CIVIL ENGINEERING

GEOTECHNICAL ENGINEERING

GATE – CIVIL ENGINEERING

List of Subjects:

1. General Aptitude
2. Engineering Mathematics
3. Engineering Mechanics
4. Solid Mechanics
5. Structural Analysis
6. Concrete Structure
7. Steel Structures
8. Construction Materials and Management
9. Geo Technical Engineering
10. Fluid Mechanics
11. Hydrology
12. Water Resources Engineering
13. Environmental Engineering
14. Transportation Engineering
15. Geomatics Engineering

Prof. B. Jayarami Reddy

GEOTECHNICAL ENGINEERING

1. **SOIL MECHANICS**
2. Origin of Soils
3. Basic Definitions and Relations
4. Index Pproperties of Soils
5. Soil Classification
6. Effective Stress
7. Permeability
8. Seepage Analysis
9. Consolidation and Settlement Analysis
10. Compaction
11. Shear Strength

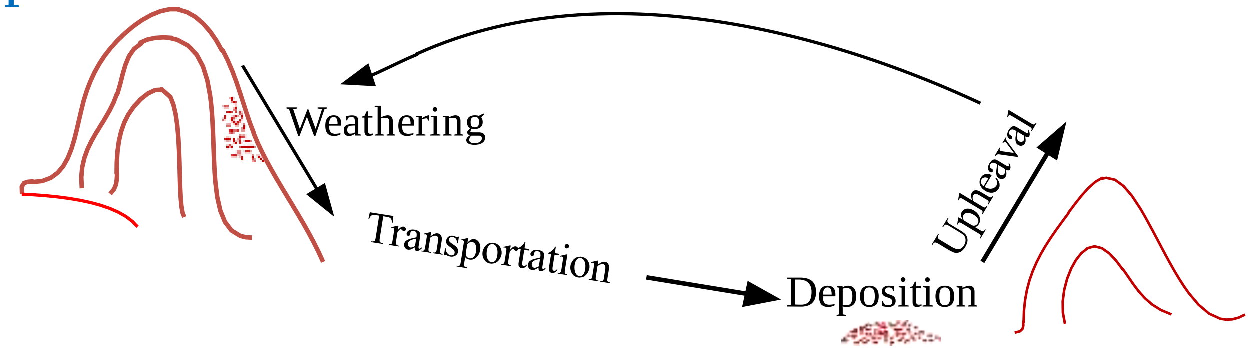
1. **FOUNDATION ENGINEERING**
2. Soil Exploration and Field Tests
3. Earth Pressure Theories
4. Stability of Slopes
5. Stress Distribution in Soils
6. Foundation Types and Bearing Capacity
7. Deep Foundations
8. Miscellaneous Topics

8.1 ORIGIN OF SOILS

Father of Soil Mechanics –Karl Terzaghi

Formation of Soils:

- Soil is naturally occurring unconsolidated earth material above the bed rock.
- When large size rocks and boulders are exposed to atmosphere, it will undergo physical disintegration and chemical decomposition due to atmospheric agencies and hence leads to formation of soils.
- Pedogenesis is a process of formation of soil.



Formation of soil particles from Rocks

Formation of Soils:

- Soils are formed by 1. Weathering of rocks 2. Geological agents

1. Weathering of Rocks:

Weathering process
a. Mechanical / Physical Weathering
b. Chemical Weathering
c. Biological weathering

a. Physical weathering:

- Due to physical effects like temperature, abrasion, wedging action of ice, etc.,
- No change in chemical composition of particles
- Results in Coarse grained and non cohesive soils.

- Soils are formed by 1. Weathering of rocks 2. Geological agents

1. **Weathering of Rocks**:

Weathering process a. Mechanical / Physical Weathering
b. Chemical Weathering
c. Biological weathering

a. Physical weathering:

- Due to physical effects like temperature, abrasion, wedging action of ice, etc.,
- No change in chemical composition of particles
- Results in Coarse grained and non cohesive soils.

b. Chemical weathering:

- Original rock minerals are transformed into clay minerals.
- Results in fine grained and cohesive soils.

i. Oxidation ii. Hydration iii. Carbonation
iv. Solution or Leaching v. Hydrolysis

c. Biological Weathering:

- Bacterial and other organisms produces some organic acids which induces chemical changes in their surroundings.
- Organic soils are formed due to Biological weathering. eg: Peat, Humus.
- Organic soils are called as Cumulose soils.

2. Geological Agents:

- Geological agents are the natural forces which are responsible for modifying irregularities on the earth surface.
- Classification based on origin: a. Endogenous geological agents
  b. Exogenous geological agents

a. Endogenous Geological Agents:

- Originate below the earth surface.
- Creates topographic irregularities

  eg: Volcanic eruption, earth quakes, Ground water, etc.,

b. Exogenous Geological Agents:

- Originates above the earth surface. eg: River, Wind, Ocean, Glaciers, etc.
- Transport the rock minerals from one place to another place.
- During transportation it causes breakdown of soil mass due to abrasion and attrition.

Types of soils:

1. Based on transportation

a. Sedimentary soils (Transported soils) b. Sedentary soils / Residual soils

a. Sedimentary Soils:

- Soil particles created at one location, transported and finally deposited in another location.

Source of Transportation	Type of soil	Examples
Lakes	Lacustrine soil	
Rivers and streams	Alluvial soil	
Sea	Marine soil	Marine silts and clays
Wind	Aeolian soil	Sand, Dunes, Loess
Gravitation	Colluvial soil	Talus
Glacier	Glacial soil	Drift, Till, Moraines
River soil near ocean	Estuarine soil	Soil near Estuaries

b. Residual soils / Sedentary soils:

- Soils which remain on the parent rock without getting transported.

  eg: Black cotton soils, laterite soils.

i. Black Cotton Soils:

- Formed due to chemical weathering
- Parent rock is basalt or trap
- Exhibits large swelling and shrinkage due to presence of montmorillonite clay mineral.

ii. Laterite Soils:

- Formed due to Leaching of some minerals away from parent rock
- Red or Pink colour is due to Iron Oxide.

1. Based on average grain size

a. Coarse grained soils: Avg. size >0.075mm eg. Gravels and Sands

b. Fine grained soils: Avg. size <0.075mm eg. Silts and Clays

Forces acting on the soil particles:

a. Gravitational force or body force:

- Body force is proportional to the mass.
- Predominant in Gravel and sand.

b. Surface Force:

- It is proportional to surface area.
- Cohesion

- Predominant in clay – clay behaviour is mainly controlled by surface force.

In silty soils both body force and surface force are to be considered.

Commonly used Soil Designations:

1. Varved Clay: Alternate layers of silt and clay. eg: lacustrine deposits

2. Loam: Mixture of Sand, Silt and Clay

3. Caliche: Conglomorite of gravel, sand and clay cemented by Calcium Carbonate.

4. Moorum: Gravel mixed with red clay

Varved clay

Loam soil

Caliche soil

Moorum soil

5. Bentonite: Obtained due to weathering of Volcanic ash
Contains high percentage of montmorillonite clay mineral
Exhibits high degree of shrinkage and swelling

6. Boulder clay: Glacier clay containing all sizes of particles from boulder to clay. It is also called as Glacier till.

7. Hard Pan: Very difficult to penetrate or excavate. eg: Glacial till, Boulder clays
Densely cemented soil which remains hard when wet

8. Loess : Uniform wind blown yellowish brown silt or silty clay
Exhibits cohesion in dry condition, which is lost on wetting.

Bentonite

Boulder clay

Hard pan soil

Loess

9. Marl: Mixture of calcarious sands or clays or loam. Clay < 75 %, Lime > 15%

10. Top soil: Surface material which supports plant life.

11. Fill: All man made deposits.

12. Tuff : Very fine particles ejected from volcanoes and deposited by wind or water

Marl

Top soil

Fill soil

Tuff

13. Peat:

- Highly decomposed organic matter and Fibrous in nature.
- Dark brown to black colour and Bad odour.

14. Humus:

- It consists of partly decomposed organic matter.
- It is dark brown, organic amorphous earth of the soil

15. Muck:

- Partly containing fine inorganic particles and partly decomposed organic matter.

Peat

Humus

Muck

16. Black Cotton soil:

- Clay obtained due to chemical weathering.
- Parent rock – Basalt or Trap
- Exhibits large swelling and shrinkage characteristics due to presence of montmorillonite clay mineral.

17. Tundra: It is a mat of leaf and shrubby vegetation-covers clayey clumsy subsoil.

- Below the soil is tundra's permafrost, a permanently frozen layer of earth.
- In tundra, soil is very low in nutrients and minerals
- The soil becomes frozen a short ways below the ground due to low temperatures.

Black cotton soil

Tundra

18. Till:

- A part of glacial drift which in directly deposited by ice.
- A Glacial clay characterised by directly marked annual deposit of sediments.

Till

8.2 BASIC DEFINITIONS AND RELATIONS

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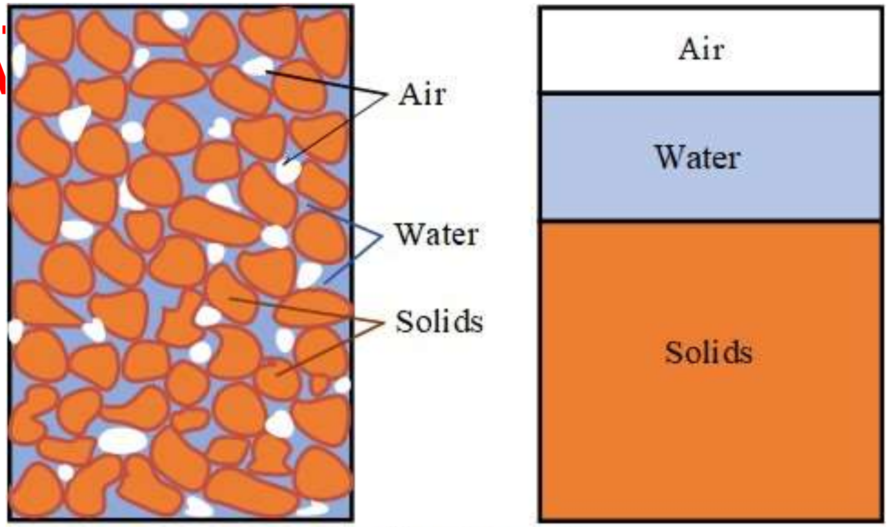
Phase Diagram:



Constituents in soil

- Soil mass - Three phase system - composed of solid, liquid and gaseous matter.
- Voids - Spaces enclosing the Solids
- Liquid phase is water that fill partly or wholly the voids.
- Gaseous phase (air) occupies the voids not filled by water.
- Three constituents are blended together to form a complex material.

Three Phase System:

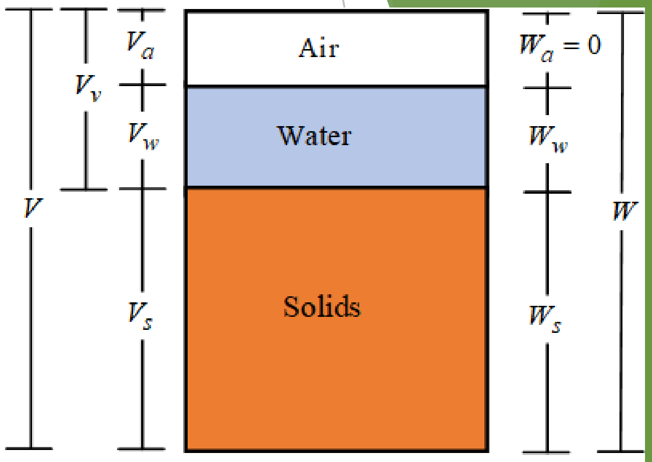
a. Volume:

Total Volume = Volume of Solids + Volume of voids

$$V = V_s + V_v$$

Volume of voids = Volume of water + Volume of air.

$$V_v = V_w + V_a \qquad V = V_s + V_w + V_a$$



Three Phase System of Soil

b. Weight:

Total weight = Weight of soils + Weigh of voids.

$$W = W_s + W_v$$

Weight of voids = Weight of water +Weight of air.

$$W_v = W_w + W_a$$ Weight of air is assumed to be zero.

$$W_v = W_w$$

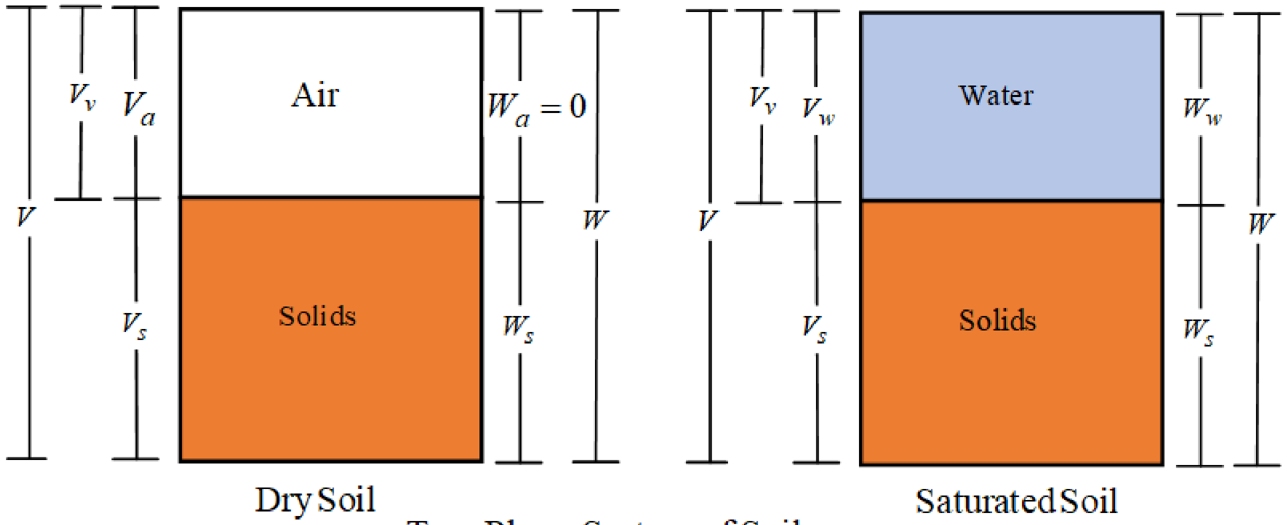
Total weight = Weight of solids +Weight of water.

$$W = W_s + W_w$$

Two Phase Diagram:

Soil becomes two phase system in some special cases.

1. When all the voids are filled with water, the sample becomes saturated thus gaseous phase is absent.
2. When the soil is absolutely in dry condition, the water phase disappears.



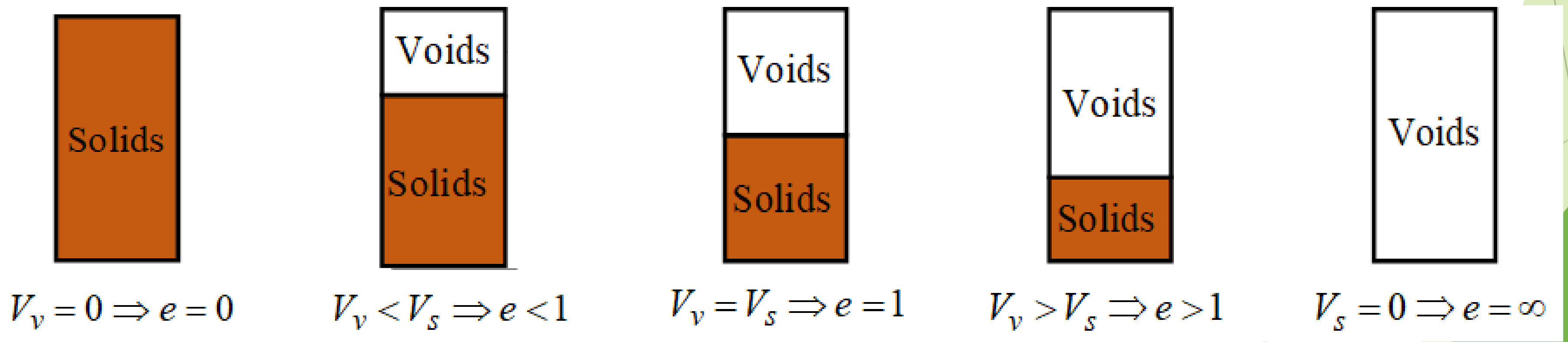
Two Phase System of Soil

Fundamental definitions:

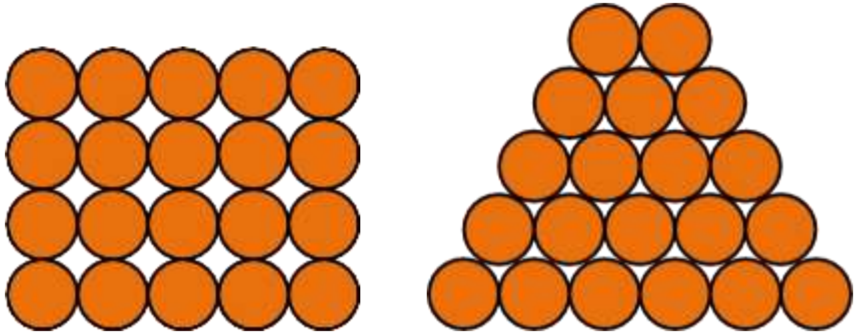
Void Ratio (e):

$$e = \frac{volume\ of\ voids}{volume\ of\ solids} = \frac{V_v}{V_s} \times 100$$

- can have any value greater than 0.
- sometimes may be greater than 1. $(0 < e < \infty)$
- void ratio for coarse grained soils is generally less than that for fine grained soils.
- when spherical grains are arranged in cubical array the maximum possible .
- When spherical grains are arranged diagonally, void ratio is least.



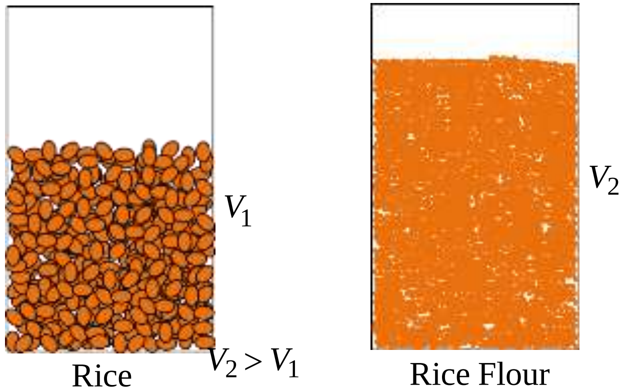
- When spherical grains are arranged in cubical array, the void ratio is maximum.
- When spherical grains are arranged diagonally, void ratio is least.



Cubical array of spherical grains (Loosest state) $e = 0.91$

Diagonal arrangement of spherical grains (Densest state) $e = 0.35$

- Void ratio for fine grained soils is more than that for coarse grained soils.



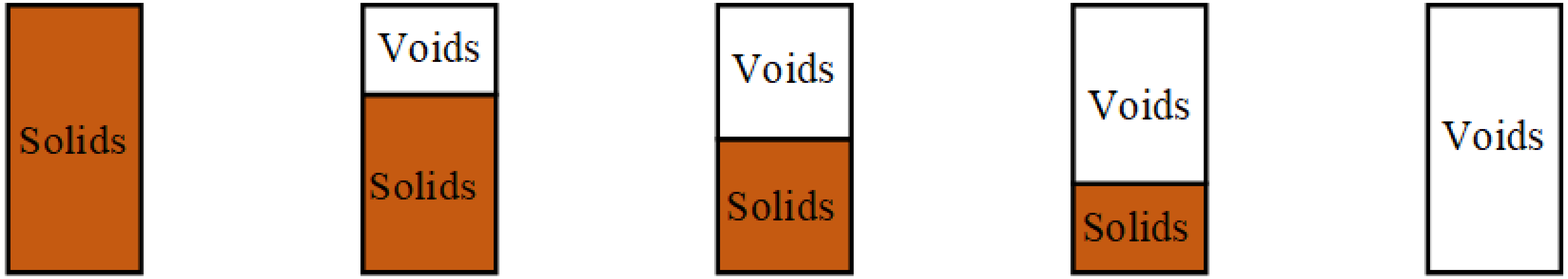
Rice

Rice Flour

Porosity: (n)

$$n = \frac{\text{Volume of voids}}{\text{Total volume of soil}} \times 100 = \frac{V_v}{V} \times 100$$

- Range $0 < n < 100\%$
- also called Percentage of voids.

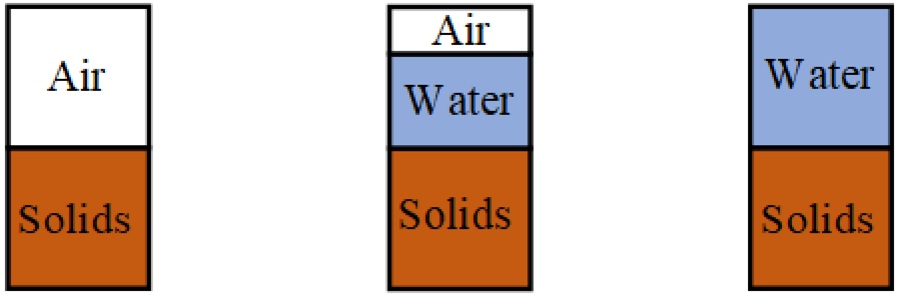


$V_v = 0 \Rightarrow n = 0$ $\quad V_v < V_s \Rightarrow n < 1$ $\quad V_v = V_s \Rightarrow n < 1$ $\quad V_v > V_s \Rightarrow n < 1$ $\quad V_s = 0 \Rightarrow n = 1$

Degree of saturation: (S)

$$S = \frac{\text{Volume of water}}{\text{Volume of voids}} \times 100 = \frac{V_w}{V_v} \times 100$$

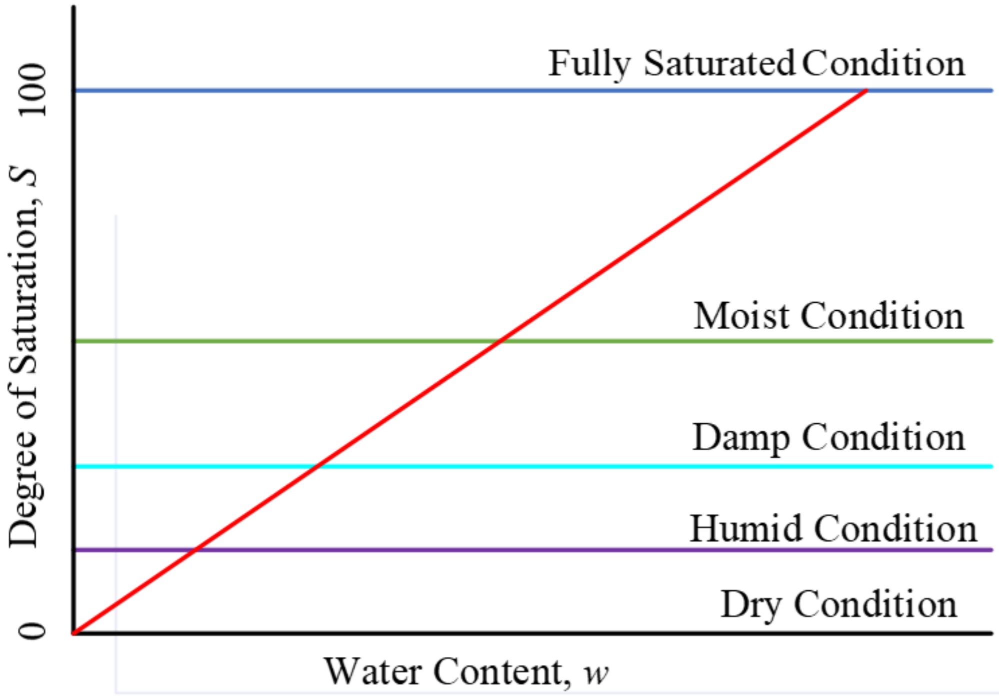
- for fully saturated soil, $S = 100\%$ or 1
- for dry soils, $S = 0$
- Range: 0 to 100%



$V_w = 0 \Rightarrow S = 0$
Dry Condition

$0 < S < 1$
Moist Condition

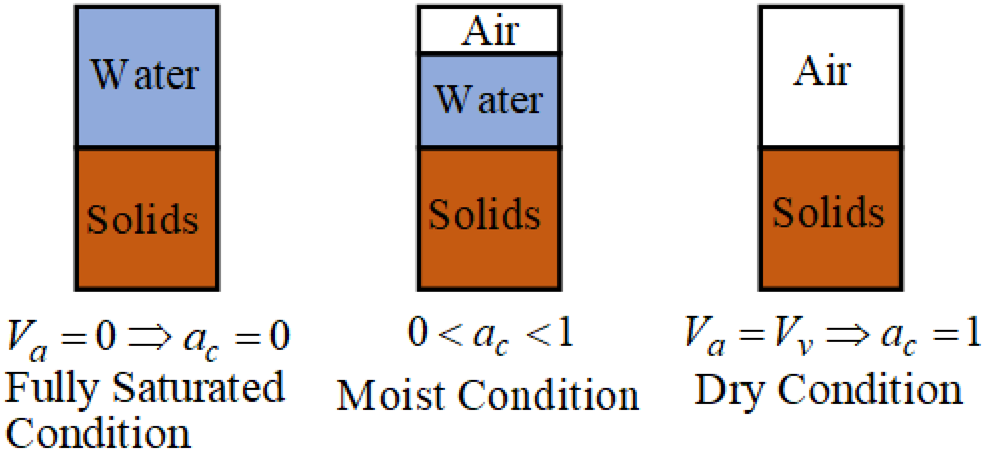
$V_w = V_v \Rightarrow S = 1$
Fully Saturated Condition



Air Content: (a_c)

$$a_c = \frac{\text{Volume of air voids}}{\text{Volume of voids}} \times 100 = \frac{V_a}{V_v} \times 100$$

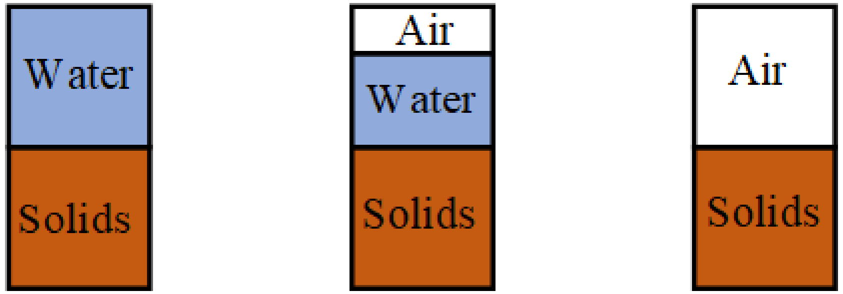
- for a saturated soil, $a_c = 0$
- for a dry soil, $a_c = 1$
- Range: $0 \le a_c \le 1$



Percentage of Air voids (n_a):

$$n_a = \frac{\text{Volume of air voids}}{\text{Total volume}} = \frac{V_a}{V} \times 100$$

- for saturated soil, $n_a = 0$
- for dry soil, $n_a = n = 1$
- Range: $0 \le n_a \le n$



$V_a = 0 \Rightarrow n_a = 0$ Fully Saturated Condition

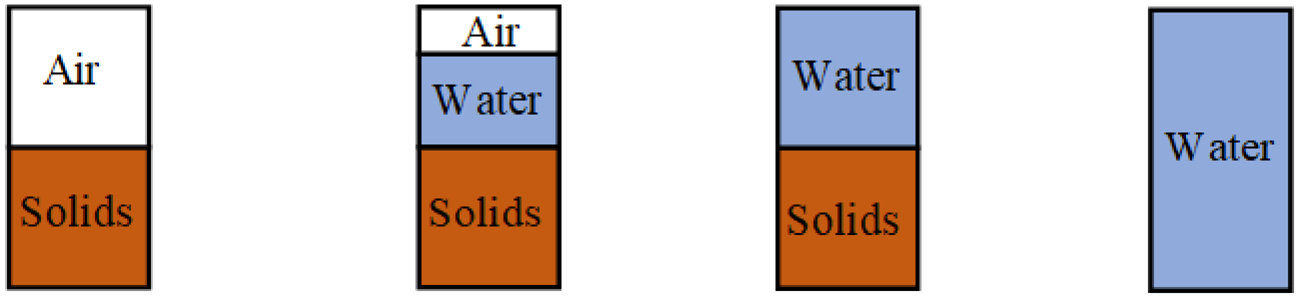
$0 < n_a < n$ Moist Condition

$V_a = V_v \Rightarrow n_a = n$ Dry Condition

Water content or Moisture content:(w)

- Water content, $w = \dfrac{\text{Weight of water}}{\text{Weight of solids}} \times 100 = \dfrac{W_w}{W_s} \times 100$

- can have any value greater than 0.
- can be greater than 100%.

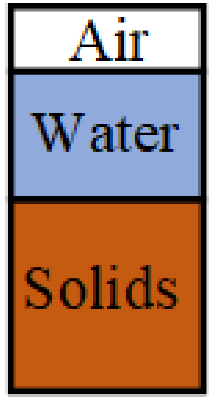


Dry Condition	Moist Condition	Fully Saturated Condition	No Solids Condition
$W_w = 0 \Rightarrow w = 0$	$w > 0$	$w > 0$	$W_s = 0 \Rightarrow w = \infty$

Bulk (or Mass) density: (γ)

$$\gamma = \frac{\text{Total weight of soil}}{\text{Total volume of soil}} = \frac{W}{V}$$

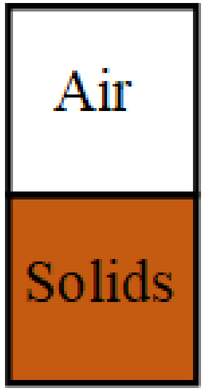
$$W = W_s + W_w \qquad V = V_s + V_w + V_a$$



Moist Condition
Bulk Density

Dry density: (γ_d)

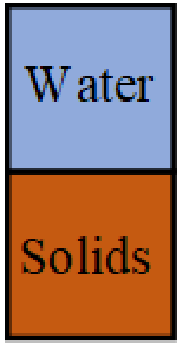
$$\gamma_d = \frac{\text{Weight of solids}}{\text{Total volume of dry soil}} = \frac{W_s}{V}$$



Dry Condition
Dry Density

Saturated density: (γ_{sat})

$$\gamma_{sat} = \frac{\text{Weight of soil when the soil is fully saturated}}{\text{Total volume of soil}} = \frac{W}{V} = \frac{W_s + W_w}{V}$$

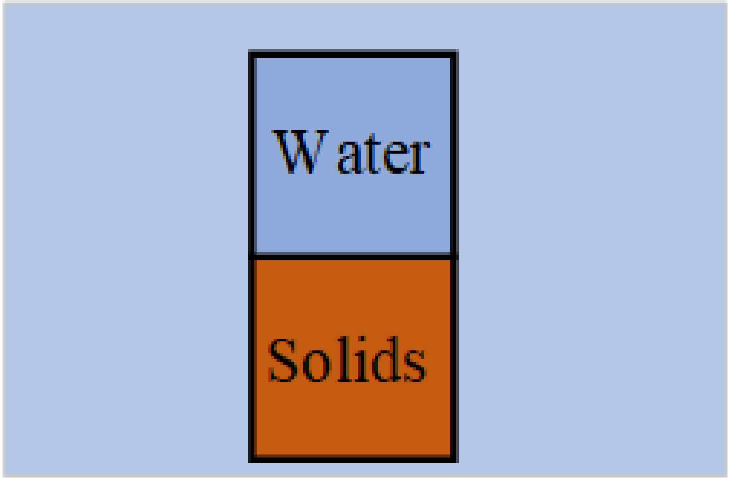


Fully Saturated condition
Saturated unit weight

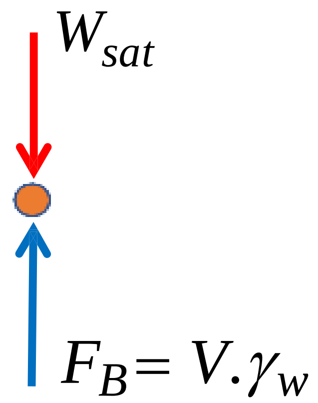
Submerged unit weight: (γ')

$$\gamma' = \frac{(W_s)_{sub}}{V} = \frac{\text{Weight of solids submerged}}{\text{Total volume of soil}} = \frac{W_{sat} - V.\gamma_w}{V} = \gamma_{sat} - \gamma_w$$

- Buoyant force F_B on the soil acts in the upward direction.
  - Buoyant force is based on the Archimedes principle.
  - Buoyant force for the submerged soil is equal to weight of water displaced by the soil.



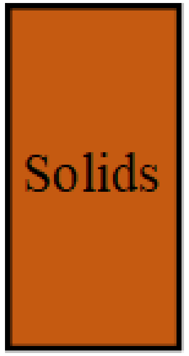
Fully Submerged condition



Unit weight of solids: (γ_s)

$$\gamma_s = \frac{\text{Weight of solids}}{\text{Volume of solids}} = \frac{W_s}{V_s}$$

- γ_s is constant for a given soil, where as γ_d is not constant



Unit weight of Soil Solids

Unit weight of Solids > Saturated unit weight > Bulk unit weight > Dry unit weight > Submerged unit weight.

$$\gamma_s > \gamma_{sat} > \gamma > \gamma_d > \gamma'$$

Specific gravity:(G)

It is the ratio of weight of a given volume of soil solids at a given temperature to the weight of an equal volume of distilled water at that temperature.
As per I.S. code standard temperature for measuring G is 27^0C

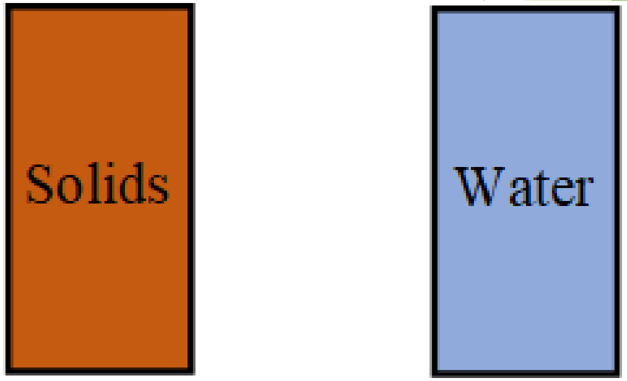
$$G = \frac{\text{Unit weight of solids}}{\text{Unit weight of water}} = \frac{\gamma_s}{\gamma_w} \quad \text{or} \quad G = \left(\frac{W_s}{W_w}\right)_{\text{Same volume}}$$

for a given soil, G remains constant.
Generally G for soils lies between 2.60 to 2.85.

$$\gamma_w = 1000\,\text{kg/m}_3 = 1\text{t/m}_3$$

$$= 9.81\text{kN/m}^3 = 10\,\text{kN/m}^3$$

$$= 1\text{g/cm}^3$$



Weight of Soil Solids and Water
Specific gravity of Soil Solids

Apparent or Mass or Bulk Specific gravity: (G_m)

$$G_m = \frac{\text{Mass or Bulk unit weight of soil}}{\text{Unit weight of water}} = \frac{\gamma}{\gamma_w}$$

- Mass Specific gravity in Saturated condition = $\frac{\gamma_{sat}}{\gamma_w}$
- Mass Specific gravity in Dry condition= $\frac{\gamma_d}{\gamma_w}$
- G_m is not constant.

  $G_m < G$
- eg. Specific gravity of cement: 3.15

  Unit weight of cement: 1440 kg/m³

$$\text{Mass specific gravity of cement}, G_m = \frac{1440}{1000} = 1.44$$

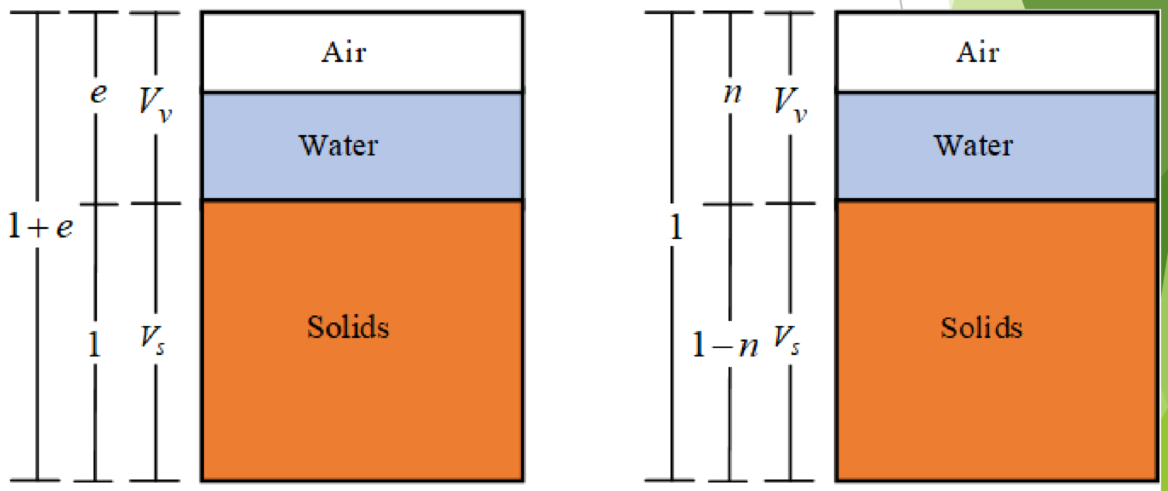
Some important relationships:

1. Relation between n and e:

$$n = \frac{V_v}{V} \qquad e = \frac{V_v}{V_s}$$

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

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



Constituents of soil in terms of Void ratio and Porosity

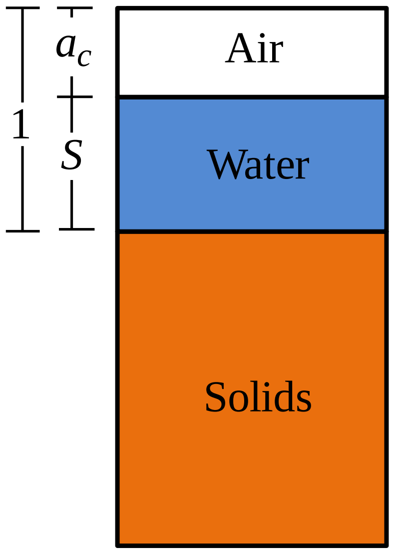
2. Relation between n_a, a_c and S

$$a_c = \frac{V_a}{V_v} \qquad S = \frac{V_w}{V_v} \qquad n_a = \frac{V_a}{V} \qquad n = \frac{V_v}{V}$$

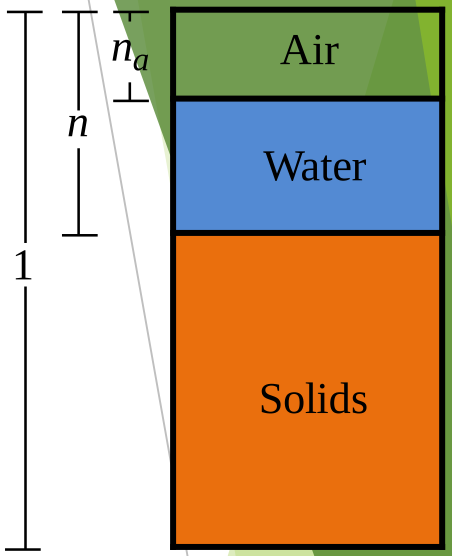
$$n.a_c = \frac{V_a}{V_v} \cdot \frac{V_v}{V} = \frac{V_a}{V} = n_a \qquad n_a = n.a_c$$

$$a_c + S = \frac{V_a}{V_v} + \frac{V_w}{V_v} = \frac{V_a + V_w}{V_v} = \frac{V_v}{V_v} = 1$$

$$S = 1 - a_c \qquad a_c = 1 - S \qquad n_a = n(1 - S)$$



$$a_c + S = 1$$
$$a_c = 1 - S$$



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

$$n_a = n.a_c$$

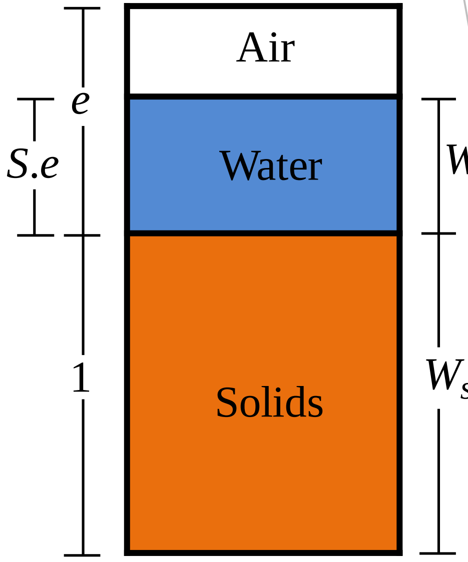
3. Relation between S, w, G and e

$$S = \frac{V_w}{V_v} \qquad w = \frac{W_w}{W_s} \qquad e = \frac{V_v}{V_s} \qquad G = \frac{\gamma_s}{\gamma_w}$$

$$S.e = \frac{V_w}{V_v}.\frac{V_v}{V_s} = \frac{V_w}{V_s}$$

$$w = \frac{W_w}{W_s} = \frac{V_w.\gamma_w}{V_s.\gamma_s} = \frac{V_w.\gamma_w}{V_s.G.\gamma_w} = \frac{V_w}{V_s.G} = \frac{S.e}{G} \Rightarrow S = \frac{w.G}{e}$$

For saturated condition, $S = 1 \Rightarrow \quad e = w_{sat}.G$



$$W_w = \gamma_w.V_w = \gamma_w.S.e$$

$$W_s = \gamma_s.V_s = \gamma_s.1 = \gamma_s$$

$$w = \frac{W_w}{W_s} = \frac{\gamma_w.S.e}{\gamma_s} = \frac{\gamma_w.S.e}{G.\gamma_w} = \frac{S.e}{G}$$

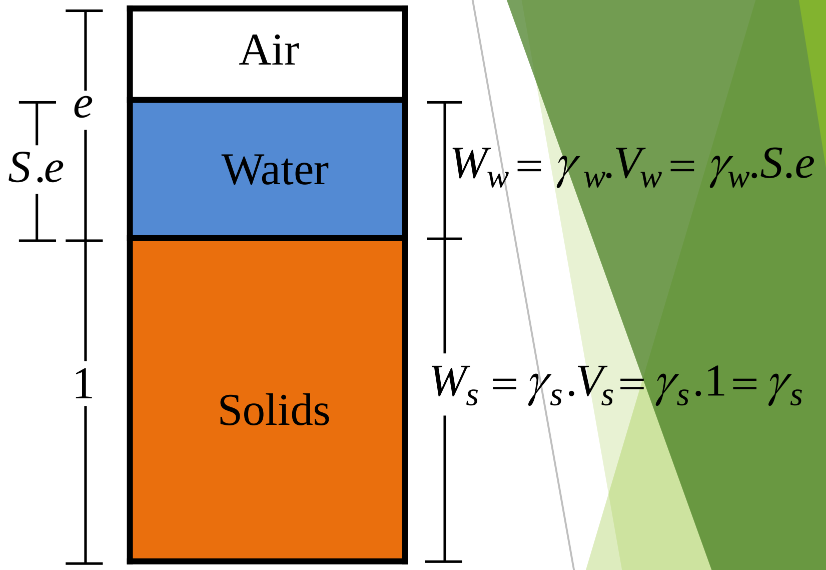
$$S = \frac{w.G}{e}$$

4. Relation between γ, G, S and e

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_v} = \frac{W_s(1 + W_w/W_s)}{V_s(1 + V_v/V_s)}$$

$$= \gamma_s . \frac{(1+w)}{(1+e)} = G.\gamma_w \left(\frac{1+w}{1+e}\right) = \frac{G + w.G}{1+e}.\gamma_w$$

$$\gamma = \left(\frac{G + Se}{1+e}\right).\gamma_w$$



- For Saturated soil ($S = 1$), $\gamma_{sat} = \left(\frac{G+e}{1+e}\right).\gamma_w$

- For Dry soil ($S = 0$) , $\gamma_d = \frac{G.\gamma_w}{1+e}$

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_v} = \frac{\gamma_s + \gamma_w.S.e}{1+e}$$

$$\gamma = \frac{G.\gamma_w + \gamma_w.S.e}{1+e} = \left(\frac{G + S.e}{1+e}\right)\gamma_w$$

$$\gamma = \left(\frac{G + Se}{1+e}\right).\gamma_w = \left(\frac{G\gamma_w}{1+e}\right) + \left(\frac{S.e.\gamma_w}{1+e}\right)$$

$$\gamma = \gamma_d + \left[\left(\frac{G+e}{1+e}\right).\gamma_w - \left(\frac{G\gamma_w}{1+e}\right)\right]$$

$$\gamma = \gamma_d + S(\gamma_{sat} - \gamma_d)$$

5. Relation between γ_{sat}, γ_w and γ'

$$\gamma' = \frac{(W_s)_{sub}}{V}$$

$(W_s)_{sub}$: Weight of solids in air -Weight of water displaced by the solids

$$= W_s - V_s.\gamma_w = W - W_w - V_s.\gamma_w = W - V_w.\gamma_w - V_s.\gamma_w$$

$$= W - \gamma_w(V_w + V_s) = W - V.\gamma_w$$

$$\frac{(W_s)_{sub}}{V} = \frac{W}{V} - \gamma_w \qquad \gamma' = \gamma_{sat} - \gamma_w$$

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

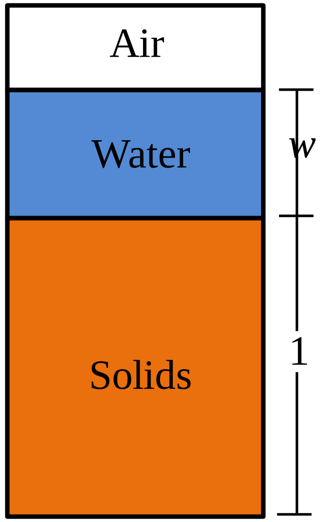
$$\gamma' = \frac{G\gamma_w}{1+e} - \frac{\gamma_w}{1+e} = \gamma_d - (1-n)\gamma_w \qquad \gamma' = \gamma_d - (1-n)\gamma_w$$

6. Relation between γ, γ_d and w

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

$$1+w = \frac{W}{V}\cdot\frac{V}{W_s} = \frac{\gamma}{\gamma_d}$$

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



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

$$W = W_s(1+w)$$

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

7. Relation between G, G_m, S and e

$$G_m = \frac{\gamma}{\gamma_w} = \frac{G + S.e}{1+e}$$

$$G_m + G_m.e = G + S.e \qquad e(G_m - S) = G - G_m$$

$$e = \frac{G - G_m}{G_m - S}$$

- For Dry condition $(S = 0)$, $G_m = \dfrac{G}{1+e}$
- For Saturated condition $(S = 1)$, $G_m = \dfrac{G+e}{1+e}$

8. **Relation between** $\gamma_d, \eta_a, G, \gamma_d$, and e

$$\gamma_d = \frac{(1-n_a)G.\gamma_w}{1+e}$$

9. Relationship between volume of soil and void ratio:

$$V = 1 + e \qquad \frac{V_s}{1} = \frac{V}{1+e} \qquad \gamma_d = \frac{W_s}{V} \Rightarrow \gamma_d \propto \frac{1}{V}$$

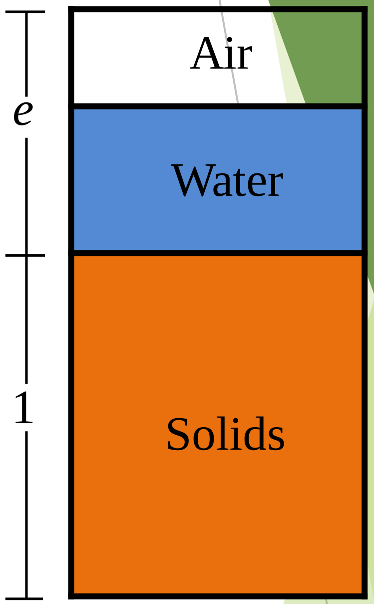
$V_1, e_1, \gamma_{d_1}, W_s$

Borrow Pit

$V_2, e_2, \gamma_{d_2}, W_s$

Embankment

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



$$\frac{V_1}{V_2} = \frac{1+e_1}{1+e_2}$$

$$\frac{V_1}{V_2} = \frac{1+e_1}{1+e_2} = \frac{\gamma_{d2}}{\gamma_{d1}}$$