BASIC DEFINITIONS AND TERMINOLOGY OF SOILS

Soil is a three phase material which consists of solid particles which make up the soil skeleton and voids which may be full of water if the soil is saturated, may be full of air if the soil is dry, or may be partially saturated as shown in Figure 1.

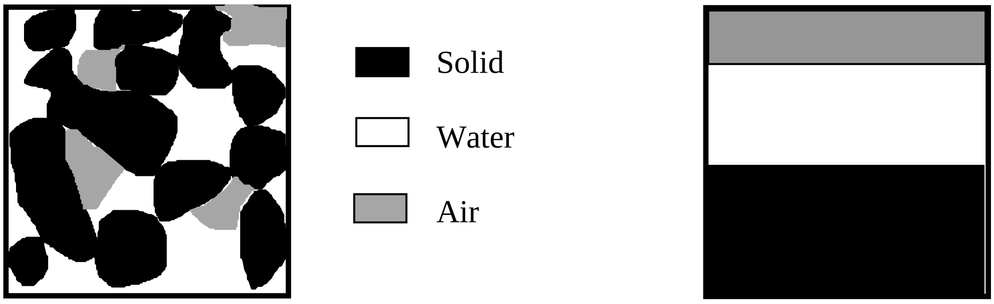

Figure 1: Air, Water and Solid phases in a typical soil

It is useful to consider each phase individually as shown in Table 1.

Phase	**Volume**	**Mass**	**Weight**
Air	V_A	0	0
Water	V_W	M_W	W_W
Solid	V_S	M_S	W_S

Table 1 Distribution by Volume, Mass, and Weight

2.1 Units

For most engineering applications the following units are used:

Length	metres
Mass	tonnes (1 tonne = 10^3 kg)
Density (mass/unit volume)	t/m^3
Weight	kilonewtons (kN)
Stress	kilopascals (kPa) 1 kPa = 1 kN/m^2
Unit Weight	kN/m^3

To sufficient accuracy the density of water ρ_w is given by

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

In most applications it is not the mass that is important, but the force due to the mass, and the weight, W, is related to the mass, M, by the relation

$$W = M g$$

where g is the acceleration due to gravity. If M is measured in tonnes and W in kN, g = 9.8 m/s^2

Because the force is usually required it is often convenient in calculations to use the unit weight, γ (weight per unit volume).

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

$$\gamma = \frac{M\,g}{V}$$

$$= \rho\, g$$

Hence the unit weight of water, γ_w = 9.8 kN/m^3

2.2 Specific Gravity

Another frequently used quantity is the Specific Gravity, G, which is defined by

$$G = \frac{Density\,of\;\;Material}{Density\,of\;\;Water} = \frac{\rho}{\rho_w}$$

$$G = \frac{Unit\,Weight\,of\;\;Material}{Unit\,Weight\,of\;\;Water} = \frac{\gamma}{\gamma_w}$$

It is often found that the specific gravity of the materials making up the soil particles are close to the value for quartz, that is

$$G_s \approx 2.65$$

For all the common soil forming minerals $2.5 < G_s < 2.8$

We can use G_s to calculate the density or unit weight of the solid particles

$$\rho_s = G_s\,\rho_w$$
$$\gamma_s = G_s\,\gamma_w$$

and hence the volume of the solid particles if the mass or weight is known

$$V_s = \frac{M_s}{G_s\,\rho_w} = \frac{W_s}{G_s\,\gamma_w}$$

2.3 Voids Ratio and Porosity

Using volumes is not very convenient in most calculations. An alternative measure that is used is the voids ratio, e. This is defined as the ratio of the volume of voids, V_v to the volume of solids, V_s, that is

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

where $V_v = V_w + V_a$

$V = V_a + V_w + V_s$

A related quantity is the porosity, n, which is defined as ratio of the volume of voids to the total volume.

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

The relation between e and n can be determined by noting that

$$V_s = V - V_v = (1 - n) V$$

Now

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

and hence

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

2.4 Degree of Saturation

The degree of saturation, S, has an important influence on the soil behaviour. It is defined as the ratio of the volume of water to the volume of voids

$$S = \frac{V_w}{V_a + V_w}$$

The distribution of the volume phases may be expressed in terms of e and S, and by knowing the unit weight of water and the specific gravity of the particles the distributions by weight may also be determined as indicated in Table 3.

$$S = \frac{V_w}{V_v} = \frac{V_w}{eV_s}$$

$$V_w = e\, S\, V_s$$

$$V_a = V_v - V_w = e\,V_s\,(1 - S)$$

Phase	Volume	Mass	Weight
Air	e (1 - S)	0	0
Water	e S	$e\,S\,\rho_w$	$e\,S\,\gamma_w$
Solid	1	$G_s\,\rho_w$	$G_s\,\gamma_w$

Table 2 Distribution by Volume, Mass and Weight in Soil

Note that Table 2 assumes a solid volume $V_s = 1\ m^3$, All terms in the table should be multiplied by V_s if this is not the case.

2.5 Unit Weights

Several unit weights are used in Soil Mechanics. These are the bulk, saturated, dry, and submerged unit weights.

The bulk unit weight is simply defined as the weight per unit volume

$$\gamma_{bulk} = \frac{W}{V}$$

When all the voids are filled with water the bulk unit weight is identical to the saturated unit weight, γ_{sat}, and when all the voids are filled with air the bulk unit weight is identical with the dry unit weight, γ_{dry}. From Table 2 it follows that

$$\gamma_{bulk} = \frac{W}{V} = \frac{\gamma_w G_s + \gamma_w e S}{1 + e} = \frac{\gamma_w (G_s + e S)}{1 + e}$$

$$\gamma_{sat} = \frac{\gamma_w (G_s + e)}{1 + e} \qquad S = 1$$

$$\gamma_{dry} = \frac{\gamma_w G_s}{1 + e} \qquad S = 0$$

Note that in discussing soils that are saturated it is common to discuss their dry unit weight. This is done because the dry unit weight is simply related to the voids ratio, it is a way of describing the amount of voids.

The submerged unit weight, γ', is sometimes useful when the soil is saturated, and is given by

$$\gamma' = \gamma_{sat} - \gamma_w$$

2.6 Moisture content

The moisture content, *m*, is a very useful quantity because it is simple to measure. It is defined as the ratio of the weight of water to the weight of solid material

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

If we express the weights in terms of e, S, G_s and γ_w as before we obtain

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

$$W_s = \gamma_s V_s = \gamma_w G_s V_s$$

and hence

$$m = \frac{e S}{G_s}$$

Note that if the soil is saturated (S=1) the voids ratio can be simply determined from the moisture content.

Example – Mass and Volume fractions

A sample of soil is taken using a thin walled sampling tube into a soil deposit. After the soil is extruded from the sampling tube a sample of diameter 50 mm and length 80 mm is cut and is found to have a mass of 290 g. Soil trimmings created during the cutting process are weighed and found to have a mass of 55 g. These trimmings are then oven dried and found to have a mass of 45 g. Determine the phase distributions, void ratio, degree of saturation and relevant unit weights.

<u>1. Distribution by mass and weight</u>

Phase	**Trimmings Mass** (g)	**Sample Mass, M** (g)	**Sample Weight, Mg** (kN)
Total	55	290	2845×10^{-6}
Solid	45	237.3	2327.9×10^{-6}
Water	10	52.7	517×10^{-6}

<u>2. Distribution by Volume</u>

Sample Volume, $V = \pi\,(0.025)^2\,(0.08) = 157.1 \times 10^{-6}\ m^3$

$$Water\,Volume,\ V_w = \frac{W_w}{\gamma_w} = \frac{517 \times 10^{-6}}{9.81} = 52.7 \times 10^{-6}\ m^3$$

$$Solid\,Volume,\ V_s = \frac{W_s}{G_s\,\gamma_w} = \frac{2327.9 \times 10^{-6}}{2.65 \times 9.81} = 89.5 \times 10^{-6}\ m^3$$

Air Volume, $V_a = V - V_s - V_w = 14.9 \times 10^{-6}\ m^3$

3. Moisture content

$$m = \frac{W_w}{W_s} = \frac{10}{45} = \frac{52.7 \times 10^{-6}}{237.3 \times 10^{-6}} = 0.222$$

4. Voids ratio

$$e = \frac{V_v}{V_s} = \frac{14.9 \times 10^{-6} + 52.7 \times 10^{-6}}{89.5 \times 10^{-6}} = 0.755$$

5. Degree of Saturation

$$S = \frac{V_w}{V_v} = \frac{52.7 \times 10^{-6}}{52.7 \times 10^{-6} + 14.9 \times 10^{-6}} = 0.780$$

6. Unit weights

$$\gamma_{bulk} = \frac{W}{V} = \frac{2845 \times 10^{-6}\ kN}{157.1 \times 10^{-6}\ m^3} = 18.1\ kN/m^3$$

$$\gamma_{dry} = \frac{W_s}{V} = \frac{2327.9 \times 10^{-6}}{157.1 \times 10^{-6}} = 14.8\ kN/m^3$$

If the sample were saturated there would need to be an additional 14.9×10^{-6} m^3 of water. This would weigh 146.2×10^{-6} kN and thus the saturated unit weight of the soil would be

$$\gamma_{sat} = \frac{(2845 \times 10^{-6} + 146.2 \times 10^{-6})}{157.1 \times 10^{-6}} = 19.04\ kN/m^3$$

Example – Calculation of Unit Weights

A soil has a voids ratio of 0.7. Calculate the dry and saturated unit weight of the material. Assume that the solid material occupies 1 m^3, then assuming $G_s = 2.65$ the distribution by volume and weight is as follows.

Phase	**Volume** (m^3)	**Dry Weight** (kN)	**Saturated Weight** (kN)
Voids	0.7	0	0.7 × 9.81 = 6.87
Solids	1.0	2.65 × 9.81 = 26.0	26.0

- Dry unit weight $\gamma_{dry} = \frac{26.0\ kN}{1.7\ m^3} = 15.3\ kN/m^3$

- Saturated unit weight $\gamma_{sat} = \frac{(26.0 + 6.87)}{1.7} = 19.3\ kN/m^3$

If the soil were fully saturated the moisture content would be

- Moisture content $m = \frac{6.87}{26.0} = 0.264 = 26.4\%$

Alternatively the unit weights may be calculated from the expressions given earlier which are on p. 5 of the Data Sheets

$$\gamma_{dry} = \frac{G_s \gamma_w}{1 + e}$$

$$\gamma_{sat} = \frac{(G_s + e)\gamma_w}{1 + e}$$

See also pages 4 and 5 of the Data Sheets for most of the definitions and equations given in this section.