# Chapter 2

# Basic Definitions and Simple Tests

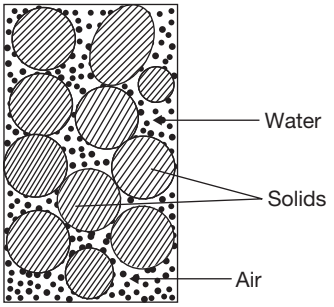
**CHAPTER HIGHLIGHTS**

- *Introduction*
- *Volumetric relationships*
- *Weight relationships*
- *Volume-weight relationships*
- *Specific gravity of solids (G)*
- *Mass specific gravity or apparent specific gravity ($G_m$)*
- *Important relationships*
- *Simple tests*

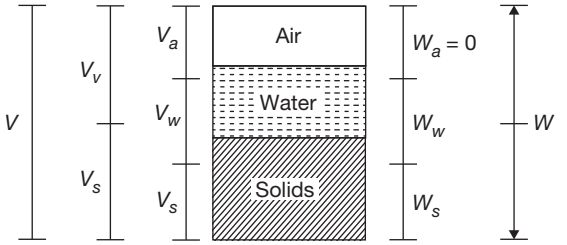
## Introduction

This chapter discusses some of the basic definitions and simple tests used throughout the subject.

- The phase diagram is a simple, diagrammatic representation of a real soil.
- The phase diagram is also known as block diagram.
- A soil mass consists of solid particles, water and air, which are segregated and placed separately, known as three-phase system.
- A three-phase system becomes a two-phase system when the soil is absolutely dry (solids + air) or when the soil is fully saturated (solids + water).
- In phase diagram, volumes are represented on the left side, whereas weights are represented on the right side.




**Constituents of soil**




**A three-phase system**

## Volumetric Relationships

In total, there are five volumetric relationships. These are as follows:

1. **Void ratio (*e*):** It is defined as the ratio of volume of voids to volume of solids.

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

**Range:** $e > 0$

- For some soils, it may have a value even greater than unity.
- The void ratio of coarse grained soils is, generally, smaller than that of a fine-grained soil.

2. **Porosity ($n$):** It is defined as the ratio of volume of voids to the total volume.

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

**Range:** $0 < n < 1$

- Also called 'percentage voids'.
- Both porosity and void ratio are the measure of the degree of denseness (or looseness) of soil.

**Relationship between $n$ and $e$:**

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

3. **Degree of saturation ($S_r$):** It is defined as the ratio of volume of water to the volume of voids, in soil.

$$S_r = \frac{V_w}{V_v}$$

- It is expressed as a percentage.

**Range:** $0 \le S \le 100\%$

- For dry soil, $V_w = 0 \Rightarrow S = 0$
- For saturated soil, $V_w = V_v \Rightarrow S = 100\%$

4. **Percentage air voids ($n_a$):** It is defined as the ratio of volume of air to total volume, of soil.

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

**Range:** $0 \le n_a \le n$

5. **Air content ($a_c$):** It is defined as the ratio of volume of air to the volume of voids, in soil.

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

**Range:** $0 \le a_c \le 100\%$

- For dry soil, $V_a = V_v \Rightarrow a_c = 100\%$
- For saturated soil, $V_a = 0 \Rightarrow a_c = 0$

**Relationships between $a_c$, $n_a$, $n$ and $s$:**

$$a_c + S = 1$$
$$n_a = n \cdot a_c$$

## Weight Relationships

1. **Water content ($w$):** It is defined as the ratio of weight of water to weight of solids.

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

- It is expressed as percentage.
- Range: $w \ge 0$
- For dry soil, $w = 0$. For saturated soil, $w > 0$.
- The water content of some of fine-grained soil may be even greater than 100%.

## Volume-Weight Relationships

The weight of soil per unit volume is known as unit weight or specific weight.

1. **Bulk unit weight ($\gamma$):** It is defined as the total weight per unit total volume.

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

- It is also known as wet unit weight or total unit weight.

2. **Dry unit weight ($\gamma_d$):** It is defined as the weight of solids per unit total volume.

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

3. **Saturated unit weight ($\gamma_{sat}$):** It is the bulk weight when the soil is fully saturated.

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

4. **Submerged unit weight ($\gamma_{sat}$ or $\gamma'$):** It is defined as submerged weight per unit of total volume.

$$\gamma' = \frac{W_{sub}}{V}$$
$$\gamma' = \gamma_{sat} - \gamma_w$$

- It is based on Archimedes' Principle.

5. **Unit weight of soil solids ($\gamma_s$):** It is defined as the ratio of weight of solids to the volume of solids.

$$\gamma' = \frac{W_s}{V_s}$$

**NOTES**

1. $\gamma_s > \gamma_{sat} > \gamma > \gamma_d > \gamma'$
2. For a given soil, $\gamma_s$ is constant, whereas $\gamma_d$ is not constant.

## Specific Gravity of Solids ($G$)

- It is defined as the ratio of weight of a given volume of solids to the weight of an equal volume of water at 4°C.

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

- Unit weight of water at 4°C is 1 gm/cc, 1000 kg/m$^3$, 9.81 kN/m$^3$.
- Generally, '$G$' for inorganic soil lies between 2.65–2.80.
- For organic soil, $G$ lies between 1.22–1.40.

## Mass Specific Gravity or Apparent Specific Gravity ($G_m$)

It is defined as a ratio of unit weight of soil to the unit weight of water.

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

- When the soil is partially saturated:
  (a) When the soil is dry:

$$(G_m)_{\text{dry}} = \frac{\gamma_d}{\gamma_w}$$

  (b) When the soil is fully saturated:

$$(G_m)_{\text{sat}} = \frac{\gamma_{\text{sat}}}{\gamma_w}$$

**NOTE**

For a given soil, $G$ is constant, whereas $G_m$ is not constant, and $G_m$ is always less than $G$.

## Important Relationships

1. $e = \dfrac{wG}{S}$
2. $\gamma = \dfrac{(G + es)\gamma_w}{1 + e}$
3. $\gamma_{\text{sat}} = \dfrac{(G + e)\gamma_w}{1 + e}$
4. $\gamma_d = \dfrac{G\gamma_w}{1 + e}$
5. $\gamma' = \dfrac{(G - 1)\gamma_w}{1 + e}$
6. $\gamma_d = \dfrac{\gamma}{1 + w}$
7. $\gamma_d = \dfrac{(1 - n_a)G\gamma_w}{1 + wG}$
8. $\dfrac{V_1}{V_2} = \dfrac{1 + e_1}{1 + e_2} = \dfrac{\gamma_{d_2}}{\gamma_{d_1}}$

## Simple Tests

### Water Content Determination

The water content of soil can be determined by any of the following methods:

1. Oven-drying method
2. Torsion balance method
3. Pycnometer method
4. Sand bath method
5. Alcohol method
6. Calcium carbide method
7. Radiation method

#### Oven Drying Method

- It is a standard, laboratory-based method.
- This method yields higher level of accuracy.
- For inorganic soils, a temperature between 105–110°C is maintained for 24 hours.
- For organic soils, a temperature of about 60°C is maintained, but for longer time.
- If soil contains gypsum, a temperature of about 80°C is maintained.
- The water content of the soil sample is calculated from the following equation:

$$W = \frac{W_w}{W_s} \times 100 = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

Where
$W_1$ = Weight of container, with lid.
$W_2$ = Weight of container, with lid and wet soil.
$W_3$ = Weight of container, with lid and dry soil.

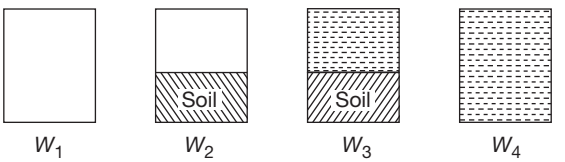
### Specific Gravity Determination

By using the following methods, specific gravity of solid particles is determined in the laboratory.

1. Density bottle method
2. Pycnometer method
3. Measuring flask method
4. Gas jar method
5. Shrinkage limit method

#### Pycnometer Method

- This method can be used for all types of soils.




$$G = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)}$$

$$W = \left[\left(\frac{W_2 - W_1}{W_3 - W_4}\right)\left(\frac{G - 1}{G}\right) - 1\right] \times 100$$

Where

$W_1$ = Weight of empty pycnometer.
$W_2$ = Weight of pycnometer + Dry soil.
$W_3$ = Weight of pycnometer, soil and water.
$W_4$ = Weight of pycnometer + Water.

## Determination of in Situ Density/ Field Density

The following methods are used for determination of undisturbed or field density.

1. Core cutter method
2. Sand replacement method

**NOTE**

Core cutter method is quite suitable for the fine-grained soils, whereas sand replacement method is suitable for any type of soil.

### SOLVED EXAMPLE

#### Example 1

The total unit weight of the glacial outwash soil is 6 kN/m$^3$. The specific gravity of the solid particles of the soil is 2.67. The water content of the soil is 17%. Assume that unit weight of water ($\gamma_w$) is 9.81 kN/m$^3$. Calculate the following:

(i) Dry unit weight
(ii) Porosity
(iii) Void ratio
(iv) Degree of saturation **[GATE, 1998]**

#### Solution

Give n

$\gamma$ : 6 kN/m$^3$, $G = 2.67$, $w = 0.17$

$\gamma_w = 9.81$ kN/m$^3$

(i) **Dry unit weight ($\gamma_d$)**

$$\gamma_d = \frac{\gamma}{1+w} = \frac{6}{1+0.17}$$

$$\gamma_d = 5.128 \text{ kN/m}^3$$

(ii) **Porosity ($n$)**

$$e = \frac{G\gamma_w}{\gamma_d} - 1$$

$$= \frac{(2.67)(9.81)}{5.128} - 1$$

$$e = 4.10$$

$$n = \frac{e}{1+e} = \frac{4.10}{1+4.10}$$

$$n = 0.803$$

$$n = 80.33\%$$

(iii) **Void ratio**

$$e = 4.10$$

(iv) **Degree of saturation**

$$e = \frac{wG}{S}$$

$$S = \frac{wG}{e} = \frac{(0.17)(2.67)}{4.10}$$

$$S = 0.1107$$

$$S = 11.07\%$$

## EXERCISES

1. If the porosity of a soil sample is 20%, the void ratio is
   (A) 0.20. (B) 0.80.
   (C) 1.00. (D) 0.25.

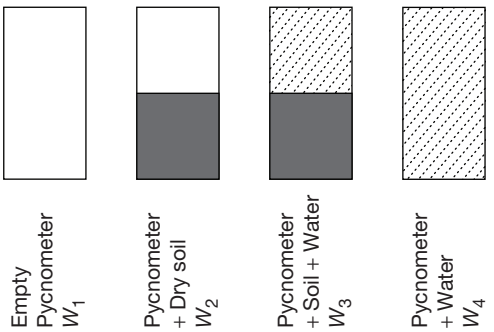
2. Principle involved in the relationship between submerged unit and saturated unit weight of a soil is based on
   (A) equilibrium of floating bodies.
   (B) archimedes principle.
   (C) Stoke's law.
   (D) Darcy's law.

3. A soil sample has a void ratio of 0.5 and its porosity will be close to
   (A) 50% (B) 66%
   (C) 100% (D) 33%

4. A borrow pit soil has a dry density of 17 kN/m$^3$. How many cubic meters of this soil will be required to construct an embankment of 100 m$^3$ volume with a dry density of 16 kN/m$^3$.
   (A) 94 m$^3$
   (B) 106 m$^3$
   (C) 100 m$^3$
   (D) 90 m$^3$

5. The ratio of saturated unit weight to dry unit weight of a soil is 1.25. If the specific gravity of solids ($G_s$) is 2.65, the void ratio of the soil is
   (A) 0.625
   (B) 0.663
   (C) 0.944
   (D) 1.325

**6.** The given figure indicate the weights of different pycnometers:




The specific gravity of the solids is given by

(A) $\dfrac{W_2}{W_4 - W_2}$

(B) $\dfrac{W_1 - W_2}{(W_3 - W_4) - (W_3 - W_4)}$

(C) $\dfrac{W_2}{W_3 - W_4}$

(D) $\dfrac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)}$

**7.** In a wet soil mass, air occupies one-sixth of its volume and water occupies one-third of its volume. The void ratio of the soil is

(A) 0.25 (B) 0.5
(C) 1.00 (D) 1.50

**8.** Consider the following statements in relation to the given table:

| Volume (cc) | Content | Weight (g) |
|---|---|---|
| 0.2 | Air | 0 |
| 0.3 | Water | 0.3 |
| 0.5 | Solids | 1.0 |

I. Soil is partially saturated at degree of saturation = 60%
II. Void ratio = 40%
III. Water content = 30%
IV. Saturated unit weight = 1.5 g/cc

Which of these statements is/are correct?

(A) I, II and III (B) I, III and IV
(C) II, III and IV (D) I, II and IV

**9.** If a soil sample of weight 0.18 kg having a volume of $10^{-4}$ m$^3$ and dry unit weight of 1600 kg/m$^3$ is mixed with 0.02 kg of water then the water content in the sample will be

(A) 30% (B) 25%
(C) 20% (D) 15%

**10.** A soil sample having a void ratio of 1.3, water content of 50% and a specific gravity of 2.60, is in a state of

(A) partial saturation.
(B) full saturation.
(C) over saturation.
(D) under saturation.

**11.** A soil sample in its natural state has mass of 2.290 kg and a volume of $1.15 \times 10^{-3}$ m$^3$. After being over dried, the mass of the sample is 2.035 kg. $G_s$ for soil is 2.68. The void ratio of the natural soil is

(A) 0.40 (B) 0.45
(C) 0.35 (D) 0.53

**12.** The void ratio and specific gravity of a soil are 0.65 and 2.72 respectively. The degree of saturation (in percent) corresponding to water content of 20% is

(A) 65.3 (B) 20.9
(C) 83.7 (D) 54.4

**13.** A saturated soil mass has a total density of 22 kN/m$^3$ and a water content of 10%. The bulk density and dry density of this soil are

(A) 12 kN/m$^3$ and 20 kN/m$^3$ respectively.
(B) 22 kN/m$^3$ and 20 kN/m$^3$ respectively.
(C) 19.8 kN/m$^3$ and 19.8 kN/m$^3$ respectively.
(D) 23.2 kN/m$^3$ and 19.8 kN/m$^3$ respectively.

**Direction for questions 14 and 15:**

For constructing an embankment, the soil is transported from a borrow area using a truck which can carry 6 m$^3$ of soil at a time. The details are as follows:

| Property | Borrow Area | Truck (Loose) | Field Compacted |
|---|---|---|---|
| Bulk density (g/cc) | 1.66 | 1.15 | 1.82 |
| Water content (%) | 8 | 6 | 14 |

**14.** The quantity of soil to be excavated from the borrow pit, in m$^3$ for a compacted earth fill of 100 m$^3$ is

(A) 104 Cum
(B) 146 Cum
(C) 98 Cum
(D) 87 Cum

**15.** The number of truck loads of soil required to obtain 100 m$^3$ of compacted earth fill is

(A) 12
(B) 56
(C) 25
(D) 33

**16.** A sheet of water of thickness 1 m is available to fill the voids of a cohesion less soil to a degree of saturation of 80%. The soil has a void ratio of 0.5. Find the thickness of soil layer required to accommodate this amount of water.

**17.** Soil has been compacted in an embankment of a bulk density of 2.15 mg/m$^3$ and a water content of 12%. The value of specific gravity of soil solids is 2.65. The water table is well below the foundation level. Estimate the dry density, void ratio, degree of saturation and air content of the compacted soil.

**Direction for questions 18 and 19:**

A soil has a bulk density of 2.05 g/cc and water content of 18%. ($G = 2.67$)

**18.** The void ratio of the soil is
(A) 0.54
(B) 0.85
(C) 0.65
(D) 0.85

**19.** The degree of saturation of the soil is
(A) 65.7%
(B) 76.6%
(C) 89.5%
(D) 93.5%

**20.** For determining the index properties of soil the sample should be
(A) disturbed
(B) undisturbed
(C) intact
(D) None of these

**21.** If $w$ represents natural water content and $w_L$, $w_p$, $w_s$ represents liquid limit, plastic limit, shrinkage limit respectively; choose the incorrect pair from the following:
(A) Plasticity index $(I_p) = w_L - w_p$
(B) Shrinkage index $(I_s) = w_p - w_s$
(C) Liquidity index $(I_L) = \dfrac{w - w_p}{w_L - w_p}$
(D) Consistency index $(I_C) = \dfrac{w - w_L}{w_L - w_p}$

**22.** Sand bath method is used to determine _____.
(A) specific gravity
(B) unit weight
(C) moisture content
(D) particle size distribution

**23.** For a sand deposit having specific gravity 2.65 and moisture content 25%; what will be the relative density in saturated condition if loose and compacted void ratios are given as 0.92 and 0.41 respectively
(A) 49%
(B) 51%
(C) 39%
(D) 31%

**24.** The water content of saturated soil and the specific gravity were found to be 30% and 2.65 respectively. Assuming the unit weight of water to be 10 kN/m$^3$, submerged unit weight (in kN/m$^2$) and porosity of the soil are _____.
(A) 19, 0.6
(B) 9, 0.45
(C) 9, 0.6
(D) 19, 0.78

**25.** Which one of the following correctly represents the dry unit weight of a soil sample which has bulk unit weight of $\gamma_t$ at a moisture content of $w$%?
(A) $\gamma_t\left(1+\dfrac{w}{100}\right)$
(B) $\dfrac{\gamma_t(100-w)}{100}$
(C) $\dfrac{w\cdot\gamma_t}{100}$
(D) $\gamma_t\left(\dfrac{100}{100+w}\right)$

**26.** A 600 cm$^3$ volume of moist sand weighs 1050 g. Its dry weight is 930 g and specific gravity of solids, $G$ is 2.67. Assuming density of water as 1 g/cm$^3$, the void ratio is _____.
(A) 0.72
(B) 0.64
(C) 0.48
(D) 0.91

**27.** For a given soil the following unit weight is constant
(A) $\gamma$
(B) $\gamma_d$
(C) $\gamma_{sat}$
(D) $\gamma_s$

**28.** A given cohesionless soil has $e_{max} = 0.85$ and $e_{min} = 0.50$. In the field, the soil is compacted to a mass density of 1800 kg/m$^3$ at a water content of 8%.

Take mass density of water as 1000 kg/m$^3$ and $G$ as 2.65. The relative density of the soil is _____.
(A) 55%
(B) 60%
(C) 65%
(D) 75%

## Previous Years' Questions

**1.** The water content of a saturated soil and the specific gravity of soil solids were found to be 30% and 2.70 respectively. Assuming the unit weight of water to be 10 kN/m$^3$, the saturated unit weight (kN/m$^3$), and the void ratio of the soil are **[GATE, 2007]**
(A) 19.4, 0.81
(B) 18.5, 0.30
(C) 19.4, 0.45
(D) 18.5, 0.45

**2.** In its natural condition, a soil sample has a mass of 1.980 kg and a volume of 0.001 m$^3$. After being completely dried in an oven, the mass of the sample is 1.800 kg, specific gravity $G$ is 2.7 and unit weight of water is 10 kN/m$^3$. The degree of saturation of the soil is **[GATE, 2013]**
(A) 0.65
(B) 0.70
(C) 0.54
(D) 0.61

**3.** A certain soil has the following properties:
$G_s = 2.71$, $n = 40\%$ and $w = 20\%$. The degree of saturation of the soil (rounded off to the nearest percent) is _____. **[GATE, 2014]**

**4.** If the water content of a fully saturated soil mass is 100%, the void ratio of the sample is **[GATE, 2015]**
(A) less than specific gravity of soil.
(B) equal to specific gravity of soil.
(C) greater than specific gravity of soil.
(D) independent of specific gravity of soil.

**5.** A 588 $cm^3$ volume of moist sand weighs 1010 gm. Its dry weight is 918 gm and specific gravity of solids, $G$ is 2.67. Assuming density of water as 1 $gm/cm^3$, the void ratio is _____. **[GATE, 2015]**

**6.** The porosity ($n$) and the degree of saturation ($S$) of a soil sample are 0.7 and 40%, respectively. In a 100 $m^3$ volume of the soil, the volume (expressed in $m^3$) of air is _____. **[GATE, 2016]**

## Answer Keys

### Exercises

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** D | **2.** B | **3.** D | **4.** A | **5.** B | **6.** D | **7.** C | **8.** B | **9.** B | **10.** B |
| **11.** D | **12.** C | **13.** B | **14.** A | **15.** C | **16.** 3.75 m | **17.** 16.3% | **18.** A | **19.** C | **20.** A |
| **21.** D | **22.** C | **23.** B | **24.** B | **25.** D | **26.** A | **27.** D | **28.** D | | |

### Previous Years' Questions

| | | | | | |
|---|---|---|---|---|---|
| **1.** C | **2.** C | **3.** 81.3% | **4.** B | **5.** 0.71 | **6.** 42 |