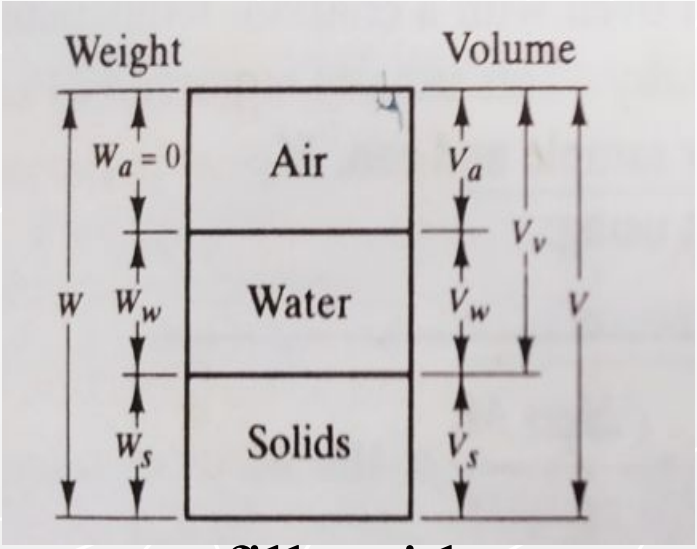
EWCE 341

Principles of Soil Mechanics

Weight–Volume Relationship

What we discussed last class?

- **Differences between soils & rocks and Other engineering Materials**.
- Soils as particulate materials.
- **Three Phase system of soils**



  * Solid phase – always present
  * Liquid phase – usually present
  * Gas phase – present when liquid does not fill voids completely

- **Hazardous effects of gas in soils other than air**

What we will discuss today?

- Phase diagram or weight-volume relationship.
- Different soil parameters

Weight–Volume Relationship

- Weight-Volume relationship is to **identify the relative proportions of solids, water and air** in a soil, because these proportions have a **significant effect on its behavior**.

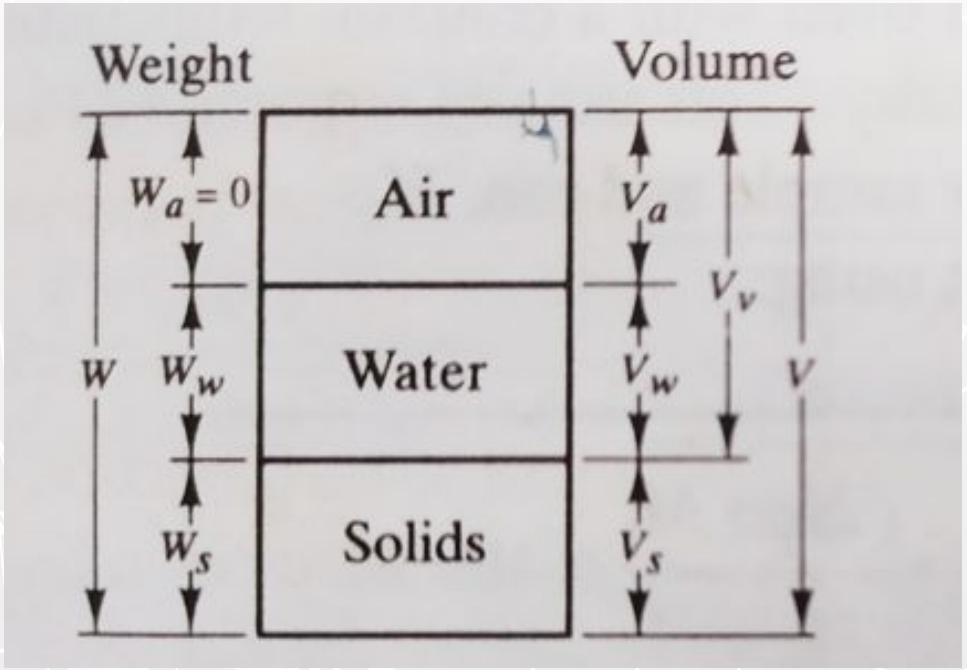
- Geotechnical engineers have developed **quantitative methods** of assessing these components.

Phase Diagrams

- Phase diagram **indicate the relative proportions of solids, water and air in a soil.**

- Left side of the diagram indicate the **weight or mass of each component,** while those on the **right side indicate their volumes.**

Three-Phase of Soil



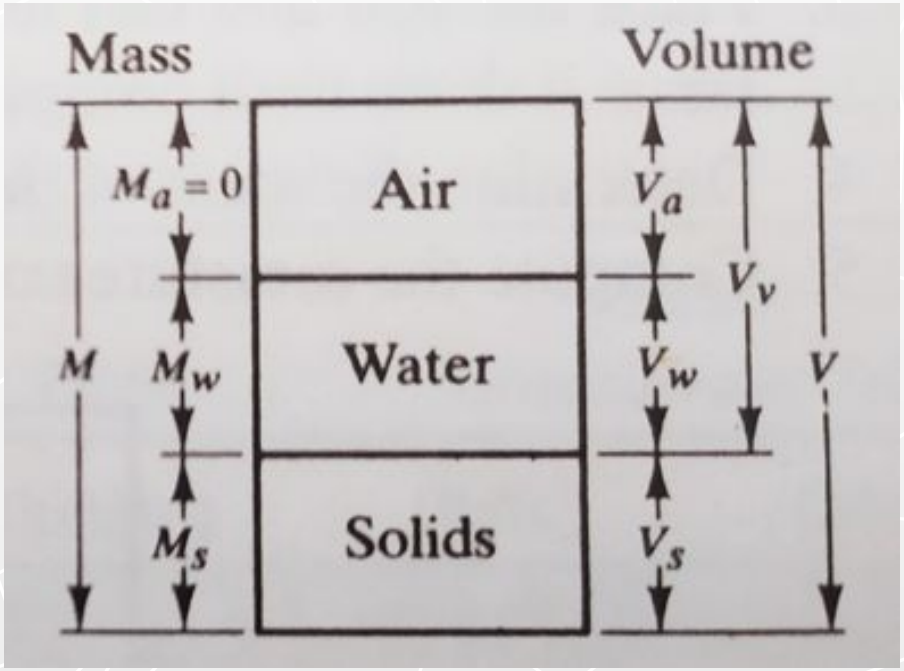
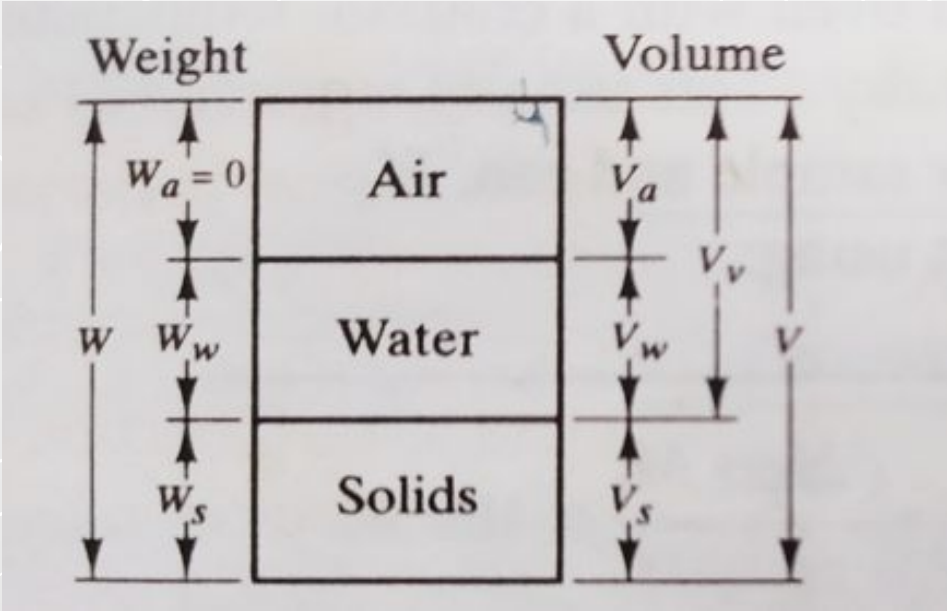


Figure: Phase diagram describe the relative proportions of solids, water and air in a soil. One side presents **weights or masses**, while other side presents **volumes**.

Definition of Weight-Volume Parameter

- Geotechnical engineers have defined **several weight-volume parameters** based on the dimensions shown in the phase diagram.
- Parameters give **important information** on the **composition of a particular soil**, and form part of the basic language of soil mechanics.



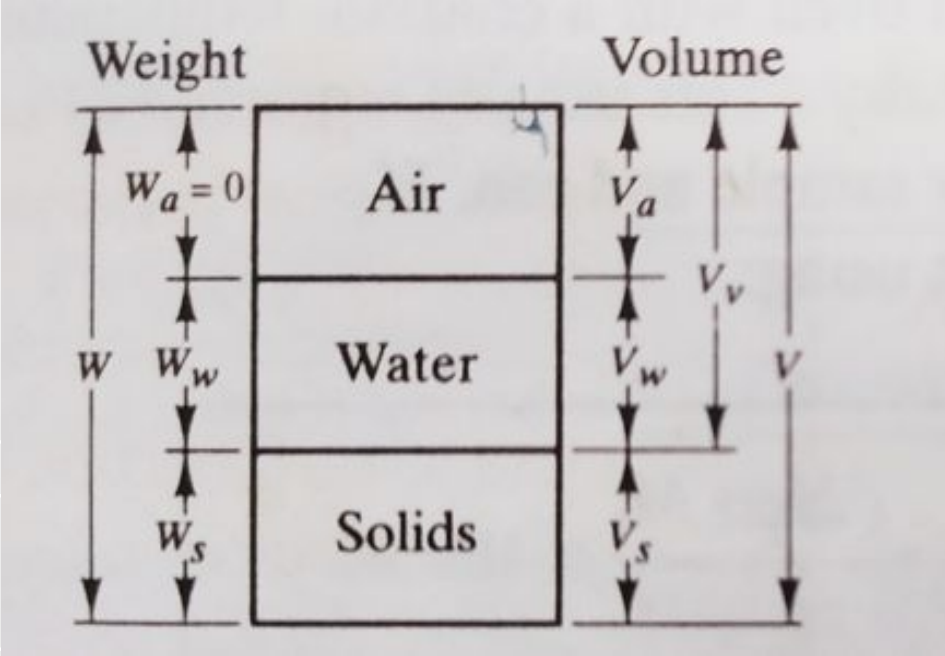
Moisture Content and Degree of Saturation

Moisture Content or Water Content (w):

- One of the most common soil parameters, which can be expressed either in terms of weights or mass.

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

$$w = \frac{M_w}{M_s} \times 100\%$$



- Values in the field between 3 and 70%.
- Values greater than 100%, are sometimes found in soft soils below the GWT, which simply means such soils have more water than solids.
- Moisture content can be easily **measured in the lab** by conducting moisture content test (ASTM D2216).

$$w = \frac{M_1 - M_2}{M_2 - M_c} \times 100\%$$

Where, M_1 = Mass of Soil+ Can, Mass of M_2= Dry soil+ Can

M_c= Mass of Can

- If there is no water w=0

Degree of Saturation (S)

- Percentage of void filled with water.

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

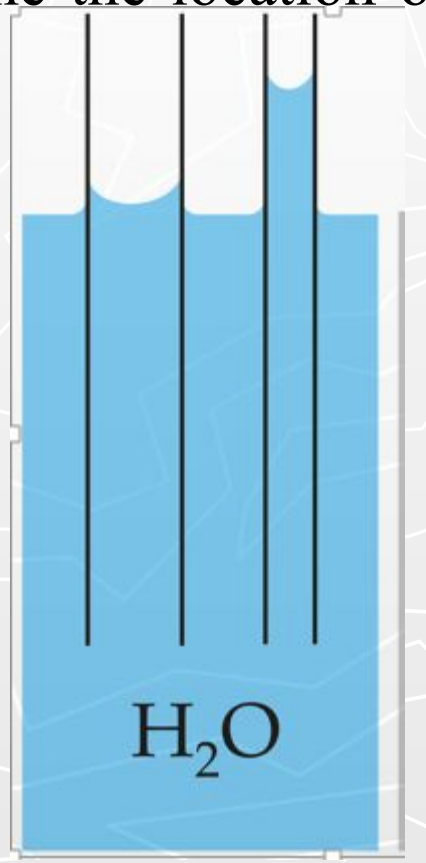
- Holding as much moisture as possible
- S=0 when there is no water..

- S has the maximum value 100%, when all of the voids are filled with water called ***saturated*** **condition**. **Below the GWT**, soils are generally saturated. (*When soil is being called saturated condition*?)
- **Values above GWT** are usually between 5 to 100%, although value approaching zero can be found in very arid region.

Why saturation conditions are not used to determine the GWT?

- In saturated condition, **capillary effects** can draw water upward from the GWT, often producing soils with S=100% well above the GWT.
- Saturation computations are not used to determine the location of GWT.

Capillary action/effect:
Capillary action is the ability of a liquid to flow in narrow spaces without the assistance of, or even in opposition to, external forces like gravity.



Unit weight and Density

- Geotechnical engineers often need to know the unit weight, γ (F-21)

$$\gamma = \frac{W}{V}$$

Why unit weight measurements should not even attempt on poor quality soil sample?

- Unit weight of **undisturbed soil samples** can easily be determined in the lab by measuring their physical dimensions and weighing them.
- Methods produce reliable measurements of γ for many soils.
- **Value of γ is affected by sample disturbance**, specially in sandy and gravely soils.
- Sometimes *unit* weight measurements are made supposedly on undisturbed soil samples that in reality have significant soil disturbance.

Unit weight and Density

- Such measurements are very misleading, so it is best to not even attempt unit weight measurements on poor quality samples.
- Following table presents typical ranges of γ for various soils.

Soil Type and Unified Soil Classification (See Section 5.3)	Typical Unit Weight, γ			
	Above Groundwater Table		Below Groundwater Table	
	(lb/ft^3)	(kN/m^3)	(lb/ft^3)	(kN/m^3)
GP — Poorly graded gravel	110 - 130	17.5 - 20.5	125 - 140	19.5 - 22.0
GW — Well graded gravel	110 - 140	17.5 - 22.0	125 - 150	19.5 - 23.5
GM — Silty gravel	100 - 130	16.0 - 20.5	125 - 140	19.5 - 22.0
GC — Clayey gravel	100 - 130	16.0 - 20.5	125 - 140	19.5 - 22.0
SP — Poorly graded sand	95 - 125	15.0 - 19.5	120 - 135	19.0 - 21.0
SW — Well graded sand	95 - 135	15.0 - 21.0	120 - 145	19.0 - 23.0
SM — Silty sand	80 - 135	12.5 - 21.0	110 - 140	17.5 - 22.0
SC — Clayey sand	85 - 130	13.5 - 20.5	110 - 135	17.5 - 21.0
ML — Low plasticity silt	75 - 110	11.5 - 17.5	80 - 130	12.5 - 20.5
MH — High plasticity silt	75 - 110	11.5 - 17.5	75 - 130	11.5 - 20.5
CL — Low plasticity clay	80 - 110	12.5 - 17.5	75 - 130	11.5 - 20.5
CH — High plasticity clay	80 - 110	12.5 - 17.5	70 - 125	11.0 - 19.5

Variations of Unit Weight

Two variations of unit weight are commonly used:

- Dry unit weight of soil: $\gamma_d = \frac{W_s}{V}$ soils in dry condition
- $\gamma_d = \frac{\gamma}{1+w}$
- Unit weight of water: $\gamma_w = \frac{W_w}{V_w}$

Normally, values of $\boldsymbol{\gamma_w = 9.81\ kN/m^3 = 62.4\ lb/ft^3}$ for fresh water and $\gamma_w = \mathbf{10.1\ kN/m^3 = 64.0\ lb/ft^3}$ are used.

- $\gamma_s = \frac{W_s}{V_s}$ unit weight of soil solids
- $\gamma_{sat} = \frac{W}{V}$ soils in saturation

$\gamma_{sub} = \frac{W_{submerged}}{V}$ soils in submerged condition $= \gamma_{sat} - \gamma_w$

- Buoyant Unit Weight, $\gamma_b = \gamma - \gamma_w$ For soils below GWT, γ_b is being used.

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V} = \frac{W_s + wW_s}{V}$$

as we know, $w = \frac{W_w}{W_s}$

$$= \frac{W_s(1++w)}{V} = \gamma_d(1+w)$$

now, $\gamma_d = \frac{\gamma}{1+w}$ (proved)

Density

- Similar parameters can be defined based on mass instead of weight. These becomes density ρ, dry density ρ_d, and density of water ρ_w:

$$\rho = \frac{M}{V}$$

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

$$\rho_w = \frac{M_w}{V_w}$$

- Design value of $\boldsymbol{\rho_w = 1000\ kg/m^3}$ **and** $\boldsymbol{62.4\ lb/ft^3}$ for fresh water.

- **Relation between unit weight and density:** $\boldsymbol{\gamma = \rho\ g}$, where g= acceleration due to gravity= 9.81 m/s^2 = 32.2 ft/s^2

Why unit weight is more useful than density in geotechnical computations?

- Unit weight is **used to compute stresses** due to weight of the soil.
- In **dynamic analysis**, it is required to consider inertial (***Inertia*** *is the resistance of any physical object to any change in its velocity*) effects that are best presented in terms of masses.
- **For example**, test programs are performed in order t**o study general statistical trends in the response of soils under simulated earthquake conditions.**

Specific Gravity of Solids

- Specific Gravity of any material is the ratio of its density to that density of water.
- In case of soils, it is required to **compute Sp Gr for the solid phase only**, and express as the specific of solids, G_s:

$$G_s = \frac{M_s}{V_s \rho_w}$$

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

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

- Specific Gravity of soil solids is quite different from the specific

Typical values of Specific Gravity Values of Soil Solids

- Nearly all real soils have $2.60 < G_s < 2.80$, which is generally a very narrow range.

- Typical Values:

Soil Type	Specific Gravity
Sand	2.65 – 2.67
Silty Sand	2.67 – 2.70
Inorganic clay	2.70 – 2.80
Soils with mica or iron	2.75 – 3.00
Organic soils	Quite variable, as low as 2.0

- Some unusual soils have G_s values well outside these limits. For example **Olivine sands in Hawaii have $G_s$values as high as 4.50**, while organic soils have G_s values, some times less than 2.00.as high as







Olivine Sand (green) Beach in Hawaii

Void Ratio and Porosity

Void ratio:

- Relative volumes of voids and solids may be expressed using the void ratio, e:

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

- **Densely packed soils** have a low void ratio.
- Typical values in the **field range from 0.1 to 2.5**

Porosity:

- Relative volume of voids to the volume of soil mass.

$$n = \frac{V_v}{V} \text{ x } 100\%$$

- Values ranges 9 to 70%.

Relation between porosity (n) and void ratio (e)

- We know, $\mathbf{n = \frac{V_v}{V} \times 100\%}$

Again $\mathbf{e = \frac{V_v}{V_s}}$, $V_v = e\ V_s$, and $V = V_v + V_s$

$$n = \frac{eV_s}{V_v + V_s} \times 100\%$$

$$= \frac{eV_s}{e\ V_s + V_s} \times 100\%$$

$$= \frac{V_s\,(e)}{V_s(e + 1)} \times 100\%$$

$$= \mathbf{\frac{e}{e + 1} \times 100\%}$$

Or, $ne + n = e$ or $e\,(1\text{-}n) = n$ or $\mathbf{e = \frac{n}{1 - n}}$

Relative Density

- Relative density is a **special weight-volume** parameter used in sandy and gravely soils.
- Defined as: $$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \text{ x } 100\%$$

Where, D_r = Relative density

e = void ratio

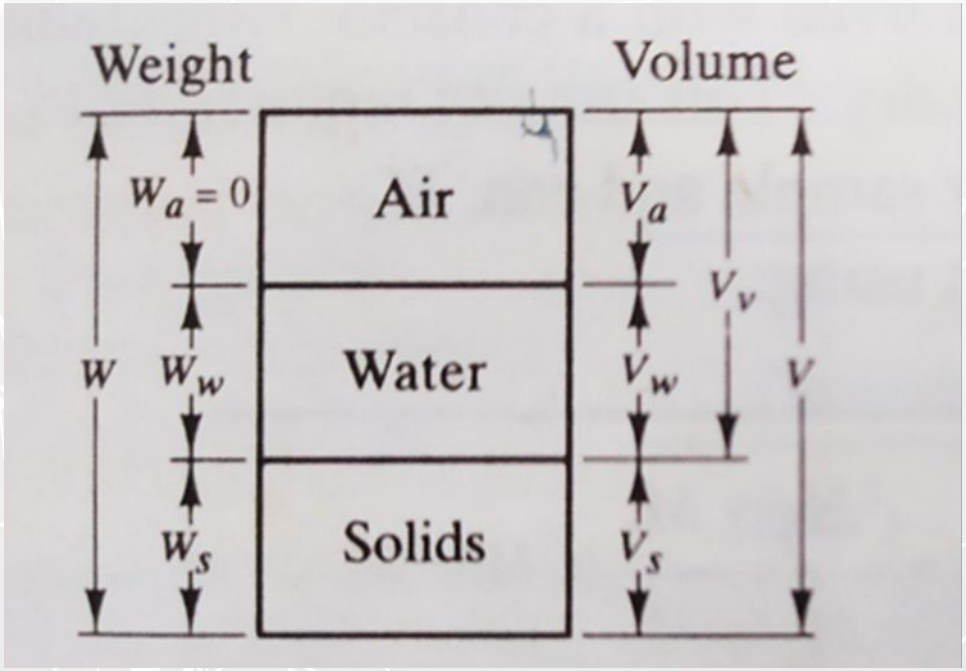
e_{min} = Minimum void ratio

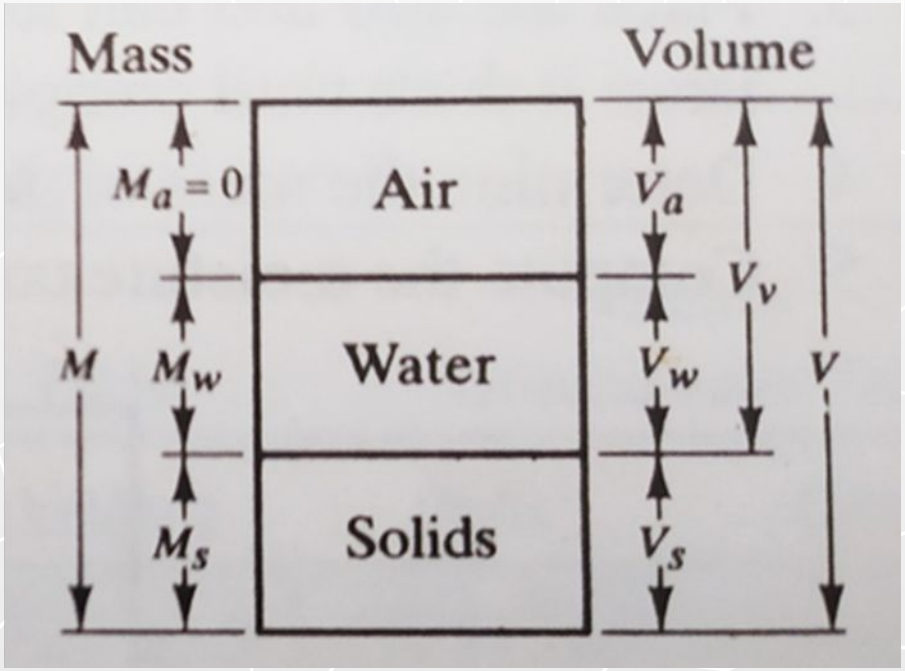
e_{max} = Maximum void ratio

- Values of e_{max} **and** e_{min} **represent the soil in very dense and very loose conditions** respectively and determined by standard laboratory test (ASTM D4253 and D4254).
- Loose soils have low values of D_r and while dense soils have high values, in theory **it varies from 0% to 100%.**

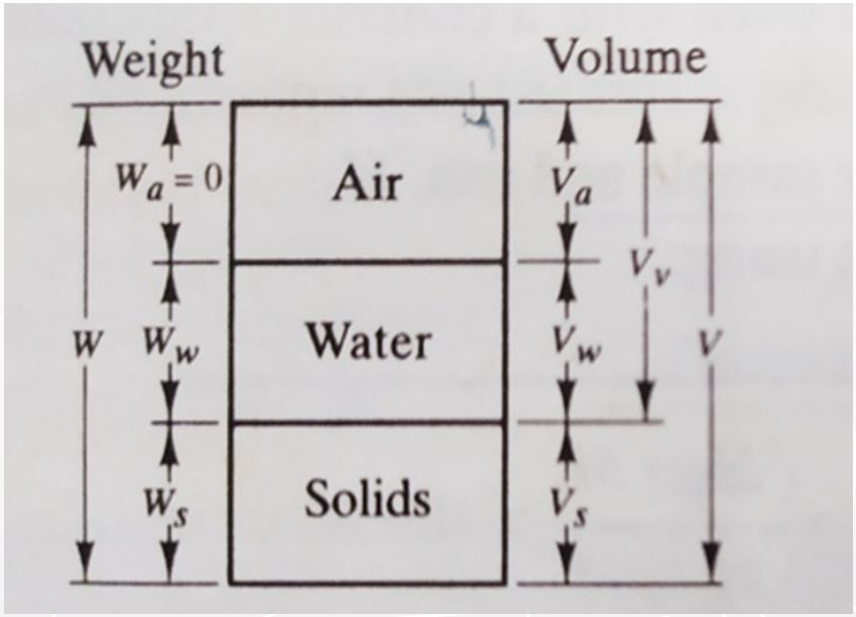
Derived Equation:

By combining definitions and the phase diagrams, we can derive a series of new weight-volume equations:





Prove that S= $\frac{w\,G_s}{e}$ x 100%. (F-21)



Solution: Let V_s=1

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

$S = \frac{V_w}{V_v}$ x 100% →

$= \frac{V_w}{e}$ x 100% gives V_w=Se

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

$G_s = \frac{W_s}{V_s \gamma_w} = \frac{W_s}{(V_s = 1)\gamma_w}$ gives $W_s = G_s \gamma_w$

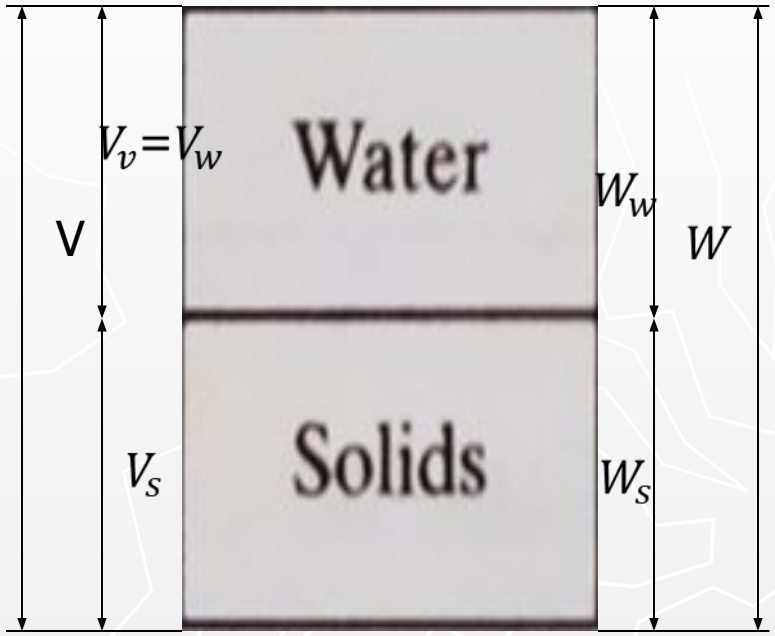
Now, $w = \frac{\gamma_w Se}{G_s \gamma_w}$ or $w = \frac{Se}{G_s}$ x100%

$G_s = \frac{Se}{w}$ or $S = \frac{wG_s}{e}$ x 100% proved.

Weight

Prove that $\gamma_d = \frac{G_s \gamma_w}{1+e}$ when water content is 100%

Solution: Let $V_s = 1$



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

$$G_s = \frac{W_s}{V_s \gamma_w} = \frac{W_s}{(V_s = 1)\gamma_w} = \frac{W_s}{\gamma_w}$$

gives $W_s = G_s \gamma_w$

Again, $e = \frac{V_v}{V_s} = \frac{V_v}{(V_s = 1)} = V_v$ or $e = V_w$

Water content, $w = \frac{W_w}{W_s}$ gives $W_w = wW_s$

$V = V_s + V_w = 1 + V_w$ or $V = 1 + V_v$

- $\gamma_d = \frac{W_s}{V} = \frac{G_s \gamma_w}{1+e}$ **Proved**

Again, $G_s = \frac{W_s}{V_s \gamma_w}$ **, Similarly** $G_w = \frac{W_w}{V_w \gamma_w}$

$$V_w = \frac{W_w}{G_w \gamma_w} = \frac{(W_w =) w W_s}{G_w \gamma_w} = \frac{w G_s \gamma_w}{G_w \gamma_w} = \mathbf{w} G_s \qquad (G_w = 1) \text{------- (1)}$$

- $\gamma_d = \frac{W_s}{V} = \frac{G_s \gamma_w}{1+V_w} = \frac{G_s \gamma_w}{1+\mathbf{w} G_s} = \frac{G_s \gamma_w}{1+\mathbf{w} G_s}$ **proved**

Again, $e = \frac{V_v}{V_s} = \frac{V_v}{(V_s=1)} = V_v = V_w$ **(from Figure)**

$e = V_w = \mathbf{w} G_s$ **---- (from 1)**

$\gamma_d = \frac{G_s \gamma_w}{1+e} = \frac{G_s \gamma_w}{1+\mathbf{w} G_s}$ **Proved.**

Thanks