PHYSICAL PROPERTIES OF SOIL

Physical Properties

- The fundamental physical properties of soil are given below:
- Color
- Structure
- Particle size
- Shape
- Specific Gravity
- Unit Weight
- Porosity
- Void Ratio
- Soil Phases
- Moisture Content
- Consistency
- Degree of saturation
- Air Void Ratio/Air Content

Color

- It is the most common property of soil.
- Soil exist in nature in a variety of color depending upon:
  - The particular type of soil mineral
  - Organic contents,
  - The amount of coloring oxides and
  - Degree of oxidation
- “Black” color of soil is due to presence of **manganese compounds**, “Green” or “blue” is due to **ferrous compounds**, “red”, “brown” or “yellow” due to **iron**, and “grey” due to **organic matters**.

Soil Structure

- Arrangement or grouping of soil particles depending upon their size and shape in various patterns of structural framework is called Soil structure.
- This arrangement is usually developed during the process of "sedimentation" or "rock weathering".
- Soil deposit at the face of earth have been developed by many natural processes of accumulation of soil particles over historical period of time.
- During the process of accumulations soil particles arranged them selves in different patterns, depending upon their size and shape.
- For Coarse grained or Non-cohesive soil, **mass to surface area ratio** is relatively higher, therefore the effect of gravity has major influence on the arrangement of particles, and the effect of electrical charge on the particle surfaces is negligible.
- The Fine grained soil (Clay) because of their low **mass to surface area ratio** is more affected by electrical forces acting on their surface compared with gravity force, and therefore particles arrange themselves in different pattern.

Different Pattern of Soil Structure

- Terzaghi grouped the most common patterns of soil structure into the following three principal group:

1. Granular or Single –Grained Structure
2. Flocculent Structure
3. Dispersed Structure

- **Granular or Single –Grained Structure**
- Cohesion-less soil (Coarse-Grained and Silt > 0.01 mm) tend to form a single –grained structure which may be loose or dense (Figure 1).
- In a single grained structure, each grain is in contact with several of its neighbors in such a way that the aggregate is stable even if there is no force of adhesion at the point of contact between the grains.
- Sands or silts are capable of developing honeycomb structure (Figure 2).
- Honeycomb is weak structure and have a large amount of void spaces.
- This unstable structure because when load or sudden shock is applied they show volume reduction.

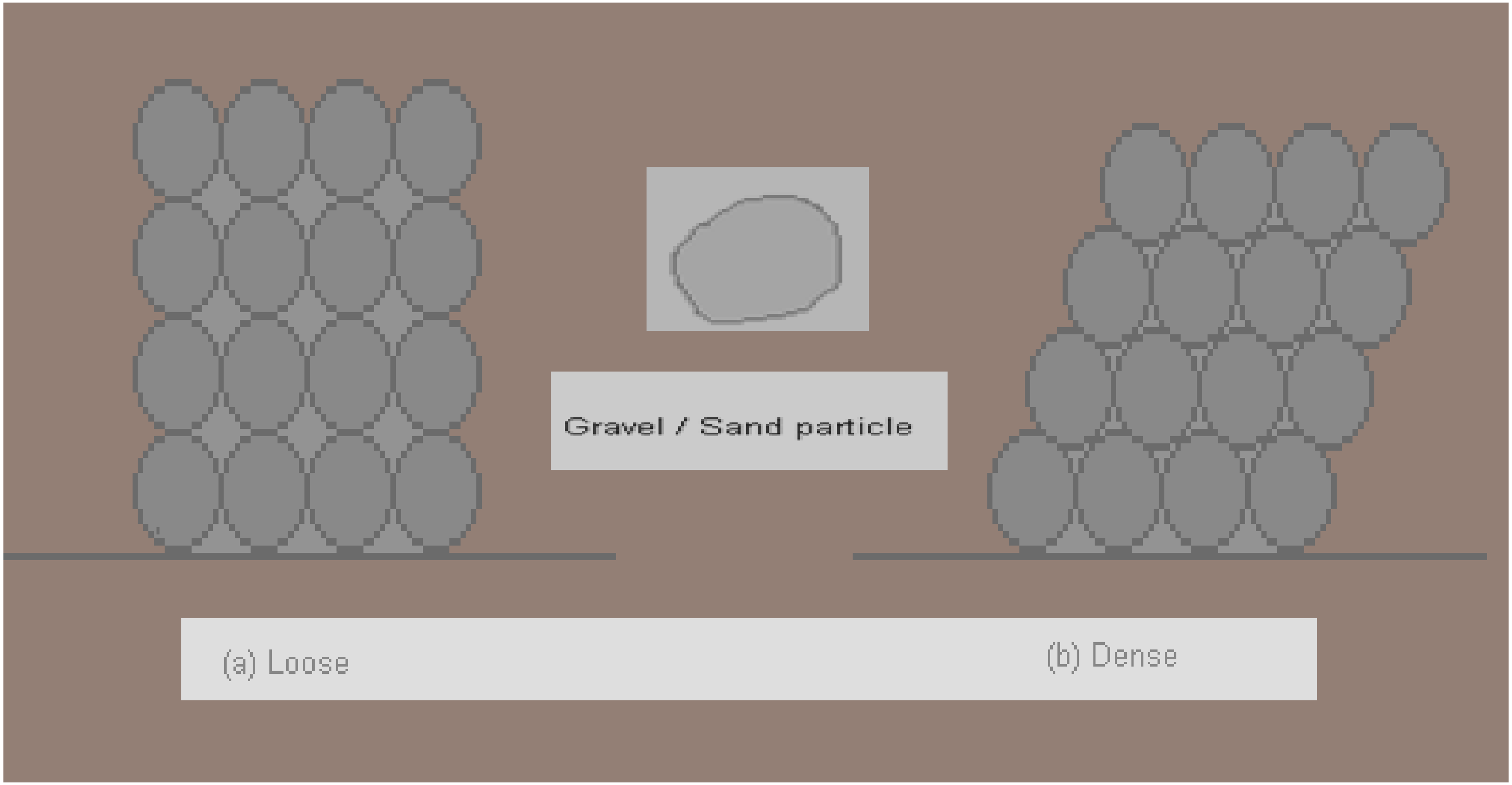


Figure 1: Granular Soil structure

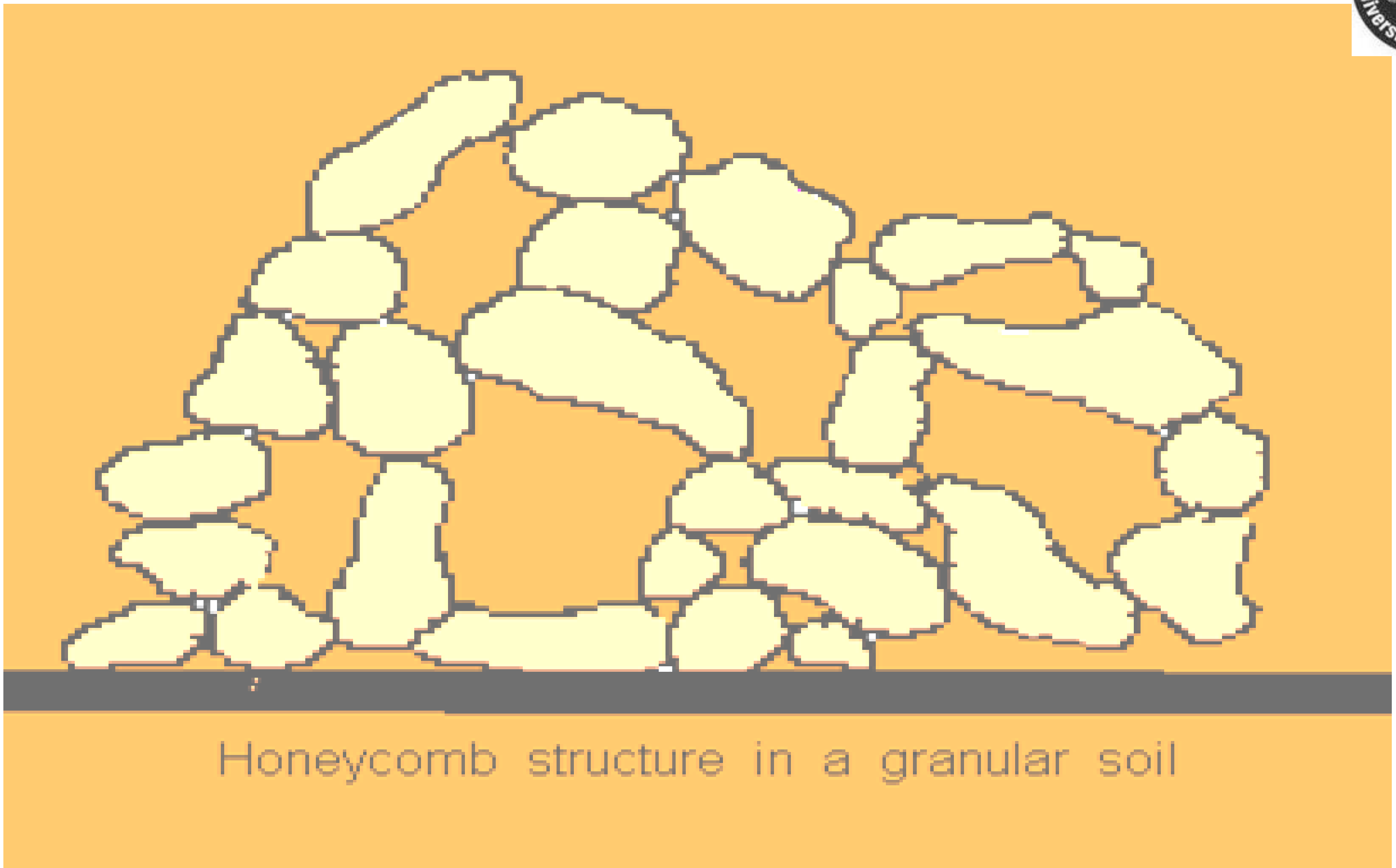
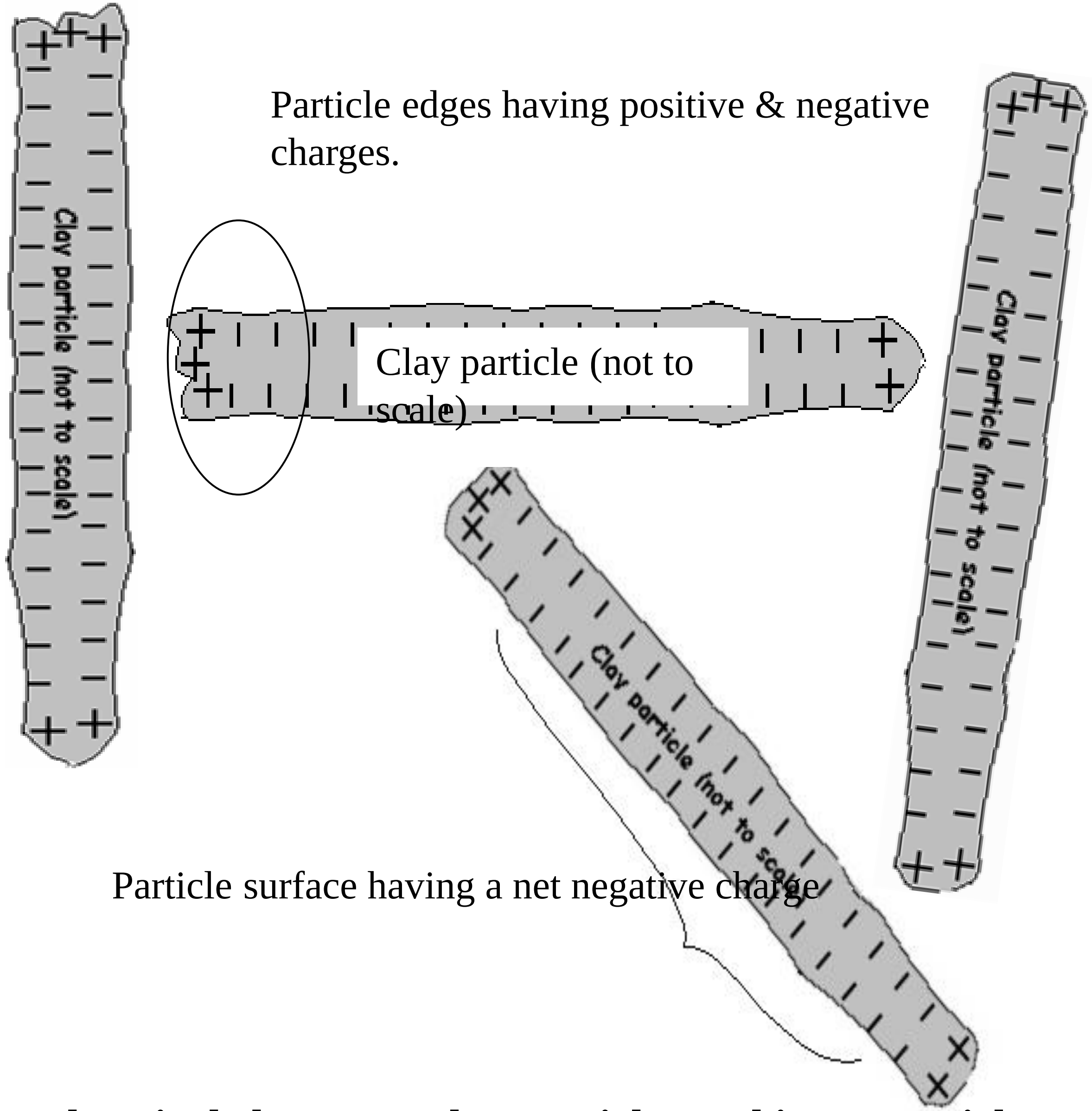


Figure 2: Honeycomb in Granular Soil

Different Pattern of Soil Structure

- **Flocculent Structure**
- Clay minerals are extremely flaky in shape and have a large **surface area to mass** ratio.
- The clay particles carry a negative electrical charge on their surfaces. The affect of electrical forces is more than the gravity forces .
- A flocculent structure is developed when the edge of one clay particle is attracted to the flat face of another (Edge to Face contact) as shown in Figure 3.
- The structure of clay settling in marine water is more flocculent than in fresh water. (Reason is that the salt water act as Electrolyte).
- **Characteristics of Flocculent Structure**
- Clay deposit with flocculent structure has:
  - High Void Ratio
  - Low Density
  - High Water Content
  - High Permeability
  - The structure is more stable and resistance to external forces



Electrical charge on clay particles and inter-particle bonding

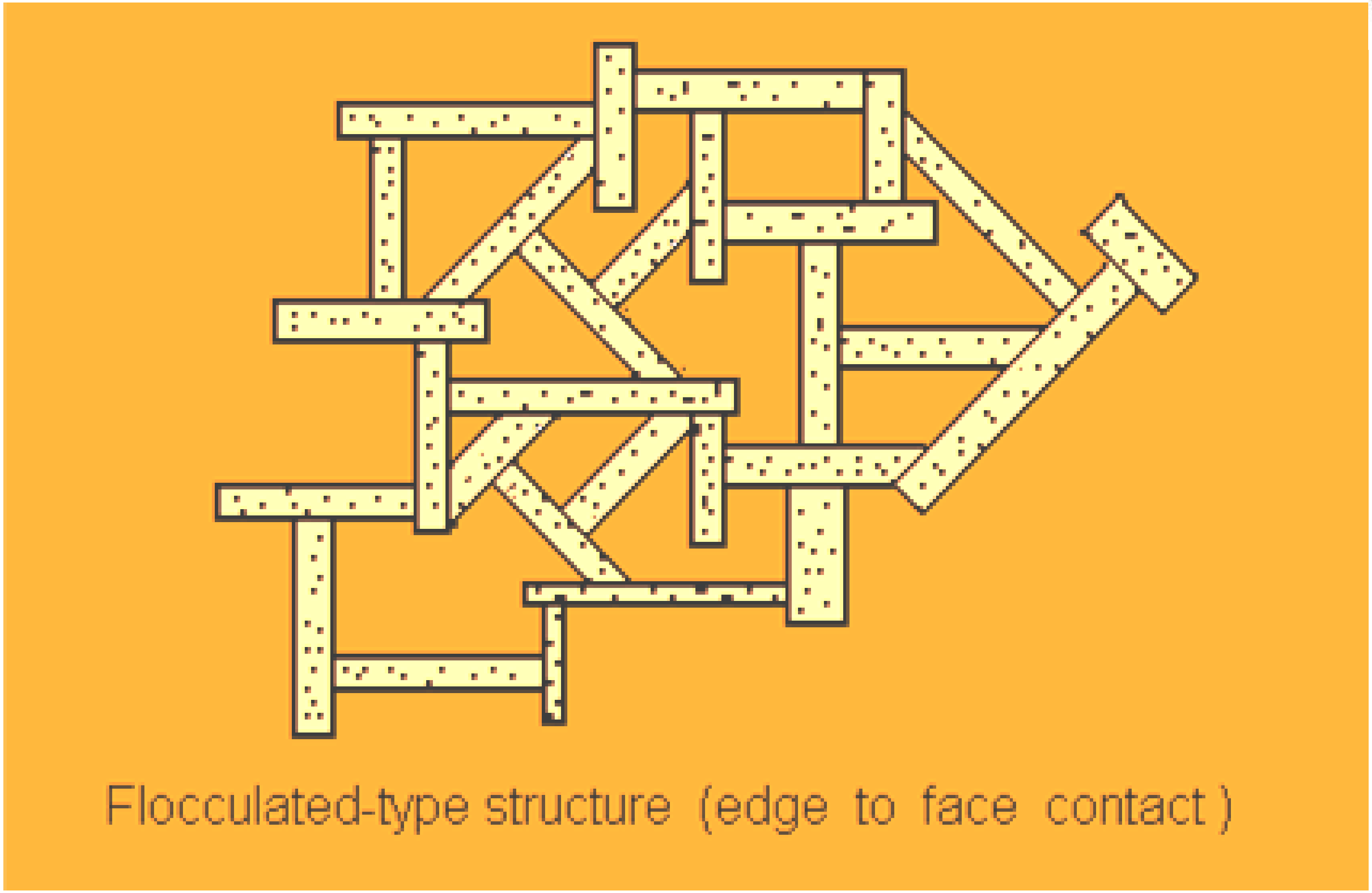
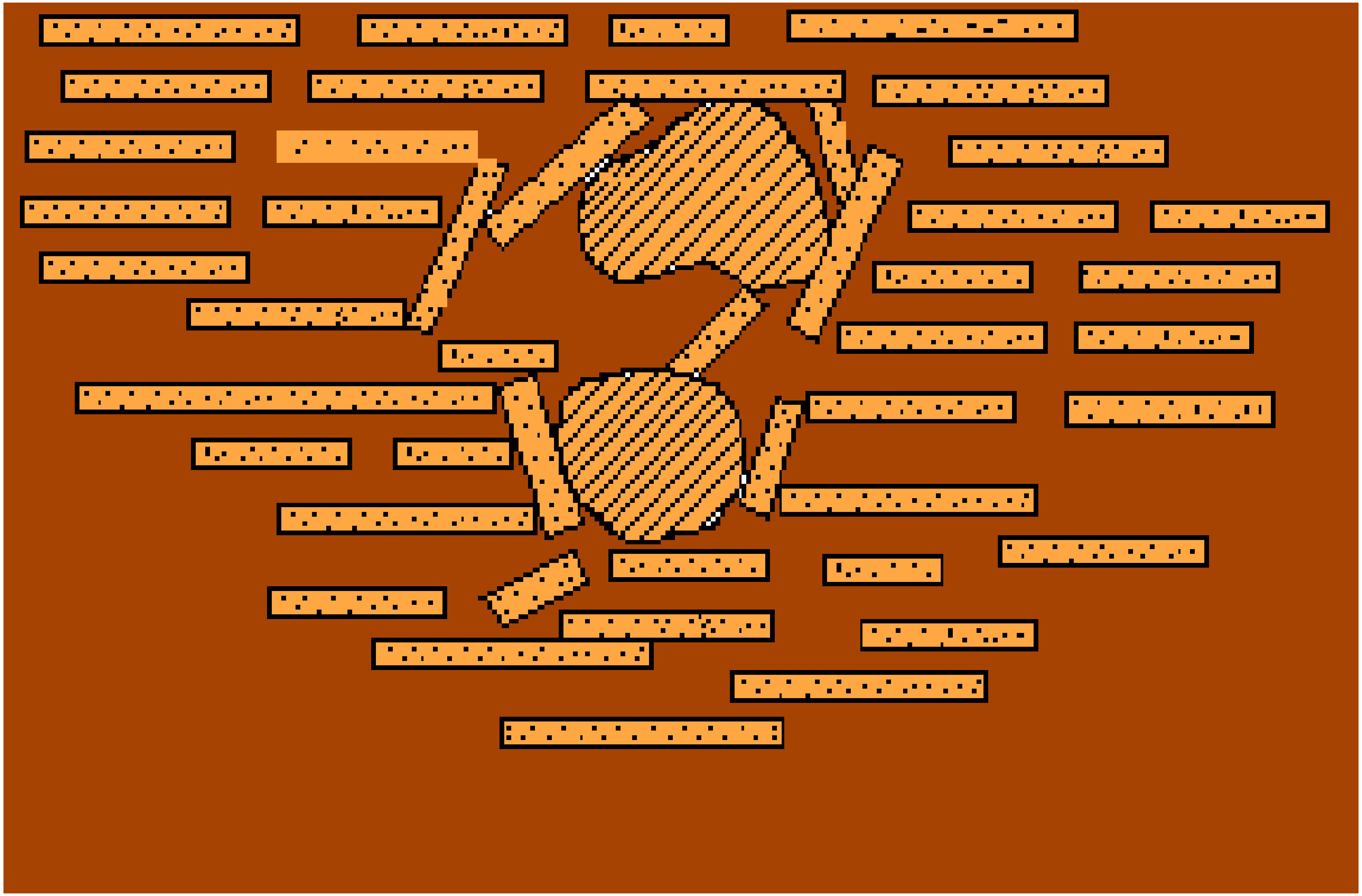


Figure 3: Flocculent Structure (Edge to Face)

Different Pattern of Soil Structure

- **Dispersed Structure**
- The dispersed structure is developed when the edges and faces have same electrical charges.
- The particles repel each other and the orientation become nearly parallel (Figure 4).
- Dispersed structure may also be developed due to man made earth fills (Remolding).
- The particles arrangements that develops from remolding has more parallel orientation of particles
- A flocculent structure with addition of water and application of compaction is changed to a dispersed structure.



Dispersed Structure (Face to Face)

Figure 4: Dispersed Structure

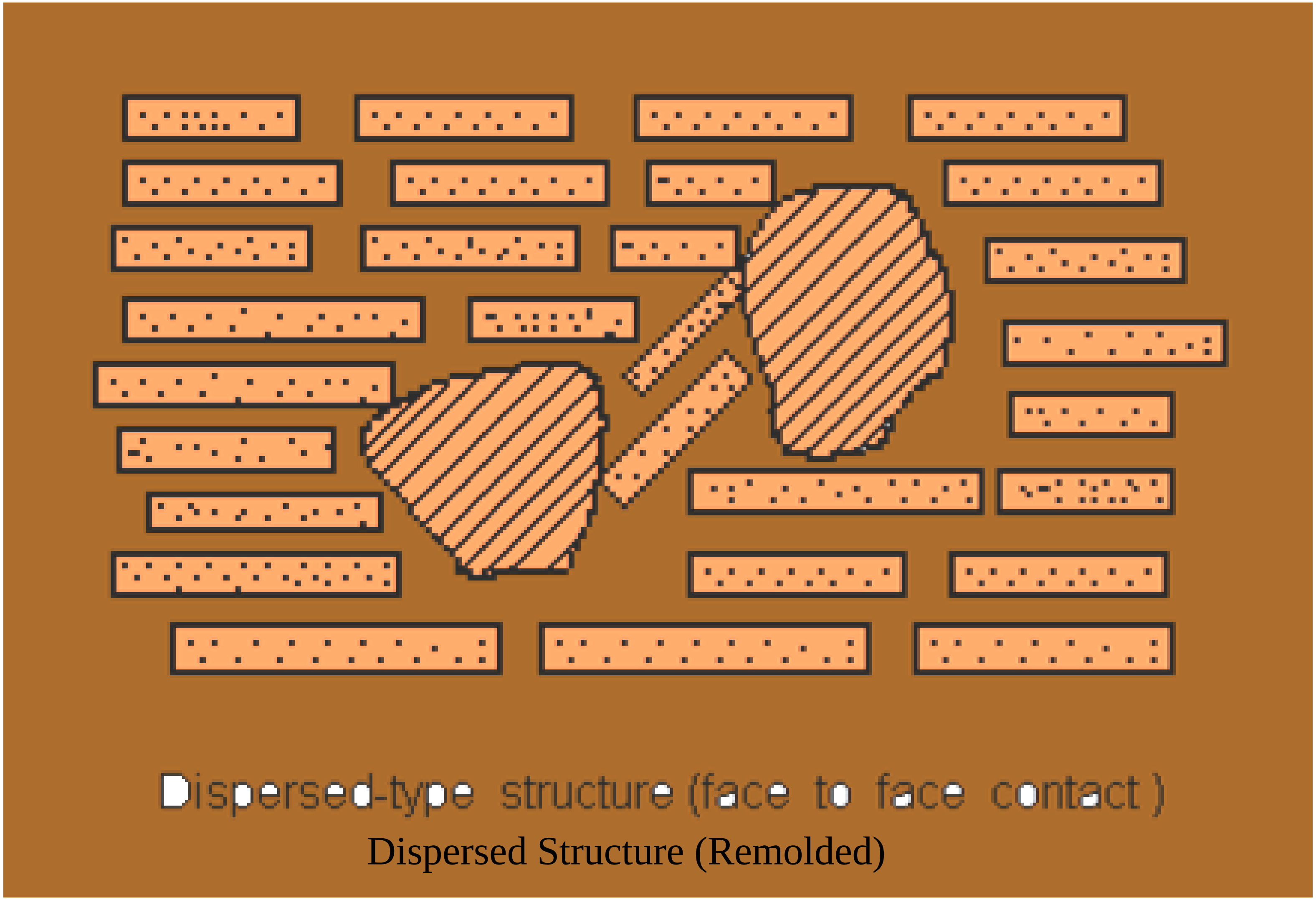


Figure 4: Dispersed Structure

Particle Shape and size

- Particle size and shape very much influence the engineering properties of soil.
- Particle of coarse-grained soil (sand, gravel, boulder etc.) are generally bulky in shape, i.e., their length, width and thickness are approximately equal.
- Different shapes are commonly termed as angular, sub-angular, sub-rounded and rounded (Figure: 5).
- The shapes of the particles however depend on the rock type, their age, weathering and transportation processes.
- The newer particles are generally angular, and rough surfaced.
- With the passage of time and as a result of weathering and transportation processes.
- The edges are broken and the particles change finally to rounded shape. Sub-angular and sub-rounded are the transition stages.

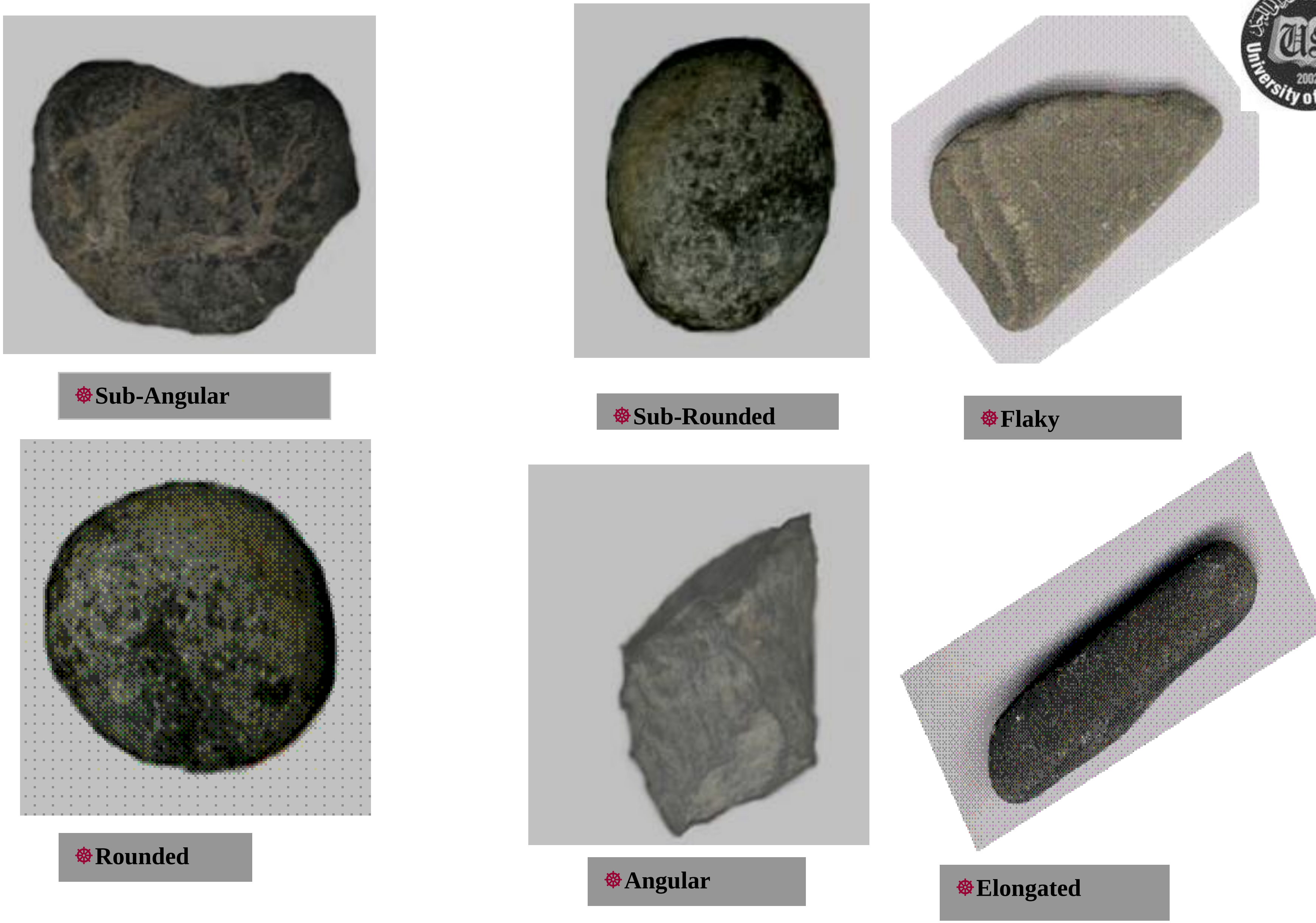


Figure 5: Particle Shape

Particle Shape and size

- The angular and rough surfaced panicles possess better engineering properties compared with those of rounded and smooth particles.
- Some of the rocks, upon weathering produce flaky particles.
- The presence of flaky particles in a granular soil mass has significant effect on the engineering properties e.g., void ratio, density and compressibility.
- The flaky & elongated particles bridge over open spaces, which can resist overburden pressure.
- Therefore they produce relatively large void ratios and loose soil mass (Figure: 6).
- The flakes, however, are incapable of resisting the applied loading.
- They bend or break and allow rearrangement of particles under applied loading, which some times produce undesirable deformations.

Figure 6: Elongated Particles Bridging a Gap

Particle Shape and size

- The silt particles although classified as fines are still bulky in shape and have the same mineralogical composition as the coarse grained soil.
- The clay particles arc flaky in shape (flat plate-like shape).
- Their length and width are many-many times greater than the thickness.
- The clay particles originate from crystalline minerals.
- Due to their distinct mineralogical composition they exhibit inter-particle attraction and bonding with ‘water molecules.
- As a result the behavior of clay soil drastically changes with change of moisture content.
- At different moisture contents, but at the same void ratio, a clay soil may behave as liquid, plastic or a solid mass.
- Individual clay particle seldom exists. Due to cohesive forces, they group together, to form a cluster.
- The clay particles are very small in size (less than .002mm or 2micron).
- However it must be kept in mind that the properties of clay (cohesion and plasticity) are due to the type of the mineral (i.e. clay mineral) and not due to its small size.

Particle Shape and size

- The particles of non-clay minerals although smaller than .002mm, do not exhibit the clay properties (i.e., cohesion and plasticity).
- Actual soil deposits consist of soil particles having variation in particle sizes.
- The variation of particle sizes may be small to large.
- An ideal particle size distribution (well-graded) produces an optimum particle arrangement and upon compaction produce a dense and sty on soil mass.
- While a mass of soil having particles of nearly the same sizes (uniformly or poorly-graded), produces a loose packing due to absence of small particles to fill the voids between bigger particles.

Specific Gravity

- The specific gravity of any substance is defined as the ratio of the unit weight of that substance, to the unit weight of water at 4°C.
- The above definition simply means that how many times a substance (or material) is heavier than water.
- For example the specific gravity of mercury of 13.6 means that if equal volumes of mercury and water are taken than mercury will be 13.6 times heavier than water.
- Similarly specific gravity of gold is 19.3 or one can say that gold is 19.3 times heavier than water
- A geological is Engineer is commonly interested in the specific gravity of the materials.

- It is Denoted as "**G_s**"

$$G_s = \frac{\gamma_s}{\gamma_w} = \frac{W_s}{V_s \cdot \gamma_w}$$

Where,

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

γ_s = Unit weight of soil solid (No Pores)

w_s = is the weight of solids which is equal to dry weight

V_s = Volume of solids (No pores)

- The term bulk specific gravity or mass specific gravity is also used

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

Where, γ_b = Bulk density of soil (With Pores)

Specific Gravity

- Average value of G_s for soil solids range from 2.50 to 2.70.
- It depends upon the mineral packing of the soil particles.
- If the mineral composing the soil is heavier the specific gravity will be greater.
- Specific gravity is unique for every solid.
- It does not depend upon state of soil deposit (i.e. moisture content, compaction etc.)
- **Bulk specific gravity** however depends upon state of solids. It is lower for loose soil and higher for dense soil.
- **"It can never be more than Specific gravity".**

Specific Gravity

- **Application of Specific Gravity**
- It can be used for determination and calculation of following soil properties:
  - Particle size analysis by hydrometer
  - Porosity and Void Ratio
  - Unit Weight
  - Degree of Saturation
- Specific Gravity of some minerals is shown in Table 1

Table 1: Specific Gravity of Common Minerals

Minerals	**Specific Gravity**	**Soil-type**	**Specific Gravity**
Dolomite	**2.8-2.9**	**Bentonite clay**	**2.13-2.18**
Feldspar	**2.5-2.6**	**Chalk**	**2.63-2.73**
Gypsum	**2.2-2.4**	**Lime**	**2.7**
Illite	**2.60**	**Clay**	**2.45-2.90**
Quartz	**2.60-2.65**	**Humus**	**1.37**
Talc	**2.7-2.8**	**Loess**	**2.65-2.75**
Kaolinite	**2.6-2.63**	**Peat**	**1.26-1.8**
Magnetite	**5.17-5.18**	**Silt**	**2.68-2.72**
Calcite	**2.8-2.9**	**Quartzsand**	**2.60-2.65**

Soil Phases

- A soil mass is a collection of solid particles of different sizes and shapes, which form porous medium.
- Depending upon seasonal variations these pores may be filled with water or air or both.
- The phase of soil means any homogeneous part of soil mass different from other parts in the mass and clearly separated from them.
- Soil is a porous medium consisting of three different homogeneous parts

1. Solid Particles
2. Water
3. Air

- On the basis of these component phases are:

1. Solid Phase
2. Liquid Phase
3. Gaseous Phase
4. Ice phase (In case of freezing of water in upper part of soil)

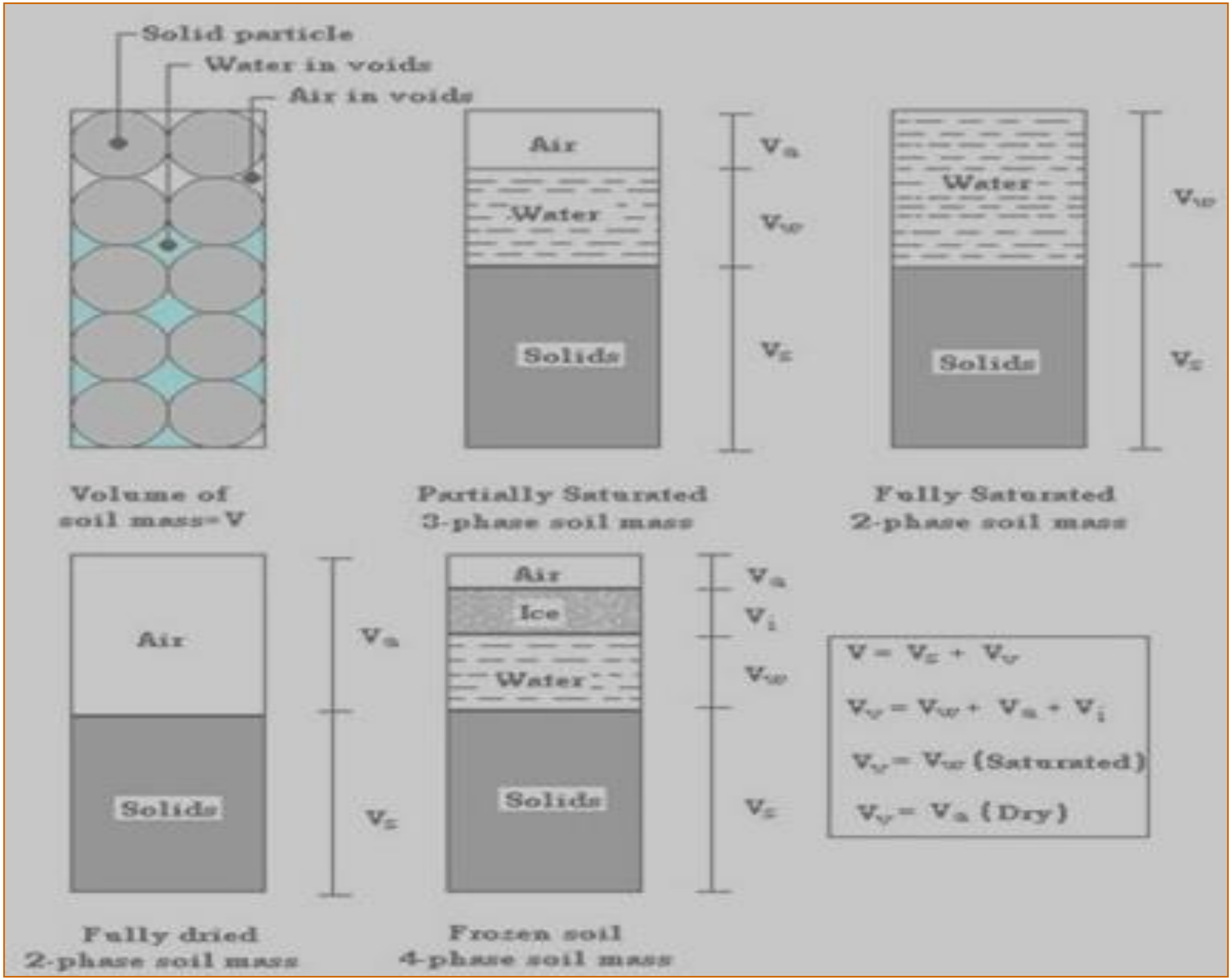


Figure 7: Schematic Diagram Indicating Different Soil Phases

Porosity

- The total volume of soil mass is the summation of volume of solid particles and the volume of pores or voids.
- Volume of pores or voids depends upon:
  - Soil Density
  - Compaction

Porosity falls in the range of
0< n < 100

Where’

$$V = V_s + V_v$$

$$V = \text{Total volume of soil mass}$$

$$V_s = \text{Volume of Solid Particles of soil}$$

$$V_v = \text{Volume of voids, which may be filled with air, water or both}$$

- The ratio of volume of all voids “V_v” to the volume of soil mass “V” is called “**Porosity**”. It is denoted by “n”

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

Porosity

- **Relationships From Basic Formulae**

$$n = \frac{V_v}{V} = \frac{V - V_s}{V} \rightarrow n = \frac{V}{V} - \frac{V_s}{V} \rightarrow n = 1 - \frac{V_s}{V}$$

- **Specific Gravity,**

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

$$G = \frac{W_s}{V_s\ \gamma_w} \qquad while\ \ \gamma_s = \frac{W_s}{V_s}$$

$$V_s = \frac{W_s}{G\gamma_w} \qquad \text{while } W_s = \text{dry weight of soil}$$

$$n = 1 - \frac{W_s}{G\gamma_w V}$$

- Since it is practically impossible to eliminate all the voids so porosity can never be zero
- The increase in the volume of voids also increase the total volume, so it can never be 100 %

Void Ratio

- The ratio of volume of voids present in a soil mass to the volume of solid particles.
- It is denoted by “e”.

$$e = \frac{volume\ of\ \ voids\ in\ soil}{volume\ of\ \ slids\ in\ soil} = \frac{V_v}{V_s}$$

- The void ratio is expressed as a number and the limiting values can be within the range.

$$\mathbf{0 < e << \infty}$$

- The common value however may range from 0.5 to 1.3
- The values for sand is low, and higher for clay
- It also depends upon compaction

Void Ratio

- **Relationship with other soil properties**

$$e = \frac{V_v}{V_s} = \frac{V - V_s}{V_s} = \frac{V}{V_s} - 1 \quad \Rightarrow \quad e = \frac{VG\gamma_w}{W_s} - 1 \;\; while \;\; V_s = \frac{W_s}{G_s \; \gamma_w}$$

$$1 + e = \frac{V}{V_s} \quad \Rightarrow \quad \frac{1}{1+e} = \frac{V_s}{V} = \frac{V - Vv}{V}$$

$$\frac{1}{1+e} = 1 - \frac{V_v}{V} = 1 - n \quad \Rightarrow \quad n = 1 - \frac{1}{1+e}$$

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

Void Ratio

- **Relationship with other soil properties**

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

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

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

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

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

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

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

Void Ratio

- **Significance and Uses of Void Ratio**

$$i - unit\ weight \qquad \gamma_b = \frac{(es + G)}{1 + e}\gamma_w$$

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

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

$$\gamma_{sub} = \frac{(G - 1)\gamma\ w}{1 + e}$$

Void Ratio

- **Significance and Uses of Void Ratio**

$$ii - Critical\ hydraulic\ gradient,\ i_c = \frac{G-1}{1+e}$$

$$iii - \mathrm{Re}lative\ density,\ D = \frac{e_{\max} - e}{e_{\max} - e_{\min}}$$

$$iv - Modulus\ of\ compressibility\ ,\ m_v = \frac{e_1 - e_2}{(p_2 - p_1)\,(1+e_1)}$$

$$v - Theoratical\ maximum\ dry\ density,\ \gamma_{d_{\max}} = \frac{G\gamma_w}{1+e}$$

$$vi - Final\ settlement,\ \Delta H = (\frac{\Delta_e}{1+e_1})\ H$$

Moisture content

- The amount of water present in the voids of a soil in its natural state

$$m = \frac{weight\ of\ water}{weight\ of\ dry\ soil} \times 100$$

- The range of water content is $0 \leq m << \infty$

- It is not unusual for some soils (marine or organic lake soil) to have moisture content up to 300-400 percent.
- The common range of moisture content for most soil is 20-40 percent.
- Oven dried soil has zero percent moisture and the soils which appear dry (i.e., air dried soil) often have 2 to 4 percent moisture content.
- Soil which behaves as solid at low moisture content is changed to liquid state at high moisture content and shear strength is practically reduced to zero.
- Increase in moisture increase the unit weight of a dry soil

Moisture content

- **Different Types of Moisture Content**

1. Hygroscopic Moisture
2. Film moisture
3. Capillary Moisture
4. Chemically Bound Moisture

- **Hygroscopic Moisture**
- The difference between the weight of an air-dried sample to its weight after oven drying at ± 105°C gives the amount of hygroscopic moisture present in the soil.
- It is also known as adsorbed moisture, contact moisture or surface bound moisture.
- This form of soil moisture exists as a very thin film of moisture surrounding the surfaces of individual soil particles and is held by the force of adhesion. Practically the moisture present in an air dried soil sample may be termed as hygroscopic moisture.
- The value of hygroscopic moisture however depends on the atmospheric temperature, relative humidity and the type of soil.

Difference Between Absorbed and Adsorbed Moisture

- **Absorption** is the process in which a fluid is dissolved by a liquid or a solid (absorbent).
- **Adsorption** is the process in which atoms, ions or molecules from a substance (it could be gas, liquid or dissolved solid) adhere to a surface of the adsorbent. (Figure 8)

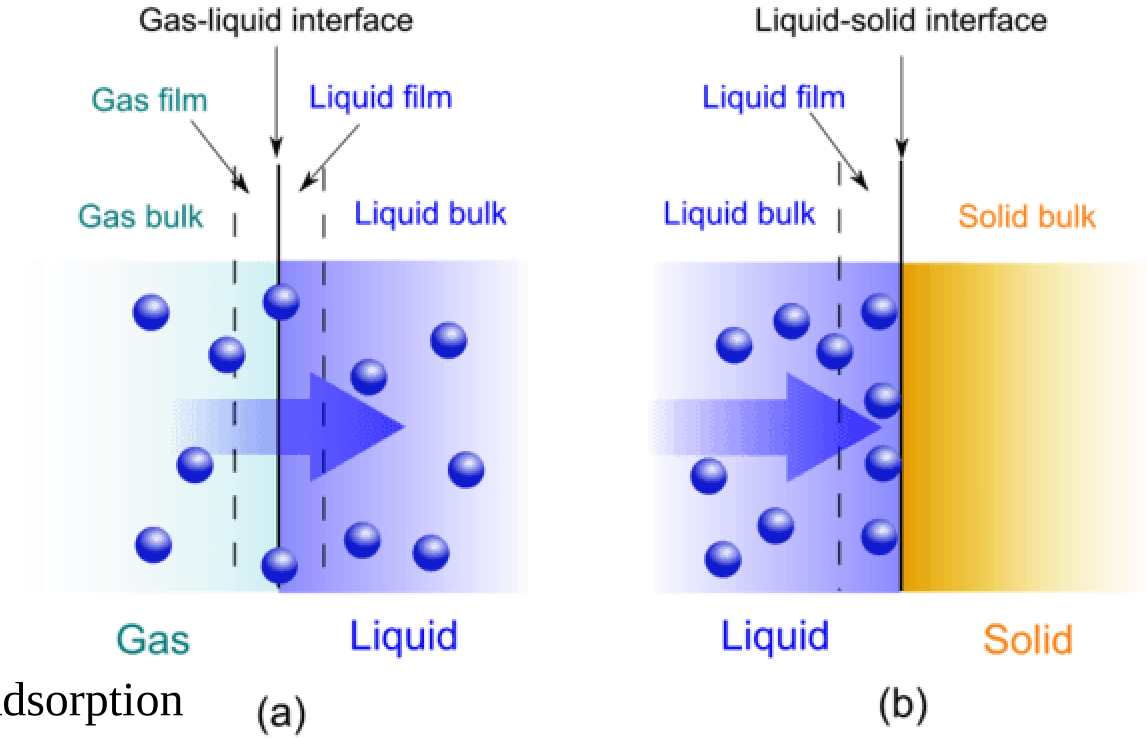


Figure 8: Absorption and Adsorption

Hygroscopic Moisture

- In fine grained soil such as clays, due to large specific surface, hygroscopic moisture is high (up to 20% or more) while in coarse grained soil (sand) it is relatively low due to limited amount of specific surface.
- The approximate values of hygroscopic moisture for various soils are as under:
- Sand----------------1-2 %
- Silt------------------7-9%
- Clay----------------17-20%
- The values are just approximate and vary with humidity and temperature; etc.
- Hygroscopic moisture is not affected by gravitational forces, capillary forces and air drying at ordinary temperature, Hygroscopic moisture film is bound so rigidly to the particle surfaces that it can not be removed even by centrifugation. It does not exert any hydrostatic pressure.

Film Moisture

- The thickness of the moisture film around soil particles varies depending upon the conditions such as weather etc.
- The moisture film attached to the soil particles, above the layer of hygroscopic moisture film, is known is film moisture.
- It is held by the molecular forces and is not affected by gravity.
- It can move from points of higher potentials (heat or electric) to lower ones or from points of thicker to thinner films.
- The amount of film moisture depends on the specific surface i.e., higher the specific surface higher will be the film moisture and vice-versa.

Capillary moisture

- It is defined as the moisture which is held within the voids of capillary size.
- The capillary moisture is continuously connected to the groundwater table.
- It rises above the water table and is held by the surface tension force of the menisci at the top of water columns in capillary tubes formed due to interconnected pores in soil.
- The voids are completely filled with water and the soil is fully saturated. The height or thickness of capillary saturated zone above the groundwater table depends on the size of soil particles.
- Finer the particles, greater is the thickness of capillary zone.
- Capillary water can be removed from the soil by drainage when the quantity of water present in the voids, is in excess of that retained by the surface tension forces.

Chemically Bound Moisture

- It is the moisture contained chemically within the mineral particles and can be removed only by chemical process which breaks the crystalline structure of the minerals.
- The chemically bound water does not influence the physical properties and behavior of soil a commonly determined.
- The moisture Content determined through oven drying method (or any other method) includes adsorbed moisture, film moisture and only that portion of capillary moisture, which is held within the voids by surface tension forces.
- All other forms of water (not discussed here) will be drained out by gravity as the soil sample is extracted from the ground (from surface or sub-surface layers).

Degree of Saturation

- The condition when voids are partially filled with water is expressed by the degree of saturation or relative moisture content.
- It is the ratio of actual volume of water in voids "V_w" to the total volume of voids "V_v".

$$S = \frac{V_w}{V_v} = \frac{W_w}{W_v} = \frac{m}{m_{sat}}$$

- W_w – is the weight of water actually present in the voids.
- W_v – is wt of water that can fill all the voids.
- m – actual moisture content.
- m_{sat} – moisture content when all voids are totally filled with water.
- The range of **"S"** $0 \leq S \leq 100$
- For an over dry soil, S=0, which means that all voids in the soil mass are filled with air, i.e. V_w =0. For fully saturated soil, S=1 that means that all voids filled with water, i.e. $V_v = V_w$

Air Void Ratio/Air Content

- The ratio of the volume of air present in the voids to the total volume of a soil mass.

$$A_v \; or \; A = \frac{V_a}{V} = \frac{V_v - V_w}{V_v + V_s}$$

Since; $\mathbf{V_v = V_a + V_w}$

Air content fall within the range of

$$0 \leq A < 100 \quad - \; percent.$$

Air Void Ratio/Air Content

$$A = \frac{V_v - SV_v}{V_s\ (1 + \frac{V_v}{V_s})} \qquad while\ \ V_w = SV_v$$

$$A = \frac{V_v\ (1 - S)}{V_s (1 + e)}$$

$$A = \frac{e\,(1 - s\ )}{1 + e}$$

$$A = n\,(1 - S) \qquad while\ \ n = \frac{e}{1 + e}$$

THANK YOU!