compressibility and consolidation. Stress distribution in soils, Shearing resistance, Stresses and failure. Soil testing in laboratories and in-situ, Earth pressure theories, Soil exploration. Types of foundations, Selection criteria, bearing capacity, Settlement, laboratory and field tests, Design of shallow foundations. Types of piles and their design and layout. Foundations on expansive soils.

SSC-JE SYLLABUS

Soil Mechanics: Origin of soil, phase diagram, Definitions-void ratio, porosity, degree of saturation, water content, specific gravity of soil grains, unit weights, density index and interrelationship of different parameters, Grain size distribution curves and their uses Index properties of soils, Atterberg's limits, ISI soil classification and plasticity chart Permeability of soil, coefficient of permeability, determination of coefficient of permeability, Unconfined and confined aquifers, effective stress, quicksand, consolidation of soils, Principles of consolidation, degree of consolidation, pre-consolidation pressure, normally consolidated soil, e-log p curve, computation of ultimate settlement Shear strength of soils, direct shear test, Vane shear test, Triaxial test Soil compaction, Laboratory compaction test, Maximum dry density and optimum moisture content, earth pressure theories, active and passive earth pressures, Bearing capacity of soils, plate load test, standard penetration test

1 ORIGIN AND STRUCTURE OF SOILS

INTRODUCTION

- The study of earth in technical manner is known as "Geo-Technical Engineering". Geotechnical engineering is a broader term which includes soil engineering, rock mechanics and geology.

Soil:

- The word soil is derived from the Latin word *'Solum'*.Soil is a loose unconsolidated material available on the earth's crust which occurs due to disintegration of rocks or decomposition of organic matter.
- The process of formation of soil is termed as *"Pedogenesis"*.
- The top soil contains a large quantity of organic matter and is not suitable as a construction material or as a foundation for structures.

Soil Mechanics

- Soil Mechanics also called as "*Particulate Mechanics*".
- Father of soil mechanics is *Dr. Karl von Terzaghi* (Austria). His book *Erdbaumechanik* was published in German in the year 1924.
- As per Terzaghi "Soil Mechanics is a branch of mechanics which deals with the action of forces on soil and with the flow of water in soil".

<u>Soil Mechanics Issues :</u>

- Study of solid and fluid mechanical issues and characteristics of soil.

Soil Mechanics Issues:

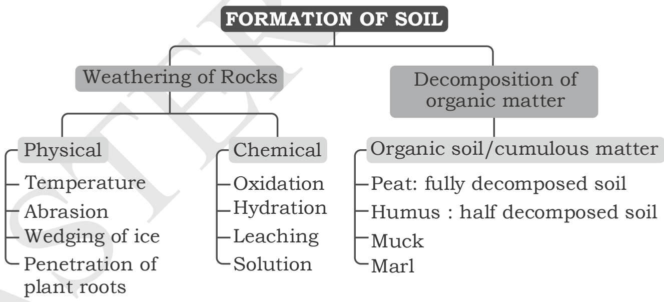
- When loads are applied, the amount of soil deformation, and rate of deformation that takes place is?
- How much load can be applied to soil before it fails and how does it fail ?

Fluid Mechanics Issues :

- How does water flows through soil?
- How can water flow through soil that causes it to fail?

Foundation Engineering

- It is the engineering field of study devoted to the design of those structures which support other structures, most typically buildings, bridges or transportation infrastructure. The principles of soil mechanics is applied to the foundation.



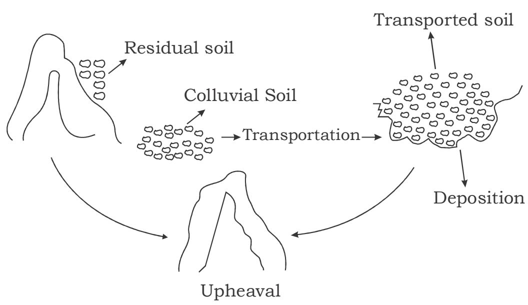
- Due to physical effects, there is no change in chemical composition. Coarse grained soils are formed. These are non-cohesive in nature.

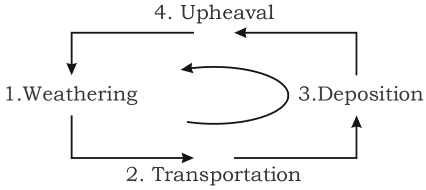
Ex: Gravel & sand.

- Due to chemical effects there may be a chance of change in chemical composition. Due to chemical effects, fine grained soils are formed. These are cohesive in nature.

Ex: Clay, Silt.

Geological Cycle





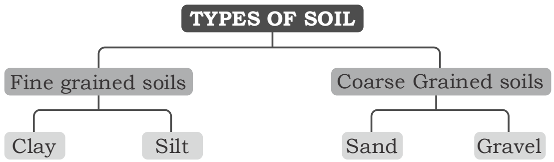
Residual Soil (or) Sedentary Soil:

The Soils which are at (or) near to the parent rock is known as residual soil.

Ex: Black cotton Soil.

Transported Soil (or) Sedimentary Soil:

The soils which are formed at one location and deposited at another location is known as transported soils. Transportation of soil may occur due to air, water, glaciers & gravity.



Fine Grained Soils :

- Majorly formed due to surface acti-vity
- Proportional to surface area

Ex: Clay

Coarse grained soils :

- Majorly formed due to gravitational effect.
- Proportional to weight

Ex: sand & gravel

Note: *In case of silt, both surface activity & gravitational forces are predominant.*

Sizes of the particles:

Different Type of Soils

- **Aeolian soil:**

  If the soils are trans-ported by air, it is called as aeolian soil.

Ex: Dune sand, loesses. (They have perfect sphere shape.)

Note :

Both loess and dune sand are collapsible soils. But dune sand is more collapsible than loess.

- **The soils which are transported due to water are:**
  - *Alluvial Soils* :

    Deposited from suspension in running water (river).
  - *Lacustrine Soils* :

    Deposited at the bottom of the lakes.
  - *Marine Soils* :

    Deposited in sea water.

Note :

Alluvial soils have alternating layers of sand, silt, clay.

- **Glacier Soil:**

  The soils transported by glacier are glacier soils.

Ex: Drift, till.

- **Colluvial Soil:**

  The soils trans-ported by gravity are colluvial soils.

Ex: Talus.

- **Black cotton Soil:**

  It is formed due to chemical weathering and the parent rock is basalt and trap, containing high percentage of clay mineral *montmorillonite*. Dark in colour & shows high swelling and shrinkage. It has low shear stren-gth and is suitable for cotton crop.

- **Laterite Soil:**

  It is a residual soil formed from basalt. This soil is red or pink in colour due to presence of iron oxide. Laterite soils are formed due to leaching of minerals from the parent rock.

- **Bentonite Clay:**

  This is chemically weathered volcanic ash which consists of high percentage of clay mineral *montmorillonite*. It is a highly plastic clay.

- **Loam :**

  It is a mixture of clay, silt & sand in equal proportions.

- **Moorum :**

  Moorum means powd-ered rock. When gravel is mixed with the red clay moorum is for-med.

- **Varved Clay:**

  The alternative layers of clay & silt is known as varved clay.

- **Loess :** Collapsible Soil. Uniformly graded wind blown silt, slightly cemented due to 'Ca' compounds. When it is wet, it loses it's cemen-tious properties and becomes soft and compressible and is collapsed.

- **Marl :**

  Fine graded $CaCO_3$ soil of marine origin, which is found due to decomposition of animal bones and aquatic plants & is greenish in colour.

- **Caliche :**

  It's a conglomerate of gravel, sand, clay cemented by $CaCO_3$.

- **Organic Soils :**
  - Muck :

    Mixture of inorganic soil & black decomposed organic matters.
  - Peat :

    It is very highly organic soil which almost entirely consist of vegeta-tive matters (wood and leaves) in different stages of decompo-sition.It's colour varies from dark to brown and it posses the organic odour and is highly compressible.
  - Humus :

    Dark brown, organic amorphous earth of the top soil. It consist of partly decomposed vegetal matter.

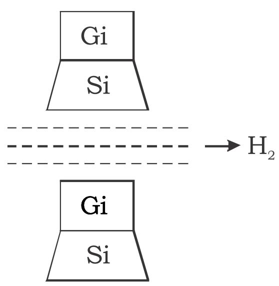
Note : Peat & muck are termed as "*Cumulose Soils*".

Minerals of the Soils

MINERALS

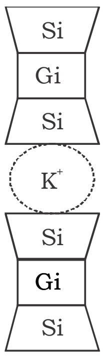
- Clay Minerals — **Eg:** Halloysite Illite Kaolinite Montmorillonite
- Rock Minerals — **Eg:** Quartz Feldsparmica

- Any clay Mineral forms with 2 sheets.
  - Silica sheet
  - Alumina (gibbsite) sheet.
  - *Silica Sheet:*
    - It is a tetrahedral ion
    - It is enclosed by 4 oxygen (or) hydrogen ions
    - The representation of silica sheet is [Si]
  - *Alumina (Gibbsite) Sheet:*
    - This is an octahedral ion.
    - It is enclosed by 6 aluminum (or) iron (or) manganese atoms.
    - The representation is [Gi]
- **Kaolinite:**
  - It has H_2 bond.
  - This is a strong bond.
  - It exhibits no swelling & no shrin-kage.
  - Water cannot enter between the structural unit & cause expansion It is electrically neutral.

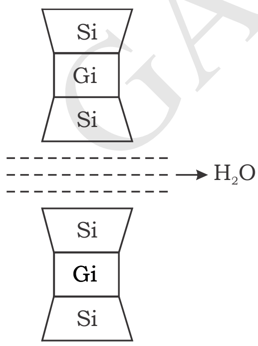


Ex: China clay, Red earth.

- **Illite:**
  - It has ionic bond.
  - Ionic bond is an intermediate strong bond.
  - Ionic bond exists between the two minerals.
  - It exhibits medium swelling & medium shrinkage.



- **Halloysite:**
  - Halloysite has similar structure as kaolinite.
  - The soils containing halloysite have a very low mass density.
- **Montmorillonite:**
  - This has the H_2O bond.
  - Large swelling & shrinkage.



Ex: Black cotton soil

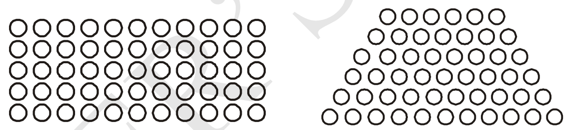
Soil Structure:

- Soil structure is defined as the arrangement of soil particles.
- The soil structure will affect engin-eering properties like permeability, shear strength, compressibility etc.

Types of Soil Structure

- Single Grained Structure
- Honeycombed Structure
- Flocculated Structure
- Dispersed Structure
- Combined Structure

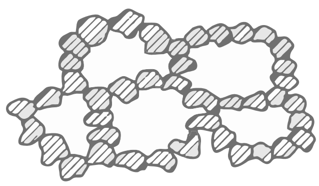
- **Single Grained Structure:**



$e_{max} = 0.91$ $e_{min} = 0.35$

  - This is possible in gravel & sand.

- **Honeycomb Structure:**
  - Possible in case of silty soils
  - In case of silt, both surface activity & gravity forces are predominant.
  - When water is sprinkled, the soil may collapse.

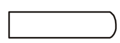


- **Flocculated structure :**
  - This type of structure are generally seen in clays.
  - Clay particle has electromagnetic charge.

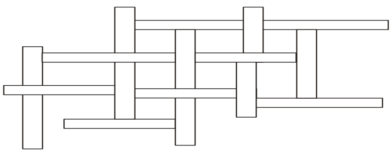
  Shape of the particle is :- + − +

  ⇨ Circular → 

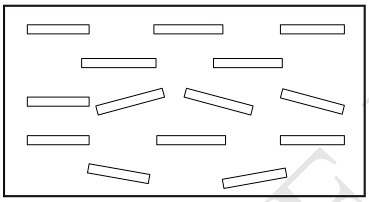
  ⇨ Angular → 

  ⇨ Needle/flaky → 

- Needle shaped particle has less thickness more surface area.
- The particle comes together to form a floc, which is known as flocculation.
- This type of structure have more shear strength and more permeability.
- This type of structure have EDGE to FACE orientation.
- The concentration of dissolved minerals in water leads to formation of flocculated structure with very high void ratio as in the case of marine deposits.



- **Dispersed Structure:**



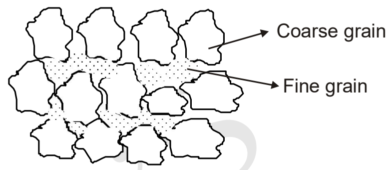
- This type of structure is possible in remoulded clays (or) disturbed clays.
- This structure have FACE to FACE or parallel orientation
- Less shear strength & less permeability
- This type of structure is common in fresh water deposits
- The conversion of flocculated to dispersed structure is known as remoulding
- The conversion of dispersed to flocculated structure is known as *thixotropy*.

Thixotropy: Regaining of its lost shear strength with passage of time without change in water content is known as thixotropy.

- **Combined structure:**

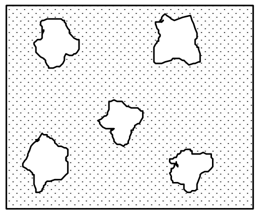
This is possible when different soils gets mixed.

- *Coarse Grained Skeleton*:



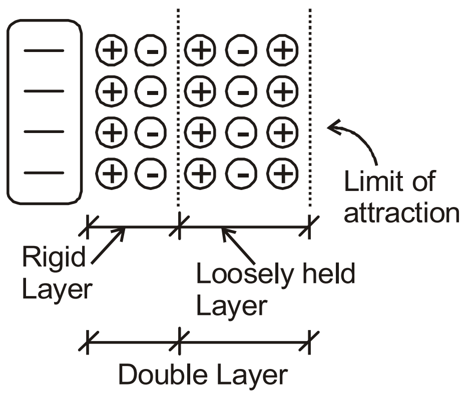
- Under the application of load, this type of structure will undergo less settlement.

- *Cohesive Matrix*:



- Under the application of external loads, this will undergo large settlement.

Diffused Double Layer Theory



- This is possible only in clays
- Water imparts plasticity to the clay.

- The layer on the clay surface up to the limit of attraction due to electromagnetic forces, is known as diffused double layer.
- The water held in up to the limit of attraction is known as adsorbed water.
- Kerosene is a nonpolar liquid, it does not impart any plasticity to the clay.

Specific Surface Area:

It is defined as the ratio of total surface area to the unit weight of the soil.

$$S.S.A = \frac{\text{Total surface area}}{\text{Unit weight of the soil(1gm)}}$$

$$\text{Total Surface Area} = 4\pi r^2 \times n$$

$$\text{Total Volume} = \frac{4}{3}\pi r^3 \times n$$

$$S.S.A. \propto \frac{1}{r}$$

AEE Previovs Year Questions

1. An agent responsible for the transportation of soil is **(AEE-2011)**
   a) Wind b) Water
   c) Gravity d) All the above
2. One of the following is known as Father of Soil Mechanics **(AEE-2011)**
   a) Casagrande b) Karl Terzaghi
   c) R.B. Peck d) D.W. Taylor
3. Water transported soils **(TSPSC AE 2015)**
   a) Loess b) Glacier
   c) Alluvial d) Marine
4. Granite is an example of **(TS GENCO 2015)**
   a) Aqueous rock
   b) Sedimentary rock
   c) Metamorphic rock
   d) Igneous rock
5. lacustrine soils according to geological classifications are **(APPSC AEE MAINS-2016)**
   a) Deposited in seas
   b) Transported by wind
   c) Transported by ice
   d) Deposited in lakes
6. The clay soil group that does not swell under wet conditions is **(AEE 2003)**
   a) Kaolinite b) Illite
   c) Vermicilite d) Montmorillonite
7. Clayey minerals are identified from non clayey minerals by **(AEE-2003)**
   a) Specific surface b) Atterberg's limits
   c) Permeability d) Lattice structure
8. The plasticity characteristics of clay are due to **(AEE - 2008)**
   a) Capillary water
   b) Adsorbed water
   c) Absorbed water
   d) Free water
9. The correct increasing order of the surface areas of the given soils is **(AEE - 2012)**
   a) Silt, sand, colloids, clay
   b) Sand, silt, colloids, clay
   c) Sand, silt, clay, colloids
   d) Clay, silt, sand, colloids
10. Deposit with flocculated structure is formed when **(Research Assistant 2013)**
    a) Clay particles settle on sea bed
    b) Clay particles settle on fresh water lake bed
    c) Sand particles settle on river bed
    d) Sand particles settle on sea bed
11. With reference to shrinkage and swelling the most active clay mineral is **(Observers-2013)**
    a) Kaolinite
    b) Montmorillonite
    c) Illite
    d) None of the above
12. Expansive soils are those which generally consists of **(TSPSC AEE 2015)**
    a) Feldspar b) Mica
    c) Silica d) Montmorillonite
13. The ability of soil particles to undergo rehabilitation and regain a part of the lost strength when left undistributed is known as **[TS AEE -2017]**
    a) Dilation b) Thixotropy
    c) Plasticity d) Swelling
14. Which of the following is deposit of glacial origin consisting of un-assorted mixture of boulders and clay particles ? **[TS AEE -2017]**
    a) Loess b) Talus

c) Till d) Eskers

15. Varved clay is **[TS SPDCL 2018]**

a) A mixture of sand, silt, clay

b) A chemically bonded soil mixture

c) Alternate thin layers of silt and clay

d) Decomposed volcanic ash deposit

16. The predominant mineral responsible for shrinkage and swelling in black cotton soil is **[TS SPDCL 2018]**

a) Illite b) Kaolinite

c) Mica d) Montmorillonite

17. Expansive soils are those which generally consist of **[TS SPDCL 2018]**

a) Feldspar b) Mica

c) Montmorillonite d) Silica

KEY

01. d	02. b	03. c	04. d	05. d	06. a	07. d	08. b	09. c	10. a
11. b	12. d	13. b	14. c	15. c	16. d	17. c			

Practice Questions

1. Lacustrine soils are soils
   a) Transported by rivers
   b) Transported by glaciers
   c) Deposited in sea beds
   d) Deposited in lake beds

2. Consider the following statements in the context of aeolian soils:
   1) The soil has low density and low compressibility.
   2) The soil is deposited by wind
   3) The soil has large permeability
   Which of these statements are correct?
   a) 1,2 and 3 b) 2 and 3
   c) 1 and 3 d) 1 and 2

3. Soil transported by wind are known as _____

4. Residual soils are formed by
   a) Glaciers b) Wind
   c) Water d) None of the above

5. Which of the following type of soil is transported by gravitational forces?
   a) Loess b) Talus
   c) Drift d) Dune sand

6. Loamy means
   a) Sandy clay with a little silt
   b) Silty clay with a little sand
   c) Sand, silt and clay
   d) Sand, silt and gravel

7. Cohesionless soils are formed due to
   a) Oxidation or rocks
   b) Leaching action of water on rocks
   c) Blowing of hot and cold wind
   d) Physical disintegration of rocks

8. Chemical weathering occurs because of
   a) Oxidation b) Carbonation
   c) Hydration d) All the above

9. Match List-I (Type of soil) with List – II (Mode of transportation and deposition) and select the correct answer using the codes given below the lists:-

	List – I	List – II
A.	Lacustrine soils	1. Transportation by wind
B.	Alluvial soil	2. Transportation by running water
C.	Aeolian soils	3. Deposited at the bottom of lakes
D.	Marine soils water	4. Deposited in sea

Codes:

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

10. Match **List – I with List – II** and select the correct answer using the codes given below the lists:

List – I	List – II
A) Loess	1. Deposited from suspension in running water
B) Peat	2. Deposits of marine orign
C) Alluvial soil	3. Deposits by wind
D) Marl	4. Organic soil

Codes:

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

11. For sand of uniform spherical particles, the void ratio in the loosest and the densest states are ______ and ______ respectively.

12. The collapsible soil is associated with
    a) Dune sands b) Late rite soils
    c) Loess d) Black cotton soils

13. The predominant mineral res-ponsible for shrinkage and swelling in black cotton soils is
   a) Illite b) Kaolinite
   d) Mica d) Montmorillonite

14. Sand particles are made of
   a) Rock minerals b) Kaolinite
   c) Illite d) Montmorillonite

15. Dispersed type of soil structure is an arrangement comprising particles having
   a) Face to face or parallel orientation
   b) Edge to edge orientation
   c) Edge to face orientation
   d) All of the above

16. The correct increasing order of the specific surface areas of the given soils is
   a) Silt, sand, colloids, clay
   b) Sand, silt, colloids, clay
   c) Sand, silt, clay, colloids,
   d) Clay, silt, sand, colloids

17. The behavior of silts is normally governed by
   a) Mass energy
   b) Surface-cum-mass energy
   c) Surface energy
   d) Friction

18. China clay is an example for
   a) Kaolinite b) Illite
   c) Montmorillonite d) Holloysite

19. Some of the structural strength of a clayey material that is lost by remoulding is slowly recovered with time. This property of soils to undergo an iso thermal trans-formation upon agitation and subsequent rest is termed.
   a) Isotropy b) Anisotropy
   c) Thixotropy d) Allotropy

20. The shape of clay particle is usually
   a) Angular b) Flaky
   c) Tubular d) Rounded

21. **Assertion (A):** Black cotton soils are clays and they exhibit characteristic property of swelling.

   Reason(R): These clays contain montmorillonite which attracts external water into its lattice structure.
   a) Both A and R are true and R is the correct explanation of A
   b) Both A and R are true but R is not a correct explanation of A
   c) A is true but R is flase
   d) A is flase but R is true

22. For a sandy soil with soil grains spherical in shape and uniform in size, what is the maximum theoretical void ratio?
   a) 0.61 b) 0.71 c) 0.91 d) 0.81

23. Match List–I (Deposit) with List–II(soil structure)and select the correct answer using the codes given below the lists:

List – I	**List-II**
A) Coarse grained soil	1. Flocculated
B) Silt deposit	2. Cohesive matrix
C) Clay deposit	3. Honeycomb
D) Composite soil	4. Single–grained

Codes:

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

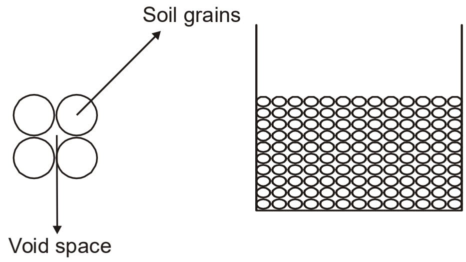
KEY

01. d 02. b 03. Aeolian Soil 04. d 05. b 06. c 07. d 08. d
09. b 10. b 11. 0.91 & 0.35 12. D 13. d 14. a 15. a 16. c
17. b 18. a 19. c 20. b 21. a 22. c 23. b

2 SOLIDS-WATER-AIR RELATIONSHIPS OF SOILS

INTRODUCTION

- Soil consists of solid grains and void spaces. The gap between the solid particles are known as void spaces.



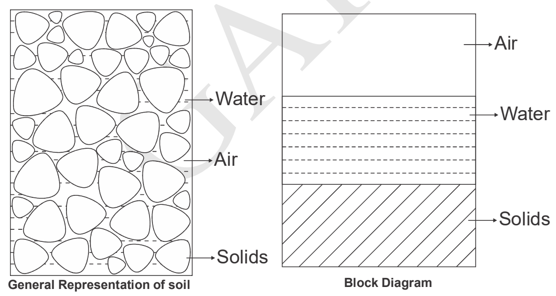
Dry soil: If all voids are filled with air

Saturated soil: If all voids are filled with water

Partially saturated soil: If all voids are filled with water + air

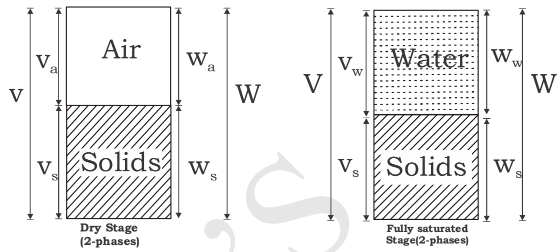
Frozen soil (Air + solid +water+ ice): If some voids are filled ice

- In general, a soil mass consists of solid particles, water & air. These 3 constituents are blended together to form a complex material.
- However,for convenience, all the solid particles are placed in the lower layer of the 3-phase diagram. This is known as "Block diagram"

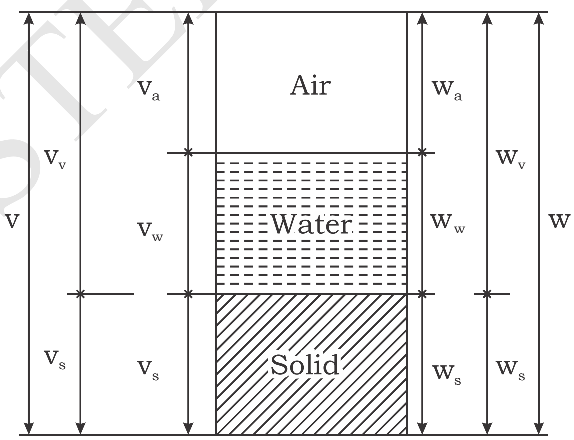


- Phase is known as homogenous part of the Material. If the material has more than one phase then it is known as "heterogeneous mate-rial". Soil is a heterogeneous mate-rial.
- To analyze the soil, generally we consider 3-phase diagram.

- Dry soil (2 phases)
- Fully saturated (2 phase)
- Partially saturated (3 phases)
- Frozen soil (4 phases)



3-Phase Diagram:



V_s - Volume of solids

V_w - Volume of water

V_a - Volume of air

V_v - Volume of voids (V_a+V_w)

V - Total volume of soil ($V_a+V_w+V_s$)

W_s - Weight of soil

W_a - Weight of air $\cong$ 0

W_w - Weight of water

W_v - Weight of voids $\cong$ W_w

W - Total weight of soil (W_s+W_w)

Volumetric Relations

Void Ratio (e) :

Ratio of volume of voids(V_v) to the volume of solids (V_s).

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

- In partially saturated state $V_v = V_a + V_w$

  In dry State $V_v = V_a$

  In saturated state $V_v = V_w$

Note :

Individual void space are larger in coarse grained soils, but less in number. "Void ratio" is high in fine grained soils. Because more number of voids spaces.

$$e_{\text{fine grained}} > e_{\text{coarse grained}}$$

Limits:

e > 0. Void ratio is expressed as a decimal. It dosen't have any upper limit.

e ≠ 0 (If e = 0. It means V_v should be 0. Then it becomes a solid material, not soil.)

Relation between V_s, V, e :

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

$$1+e = 1+\frac{V_v}{V_s} = \frac{V_s+V_v}{V_s} = \frac{V}{V_s} \quad (\because V_s + V_v = V)$$

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

Porosity (n) :

Ratio of the volume voids (V_v) to the total volume of soil (V)

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

Limits:

0 < n <100%. Porosity is expressed as a percentage.

n ≠ 0. (If n=0 it means Vv should be 0. Then it becomes a solid material not soil).

n ≠ 100. (If n=100, it means Vv=V. So there is completely voids only).

Relation between n & e:

$$n = \frac{e}{1+e} \quad \text{and} \quad e = \frac{n}{1-n}$$

Note :

Both "e" and "n" represents the volume of voids in soil mass. But "e" is more significant because it represents volume of voids to volume of solids ratio. Volume of solids is more stable than total volume of soil. [If you pour water in soil total volume of soil will be increase, but volume of solid particles remains same.]

Degree of Saturation (S):

It is the ratio of volume of water (V_w) to the volume of voids (V_v).

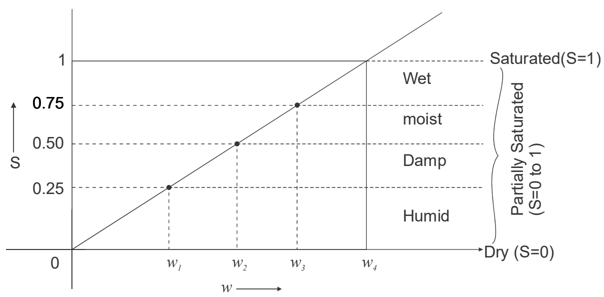
$$S = \frac{V_w}{V_v} \times 100$$

Limits:

$0 \le S \le 100\%$ in 3-phase system. It is expressed as a percentage.

Note:

- For fully saturated soil, $V_v = V_w$. Then S = 100%.
- For dry soil V_w = 0. Then S= 0%.
- Depending upon 'S', soil may be classified as dry, humid, moist, wet and saturated.



Air Content (a_c):

- It is the ratio of volume of air(V_a) to the volume of voids(V_v).

$$a_c = \frac{V_a}{V_v} \times 100$$

Limits:

$0 \le a_c \le 100$. It is expressed as a percentage.

Note : Relation between S & a_c $a_c + S = 1$

- **Percentage of air voids (n_a) :**
- It is ratio of the volume of air (V_a) to the total volume of soil (V).

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

Limits:

0% ≤ n_a <100%. It is represented as a percentage.

Relation between n_a & a_c: $n_a = n.a_c$

Volume-Weight/Volume Mass Relationships

$$\text{Density } (\rho) = \frac{\text{Mass}}{\text{Volume}}, g/cc(or)kg/m^3$$

$$\rho_w = 1000 kg/m^3 = 1.0 g/ml$$

$$\text{Unit weight } (\gamma) = \frac{\text{Weight}}{\text{Volume}}, kN/m^3$$

$$\gamma_w = 9810 N/m^3 = 9.81 kN/m^3 \cong 10 kN/m^3$$

Bulk unit weight (γ or γ_b)/Bulk density (ρ or ρ_b):

- It is defined as weight or Mass to the total volume of soil in existing condition.

$$\gamma (or) \gamma_b = \frac{W}{V}$$

$$\rho (or) \rho_b = \frac{M}{V}$$

- Where, W = Total weight of soil, V = Total volume of soil, M = Total mass of soil
- Forsoil

$$V = V_s + V_w + V_a, \; W = W_s + W_w \; (\because W_a = 0)$$

Saturated Unit Weight (γ_{sat}) / Saturated Density (ρ_{sat}):

- This is the ratio of weight of soil in saturated condition (W_{sat}) to the total volume of given soil mass (V).

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

W_{sat} = Saturated weight of soil

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

M_{sat} = Mass of saturated soil

- For saturated soil

$$W = W_s + W_w, V = V_s + V_w$$

($\because V_a = 0$ in saturated soil)

Dry unit weight (γ_d) / Dry density (ρ_d):

- It is defined as the ratio of dry weight of soil mass (W_d) to the volume of given soil (V).

$$\gamma_d = \frac{W_d}{V} = \frac{W_s}{V}$$

$$\rho_d = \frac{M_d}{V} = \frac{M_s}{V}$$

- W_d= Dry weight of soil, W_s= Weight of solids, M_d= Dry mass of soil, M_s=Mass of solids
- In Dry state W_W=W_a=0. only W_s exist.So W_d=W_s.
- In Dry state V = V_a +V_s $(\therefore V_w = 0)$
- If soil is dry, it's bulk unit weight (γ_b) is same as of it's dry unit weight (γ_d).

If S = 0, Then $\boxed{\gamma_b = \gamma_d}$, $\boxed{\rho_b = \rho_d}$

- If soil is saturated, its bulk unit weight (γ_b) will be same as that of it's saturated unit weight (γ_{sat});

For saturated Soil S = 1 then

$\boxed{\gamma_b = \gamma_{sat}}$, $\boxed{\rho_b = \rho_{sat}}$

<u>*Submerged unit weight*</u> $(\gamma_{sub}\,(\text{or})\,\gamma)$ <u>*/ Submerged density*</u>$(\rho_{sub}\,(or)\,\rho')$**:**

- When soil is submerged below the GWT it is being acted upon by force of buoyancy (F_B) in vertically upward direction, magnitude of which is equal to the weight of water displaced by soil solids. Hence it results in reduced weight of soil solids.

$$\boxed{\gamma_{sub}(\text{or})\gamma' = \frac{(W_s)_{sub}}{V}}$$

$(W_s)_{sub}$ = Weight of solids submerged

$$\boxed{\rho_{sub}\ (\text{or})\ \rho' = \frac{(M_s)_{sub}}{V}}$$

$(M_s)_{sub}$ = Mass of solids submerged

Relation between γ_{sat} & $\gamma(\text{or})\gamma_{sub}$:

$\boxed{\gamma_{sub} = \gamma_{sat} - \gamma_w}$ Similarly, $\boxed{\rho_{sub} = \rho_{sat} - \rho_w}$

Note :

Soil in submerged condition will be in saturated state but soil in saturated condition need not be in submerged condition.

- **Unit Weight of Solids** (γ_s)**/ Density of Solids** (ρ_s)**:**

- The ratio of weight of solids (W_s) to the volume of solids (V_s) presently given in a soil mass.

$\boxed{\gamma_s = \frac{W_s}{V_s}}$ Similarly, $\boxed{\rho_s = \frac{M_s}{V_s}}$

Note :

Unit weight of solids are more significant than dry unit weight of soil because volume of solids are more stable than total volume.

- $\boxed{\gamma_s > \gamma_{sat} > \gamma_b > \gamma_d > \gamma(\text{or})\gamma_{sub}}$

- $\boxed{\gamma' \cong \frac{\gamma_{sat}}{2}}$

- Generally soil has

$\gamma_s = 26 \text{ to } 29 KN/m^3$, $\gamma_{sat} = 20 \text{ to } 22\ KN/m^3$

$\gamma_d = 16 \text{ to } 18\ KN/m^3$, $\gamma' = 10\ KN/m^3$

- **Water Content (*w*):**

- Ratio of weight of water (W_w) to the weight of solids (W_s). It is also known as moisture content.

$\boxed{w = \frac{W_w}{W_s} \times 100}$ $\boxed{w = \frac{M_w}{M_s} \times 100}$

M_w = Mass of water, M_s=Mass of solids

<u>*Limit:*</u> $w \geq 0\%$.

It is expressed as percentage, but used as a decimal in computation.

Relation between W_s, w & W :

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

- It can be expressed as part of total weight of soil mass(w') generally used in geology.

$$\boxed{w' = \frac{W_w}{W} \times 100}$$

Range of w': $0 \leq w' < 100\%, (w' \neq 100\%)$

- If $w' = 100\%$ means W_w=Wtotally water not soil.

Relation between w & w' :

$$w = \frac{w'}{1-w'}$$

- Weight of solids is a stable quantity in comparision to total weight of soil because it doesn't change with change in weight of water, hence in engineering '*w*' is preferred not w'.

Specific Gravity of Soil

True specific Gravity / Absolute specific Gravity (G/G_s):

- Ratio of unit weight of solids (γ_s) of given volume to the unit weight of standard fluid (γ_0) of same volume.

$$G(or)G_s = \frac{\gamma_s}{\gamma_0} = \frac{\text{weight of solid particles}}{\text{weight of water at eqvivalent volume}}$$

γ_s = Unit weight of solids;

γ_0 = Unit weight of water at 4^0C

Note :

- For organic soil G = 1 to 2
- For inorganic soil G = 2.6 to 2.9.

Units: No units.

- Mass/Bulk/Apparent Specific Gravity (G_m)

$$G_m = \frac{\text{Weigth of soil in given volume}}{\text{Weight of water having same volume}}$$

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

γ_b = Bulk unit weight of soil; γ_w = Unit weight of soil.

Note :

- $G > G_m$ $(\gamma_s > \gamma_b)$
- In India 'G' is reported at 27°C and if it is required to be computed at any other temepraturе corresponding change in unit weight of water should also be considered.

Now,
$$(G)_{27^oC} = \frac{G_{T^oC}(\gamma_w)_{T^oC}}{(\gamma_w)_{27^oC}}$$

- If two soils are mixed then the summation of solids (either by weight or by volume) will be equal to the solids of mixture.
- If we are constructing embankment or road then solids of bore pit will be equivalent to the solids of construction site.

Soil Type	Specific Gravity
Gravel	2.65 - 2.68
Sand	2.65 - 2.68
Silt	2.66 - 2.70
Silty sand	2.66 - 2.70
Inorganic clays	2.68 - 2.80
Organic soils	Variable, may be<2.00

S.No.	Term	Formula	Range	Relation
01.	Void Ratio	$e=\frac{V_v}{V_s}$	$e>0$	$e=\frac{n}{1-n}$
02.	Porosity	$n=\frac{V_v}{V}\times100$	$0<n<100\%$	$n=\frac{e}{1+e}$
03.	Degree of Saturation	$S=\frac{V_w}{V_v}\times100$	$0\le S\le 100$	$S+a_c=1$
04.	Air Content	$a_c=\frac{V_a}{V_v}\times100$	$0\le a_c\le 100\%$	
05.	% of Air Voids	$n_a=\frac{V_a}{V}\times100$	$0\le n_a<100\%$	$n.a_c=n_a$
06.	Water Content	$w=\frac{W_w}{W_s}\times100$	$w\ge 0$	

Important Relationships:

1. $Se = wG$
2. $\gamma_b=\frac{(G+Se)\gamma_w}{1+e}$
3. $\gamma_{sat}=\frac{(G+e)\gamma_w}{1+e}$
4. $\gamma'=\frac{(G-1)}{1+e}\gamma_w$
5. $\gamma_d=\frac{G\gamma_w}{1+e}$
6. $\gamma_d=\frac{\gamma_b}{1+w}$
7. $\gamma_d=\frac{(1-n_a)G.\gamma_w}{1+wG}$
8. $e=\frac{n}{1-n}$
9. $n=\frac{e}{1+e}$
10. $W_s=\frac{W}{1+w}$
11. $V_s=\frac{V}{1+e}$
12. $n_a=n.a_c$
13. $a_c+S=1$
14. $\gamma'\cong\frac{\gamma_{sat}}{2}$
15. $e=\frac{wG}{S}$
16. $w=\frac{w'}{1-w'}$