

# Geotechnical Engineering
# Unit-1

Lecture -2

By

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Subject – Geotechnical Engineering

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## Content

- Weight  Volume Relationship
- Phase Diagram
- Volume Relationship
- Weight mass relationships
- Physical Properties of soil

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# Weight Volume Relationship

## GENERAL (continued)

- **Bulk soil as it exists in nature is a more or less random accumulation of soil particles, water, and air as shown above.**
- **Properties such as strength, compressibility, permeability are directly related to the ratio and interaction of these three phases.**
- **Therefore, an understanding of the terminology and definitions relating to soil composition is fundamental to the study of soil mechanics and geotechnical engineering as a whole.**



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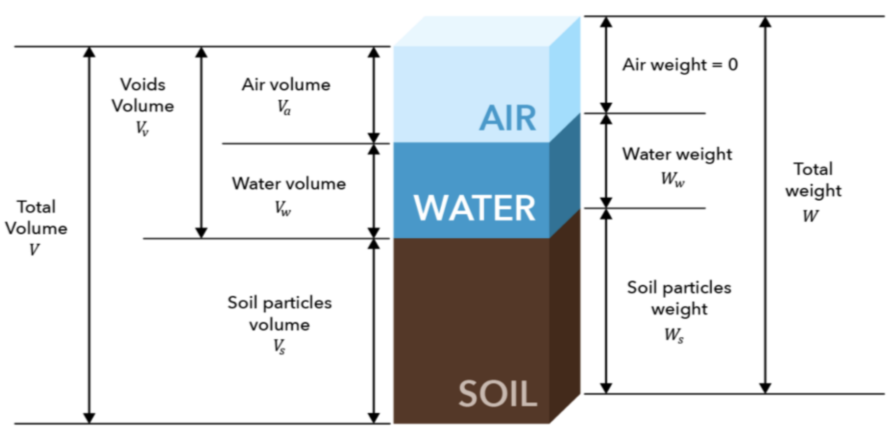
# Weight Volume Relationship

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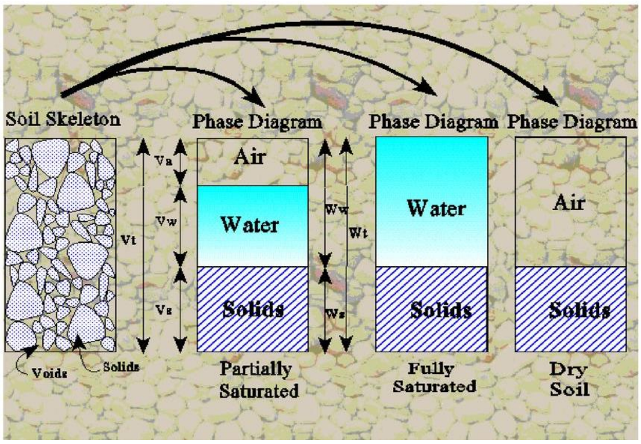
# Weight Volume Relationship

**Possible Cases:**








- The total volume of a given soil sample can be expressed as:

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

Where
- $V$ = Total volume
- $V_s$ = Volume of soil solids
- $V_v$ = Volume of voids
- $V_w$ = Volume of water
- $V_a$ = Volume of air

- Assuming that the weight of the air is **negligible**, we can give the total weight of the sample as

$$W = W_s + W_w$$

Where $W_s$ = weight of solids
$W_w$ = weight of water

- In engineering practice we usually measure the total volume, $V$, the mass of water, $M_w$, and the mass of dry solid $M_s$.

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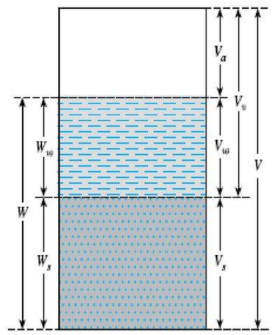
**Volume Relationships**

**There are <u>three</u> volumetric ratios that are very useful in geotechnical engineering , and these can be determined directly from the phase diagram**

**1. Void Ratio** $e = \dfrac{V_v}{V_s}$

**2. Porosity** $n = \dfrac{V_v}{V}$

**3. Degree of Saturation** $S = \dfrac{V_w}{V_v}$




**Porosity and degree of saturation are commonly expressed as a percentage.**

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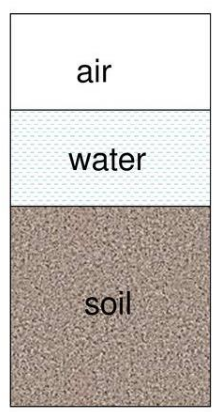
In this illustration,

e = 1

n = 50%

S = 50%

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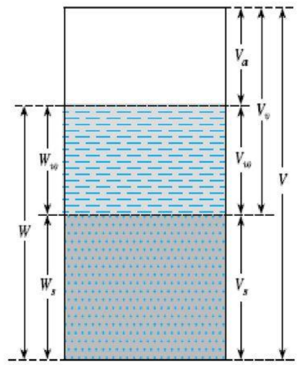
## Weight or Mass Relationships

**The common term used for weight relationships are:**

- **Moisture content**

***Moisture content (w)*** **is also referred to as water content and is defined as the ratio of weight of water to the weight of solids in a given volume of soil:**

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



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## Weight-Volume, Mass-Volume Relationships

### I. Unit Weights (N/m³ or kN/m³)

**1. Unit weight (total, wet or moist unit weight) (γ) is the weight of soil per unit volume.**

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

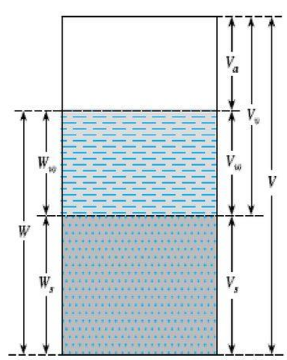
**2. Solid unit weight**

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

**3. Unit weight of water**

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

$$(\gamma_w = 9.807 kN/m^3)$$

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## Weight-Volume, Mass-Volume Relationship

**4. Dry unit weight**

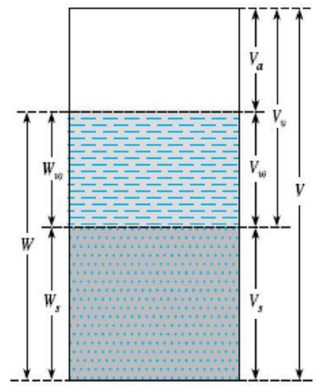
$$\gamma_d = \frac{W_s}{V}$$

**5. Saturated unit weight**

$$\gamma_{sat} = \frac{W_s + W_w}{V} \qquad (S = 100\%)$$

**6. Submerged unit weight**

$$\gamma' = \gamma - \gamma_w$$








## II. Densities (g/cm³ or kg/m³)

- ✓ Because the Newton is a derived unit, working with mass densities $\rho$ of soil may sometimes be convenient.
- ✓ The SI unit of mass density is kilograms per cubic meter (kg/m³). We can write the density equations by replacing weight with mass in all equations in the preceding slides.
- ✓ The density of water $\rho_w$ varies slightly, depending on the temperature. At 4C° when water is at its densest, exactly equal 1000 kg/m³ or 1g/cm³)

### Relationship between unit weight and density

The unit weights of soil in N/m³ can be obtained from densities in kg/m³ as

$$\gamma_x = \rho_x . g = 9.807 \rho_x = 9.81 \rho_x$$

The unit weight in kN/m³ can be obtained from densities in kg/m³ as

$$\gamma\,(\text{kN/m}^3) = \frac{g\rho(\text{kg/m}^3)}{1000}$$

## Density and Unit Weight

- Mass is a measure of a body's inertia, or its "quantity of matter". Mass does not changed at different places.
- Weight is force, the force of gravity acting on a body. The value is different at various places.
- The unit weight is more frequently used than the density is (e.g. in calculating the overburden pressure).

$$\text{Density, } \rho = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Unit weight, } \gamma = \frac{\text{Weight}}{\text{Volume}} = \frac{\text{Mass} \cdot g}{\text{Volume}}$$

g : acceleration due to gravity

$$\gamma = \rho \cdot g = \rho \cdot 9.8 \, {}^{m}\!/_{sec^2}$$

$$\text{Water, } \gamma = 9.8 \, {}^{kN}\!/_{m^3}$$

$$G_s = \frac{\rho_s}{\rho_w} = \frac{\rho_s \cdot g}{\rho_w \cdot g} = \frac{\gamma_s}{\gamma_w}$$

**Note:** The density/or unit weight are ratios which connects the volumetric side of the PHASE DIAGRAM with the mass/or weight side.





## Relationships Between Various Physical Properties

All the weight - volume relationships needed in soil mechanics can be derived from appropriate combinations of six fundamental definitions. They are:

1. Void ratio
2. Porosity
3. Degree of saturation
4. Water content
5. Unit weight
6. Specific gravity


## 1. Relationship between void ratio and porosity

$$e = \frac{V_v}{V_s} = \frac{V_v}{V - V_v} = \frac{\left(\frac{V_v}{V}\right)}{1 - \left(\frac{V_v}{V}\right)} = \frac{n}{1-n} \tag{3.6}$$

Also, from Eq. (3.6),

$$n = \frac{e}{1+e} \tag{3.7}$$



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## 2. Relationship among Void ratio, Degree of Saturation, Water content, and Specific Gravity

$$w = \frac{W_w}{W_s} = \frac{\gamma_w V_w}{\gamma_s V_s} = \frac{\gamma_w V_w}{\gamma_w G_s V_s} = \frac{V_w}{G_s V_s}$$

**Dividing the denominator and numerator of the R.H.S. by $V_v$ *yields:***

$$Se = wG_s$$

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$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V} = \frac{G_s\gamma_w + wG_s\gamma_w}{1+e} = \frac{(1+w)G_s\gamma_w}{1+e} \tag{3.15}$$

and

$$\gamma_d = \frac{W_s}{V} = \frac{G_s\gamma_w}{1+e} \tag{3.16}$$

or

$$e = \frac{G_s\gamma_w}{\gamma_d} - 1 \tag{3.17}$$



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Because the weight of water for the soil element under consideration is $wG_s\gamma_w$, the volume occupied by water is

$$V_w = \frac{W_w}{\gamma_w} = \frac{wG_s\gamma_w}{\gamma_w} = wG_s$$

Hence, from the definition of degree of saturation [Eq. (3.5)],

$$S = \frac{V_w}{V_v} = \frac{wG_s}{e}$$

or

$$Se = wG_s \tag{3.18}$$

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### 3. Relationship among Unit Weight, Void Ratio, Degree of Saturation and Specific Gravity

$$\gamma = \frac{W}{V} = \frac{W_w + W_s}{V_s + V_v} = \frac{\gamma_w V_w + \gamma_s V_s}{V_s + V_v} = \frac{\gamma_w V_w + \gamma_w G_s V_s}{V_s + V_v}$$

$$\gamma = \frac{(Se + G_s)}{1 + e}\gamma_w$$

**Notes:**

- Unit weights for dry, fully saturated and submerged cases can be derived from the upper equation
- Water content can be used instead of degree of saturation.
- Submerged unit weight can be approximated as $\gamma_{sub} \approx \frac{\gamma}{2}$





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## Various Unit Weight Relationships

Table 3.1 Various Forms of Relationships for $\gamma$, $\gamma_d$, and $\gamma_{sat}$

| Moist unit weight ($\gamma$) | | Dry unit weight ($\gamma_d$) | | Saturated unit weight ($\gamma_{sat}$) | |
|---|---|---|---|---|---|
| Given | Relationship | Given | Relationship | Given | Relationship |
| $w, G_s, e$ | $\frac{(1+w)G_s\gamma_w}{1+e}$ | $\gamma, w$ | $\frac{\gamma}{1+w}$ | $G_s, e$ | $\frac{(G_s+e)\gamma_w}{1+e}$ |
| $S, G_s, e$ | $\frac{(G_s+Se)\gamma_w}{1+e}$ | $G_s, e$ | $\frac{G_s\gamma_w}{1+e}$ | $G_s, n$ | $[(1-n)G_s+n]\gamma_w$ |
| $w, G_s, S$ | $\frac{(1+w)G_s\gamma_w}{1+\frac{wG_s}{S}}$ | $G_s, n$ | $G_s\gamma_w(1-n)$ | $G_s, w_{sat}$ | $\left(\frac{1+w_{sat}}{1+w_{sat}G_s}\right)G_s\gamma_w$ |
| $w, G_s, n$ | $G_s\gamma_w(1-n)(1+w)$ | $G_s, w, S$ | $\frac{G_s\gamma_w}{1+\left(\frac{wG_s}{S}\right)}$ | $e, w_{sat}$ | $\left(\frac{e}{w_{sat}}\right)\left(\frac{1+w_{sat}}{1+e}\right)\gamma_w$ |
| $S, G_s, n$ | $G_s\gamma_w(1-n)+nS\gamma_w$ | $e, w, S$ | $\frac{eS\gamma_w}{(1+e)w}$ | $n, w_{sat}$ | $n\left(\frac{1+w_{sat}}{w_{sat}}\right)\gamma_w$ |
| | | $\gamma_{sat}, e$ | $\gamma_{sat} - \frac{e\gamma_w}{1+e}$ | $\gamma_d, e$ | $\gamma_d + \left(\frac{e}{1+e}\right)\gamma_w$ |
| | | $\gamma_{sat}, n$ | $\gamma_{sat} - n\gamma_w$ | $\gamma_d, n$ | $\gamma_d + n\gamma_w$ |
| | | $\gamma_{sat}, G_s$ | $\frac{(\gamma_{sat}-\gamma_w)G_s}{(G_s-1)}$ | $\gamma_d, S$ | $\left(1-\frac{1}{G_s}\right)\gamma_d + \gamma_w$ |
| | | | | $\gamma_d, w_{sat}$ | $\gamma_d(1+w_{sat})$ |

## Example 1

The moist unit weight of a soil is 19.2 kN/m³. Given that $G_s$ 2.69 and $w = 9.8\%$, determine

a. Dry unit weight
b. Void ratio
c. Porosity
d. Degree of saturation

Instead think of ➡ $\gamma = \frac{(Se+G_s)}{1+e}\gamma_w$

$Se = wG_s$

a. $\gamma_d = \frac{\gamma}{1+w} = \frac{19.2}{1+\frac{9.8}{100}} = \mathbf{17.5\ kN/m^3}$

b. $\gamma_d = 17.5 = \frac{G_s\gamma_w}{1+e} = \frac{(2.69)(9.81)}{1+e}$; $e = \mathbf{0.51}$

c. $n = \frac{e}{1+e} = \frac{0.51}{1+0.51} = \mathbf{0.338}$

d. $S = \frac{wG_s}{e} = \frac{(0.098)(2.69)}{0.51} \times 100 = \mathbf{51.7\%}$



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## Example 2

**Field density testing (i.e., sand replacement method) has shown bulk density of a compacted road base to be 2.06 t/m³ with a water content of 11.6%. Specific gravity of the soil grains is 2.69. Calculate the dry density, porosity, void ratio and degree of saturation.**

Solution:

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

$$\therefore Se = (0.116)(2.69) = 0.312$$

$$\rho_m = \frac{G_s + Se}{1+e}\rho_w$$

$$\therefore 2.06 = \frac{2.69 + 0.312}{1+e} \times 1.0$$

$$\therefore e = 0.457$$

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# THANK YOU