

# POSTAL Book Package

# 2023

## CIVIL ENGINEERING

### Soil Mechanics and Foundation Engineering

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## Properties of Soil

**Q1** A certain soil has the following properties:  $G_s = 2.71$ ,  $n = 40\%$  and  $w = 20\%$ . Find the degree of saturation of the soil.

**Solution:**

$$Se = wG$$

and

$$e = \frac{n}{1-n} = 0.67$$

$\Rightarrow$

$$S = \frac{2.71 \times 20}{0.67} = 81.3\%$$

**Q2** A sampler with a volume of  $45 \text{ cm}^3$  is filled with a soil sample. When the soil is poured into a graduated cylinder, it displaces  $25 \text{ cm}^3$  of water. What is the porosity and void ratio of the soil.

**Solution:**

**Given:** Volume of soil sample,  $V = 45 \text{ cm}^3$

When the soil sample is poured into cylinder, it displaces  $25 \text{ cm}^3$  of water.

$\therefore$  Volume of solids,  $V_s = 25 \text{ cm}^3$

**Void ratio,**

$$e = \frac{\text{Volume of voids}}{\text{Volume of solids}}$$

$\Rightarrow$

$$e = \frac{V - V_s}{V_s} = \frac{45 - 25}{25} = 0.8$$

**Porosity,**

$$n = \frac{\text{Volume of voids}}{\text{Volume of soil sample}} \times 100$$

$$= \left( \frac{V - V_s}{V} \right) \times 100$$

$$= \frac{45 - 25}{45} \times 100$$

$$n = 44.44\%$$

**Q3** In order to determine the water content, 370 g of a wet sandy sample was placed in a pycnometer. The mass of the pycnometer, sand and water full to the top of the conical cap was found to be 2148 g. The mass of pycnometer full of clean water was 1932 g. Taking  $G = 2.65$ , determine the water content of the sample

**Solution:**

$$w = \left[ \frac{M_2 - M_1}{M_3 - M_4} \left( \frac{G-1}{G} \right) - 1 \right] \times 100 = \left[ \frac{M}{M_3 - M_4} \frac{G-1}{G} - 1 \right] \times 100$$

where

$M$  = wet mass of soil = 370 g

$M_3$  = 2148 g

$$M_4 = 1932 \text{ g}$$

$$w = \left[ \frac{370}{2148 - 1932} \times \frac{2.65 - 1}{2.65} - 1 \right] \times 100$$

$$= 6.656\% \approx 6.7\%$$

**Q4** The void ratio and specific gravity of a sample of clay are 0.73 and 2.7 respectively. If the voids are 92% saturated, find the bulk density, the dry density and the water content.

What would be the water content for complete saturation, the void ratio remaining the same?

**Solution:**

**Given data:**  $e = 0.73$ ,  $G = 2.7$ ,  $S = 92\%$

We know that

$$Se = wG$$

$$\Rightarrow w = \frac{Se}{G}$$

$$\Rightarrow w = \frac{0.92 \times 0.73}{2.7}$$

$$\Rightarrow w = 0.2487 \text{ or } 24.87\%$$

Now,

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

$$\Rightarrow \gamma = \left[ \frac{2.7 + (0.92 \times 0.73)}{1 + 0.73} \right] \times 9.81$$

$$\Rightarrow \gamma = 19.12 \text{ kN/m}^3$$

But Bulk density,

$$\rho = \frac{\gamma}{g} = \frac{19.12 \times 10^3}{9.81} = 1949.0316 \text{ kg/m}^3$$

Dry density,

$$\rho_d = \frac{\rho}{1 + w} = \frac{1949.0316}{1 + 0.2487} = 1560.85 \text{ kg/m}^3$$

When

$$S = 100\%$$

then

$$Se = Gw$$

$$\Rightarrow w = \frac{Se}{G} = \frac{1 \times 0.73}{2.7}$$

$$\Rightarrow w = 0.2703 \text{ or } 27.03\%$$

**Q5** A solid sample has a porosity of 40%. The specific gravity of solids is 2.7. Calculate the (i) void ratio (ii) dry density (iii) unit weight if the soil is 50% saturated and (iv) unit weight if the solid is completely saturated.

**Solution:**

**Given data:** Porosity of soil sample ( $n$ ) = 40%, Specific gravity of soil solids ( $G_s$ ) = 2.7

Now, as we know

(i)

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

$\therefore$

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

$$= \frac{0.4}{1 - 0.4} = 0.667$$

(ii) Also

$$\gamma_d = \left( \frac{G_s}{1+e} \right) \gamma_w$$

Taking

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

$$\gamma_d = \frac{2.7}{1.667} \times 9.81$$

 $\Rightarrow$ 

$$\gamma_d = 15.889 \text{ kN/m}^3$$

(iii) When soil is 50% saturated

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

where

$$S = 0.5$$

 $\therefore$ 

$$\gamma = \left( \frac{2.7 + 0.5 \times 0.667}{1 + 0.667} \right) \times 9.81 = 17.852 \text{ kN/m}^3$$

(iv) When the soil is completely saturated,  $S = 1$ 

$$\gamma_{\text{sat}} = \left( \frac{2.7 + 1 \times 0.667}{1 + 0.667} \right) \times 9.81 = 19.814 \text{ kN/m}^3$$

**Q6** A soil has a void ratio of 0.70, degree of saturation 50% and  $G_s = 2.7$ . Find the water content, porosity, bulk density and dry density. By how much can the water content be increased without changing  $\gamma_d$ ?

**Solution:**

**Given:** Void ratio ( $e$ ) = 0.70, Degree of saturation ( $S$ ) = 0.50, Specific gravity ( $G_s$ ) = 2.70

(i) We know,

$$Se = wG_s$$

 $\Rightarrow$ 

$$w = \frac{Se}{G_s} = \frac{0.50 \times 0.70}{2.70} = 0.1296$$

 $\therefore$  Water content,

$$w = 12.96\%$$

(ii) Bulk density,

$$\gamma_t = \left( \frac{G_s + Se}{1+e} \right) \gamma_w = \left( \frac{2.70 + 0.50 \times 0.70}{1 + 0.70} \right) \times 9.81 = 17.6 \text{ kN/m}^3$$

(iii) Dry density,

$$\gamma_d = \frac{\gamma_t}{1+w} = \frac{17.6}{1 + 0.1296} = 15.58 \text{ kN/m}^3$$

(iv) Porosity,

$$n = \frac{e}{1+e} = \frac{0.70}{1 + 0.70} = 0.4118 = 41.18\%$$

In order to have  $\gamma_d$  = constant

$$e = \text{constant}$$

We know,

$$Se = wG_s$$

Taking,  $S = 100\%$  [Maximum possible degree of saturation is 100% for  $w_{\text{max}}$ ] $\therefore$ 

$$\frac{100}{100} \times e = w_{\text{max}} \times G_s$$

 $\Rightarrow$ 

$$w_{\text{max}} = \frac{e}{G_s} = \frac{0.70}{2.70} = 0.2593 = 25.93\%$$

 $\therefore$ 

$$\text{Increase in water content} = (25.93 - 12.96)\% = 12.97\%$$

Therefore, water content may be increased by 12.97% without changing  $\gamma_d$  value.

**Q7** The liquid limit of a clay soil is 66% and its plasticity index is 25%.

- In what state of consistency is this clay, if its natural moisture content is 45%?
- The void ratio of the clay on drying to minimum volume is 0.88. What is its shrinkage limit if the specific gravity of clay is 2.71?

**Solution:**

Given:  $w_L = 66\%$ ;  $I_P = 25\%$

①

$$I_P = w_L - w_P$$

$$25 = 66 - w_P$$

$$\therefore w_P (\text{plastic limit}) = (66 - 25)\% = 41\%$$

As moisture content,

$$w = 45\%$$

and

$$w_P < w < w_L$$

$\therefore$  Soil is in **plastic state**

(ii) At shrinkage limit, soil is fully saturated.

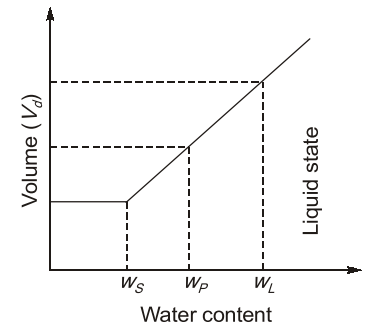
$$\therefore S = 1; e = 0.88; G = 2.71$$

$$S \cdot e = w_s \cdot G$$

$$1 \times 0.88 = w_s \times 2.71$$

$$\therefore w_s = 0.3247$$

$$\Rightarrow \text{shrinkage limit, } w_s = 32.47\%$$



**Q8** A soil sample has wet density of  $20 \text{ kN/m}^3$  and dry density of  $18 \text{ kN/m}^3$ . If the specific gravity of soil is 2.67. Calculate the void ratio, porosity, moisture content and degree of saturation. Assume unit weight of water =  $10 \text{ kN/m}^3$ .

**Solution:**

Given:  $\gamma = 20 \text{ kN/m}^3$ ;  $\gamma_d = 18 \text{ kN/m}^3$ ;  $G = 2.67$ ;  $\gamma_w = 10 \text{ kN/m}^3$

$$\gamma_d = \frac{G \cdot \gamma_w}{1 + e}$$

$$\text{or, } 18 = \frac{2.67 \times 10}{1 + e}$$

$$\Rightarrow e = 0.4833$$

$$\therefore \text{Void ratio, } e = 0.4833$$

Porosity,

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

$$= \frac{0.4833}{1.4833} = 0.3258 = 32.58\%$$

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

$$18 = \frac{20}{1 + w}$$

$$\Rightarrow w = 0.1111$$

$$\therefore \text{Moisture content, } w = 11.11\%$$

we know,

$$Se = wG$$

$$\Rightarrow \text{Degree of saturation, } S = \frac{wG}{e} = \frac{0.1111 \times 2.67}{0.4833} = 0.6138 = 61.38\%$$

- Q9** The moisture content, void ratio and specific gravity of soil solids of a given soil mass are 10.5%, 0.67 and 2.68 respectively. It is required to prepare three triaxial test specimens (dia 3.75 and height 7.5 cm) from this soil mass. Each specimen should have a moisture content of 15% and a dry density of 1.6 g/cc. Determine (i) the quantity of the given soil to be used for this purpose and (ii) the quantity of water to be mixed with it.

**Solution:**

Given: Specimen no. = 3;  $d = 3.75$  cm;  $h = 7.5$  cm;  $w = 15\%$ ;  $\rho_d = 1.6$  g/cc

Total volume of specimens = 3  $\times$  vol. of 1 specimen

$$V = 3 \times \frac{\pi}{4} \times d^2 \times h = 3 \times \frac{\pi}{4} \times 3.75^2 \times 7.5$$

$$= 248.505 \text{ cm}^3$$

Volume of solids,

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

$$\rho_d = \frac{G \cdot \rho_w}{1+e}$$

$$\Rightarrow 1.6 = \frac{2.68 \times 1}{1+e}$$

$$\therefore e = 0.675$$

$$V_s = \frac{248.505}{1+0.675} = 148.3612 \text{ cm}^3$$

Soil mass:  $w = 10.5\%$ ,  $e = 0.67$ ;  $G = 2.68$

(i) Let 'V' volume of soil mass is required,

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

$$148.3612 = \frac{V}{1+0.67}$$

$$\Rightarrow V = 247.7632 \text{ cm}^3$$

Now,

$$S.e. = w \cdot G$$

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

$\Rightarrow$

$$\rho = \left( \frac{G + w \cdot G}{1+e} \right) \rho_w$$

$$= \frac{2.68 + 0.105 \times 2.68}{1.67} \times 1$$

$$\frac{W}{V} = \rho = 1.7733$$

$\therefore$  Quantity Required,

$$W = (247.7632 \times 1.7733) \text{ gm}$$

$$= 439.3585 \text{ gm}$$

$$\begin{aligned}
 \text{(ii) Quantity of water to be mixed} &= 0.15 \times W_s - 0.105 W_s \\
 W_w &= 0.045 \times W_s = 0.045 \times (G \cdot \rho_w \times V_s) \\
 &= 0.045 \times 2.68 \times 1 \times 148.3612 \\
 &= 17.8924 \text{ gm}
 \end{aligned}$$

**Q.10** A core-cutter 12.6 cm in height and 10.2 cm in diameter weighs 1071 gm when empty. It is used to determine the in-situ unit weight of an embankment. The weight of core-cutter full of soil is 2970 gm. If the water content is 6% what are the in-situ dry unit weight and porosity? If the embankment gets fully saturated due to heavy rains what will be the increase in water content and bulk unit weight, if no volume change occurs? The specific gravity of the soil solids is 2.69.

**Solution:**

$$\begin{aligned}
 \text{Given: Mass of empty core cutter} &= 1071 \text{ gm} \\
 \text{Mass of core cutter + Mass of soil} &= 2970 \text{ gm} \\
 \text{Mass of soil} &= (2970 - 1071) \text{ gm} \\
 M &= 1899 \text{ gm} \\
 \text{Volume of core cutter} &= \text{Volume of soil sample}
 \end{aligned}$$

$$\begin{aligned}
 V &= \frac{\pi}{4} \times (10.2)^2 \times 12.6 \text{ cc} \\
 &= 1029.58 \text{ cc}
 \end{aligned}$$

$$\text{in-situ density, } \rho = \frac{M}{V} = \frac{1899}{1029.58} = 1.844 \text{ gm/cc}$$

$$\text{in-situ dry density, } \rho_d = \frac{\rho}{1+w} = \frac{1.84}{1+0.06} = 1.74 \text{ gm/cc}$$

$$\therefore \text{ in-situ dry unit weight, } \gamma_d = \rho_d \cdot g = 17.97 \text{ kN/m}^3$$

$$\rho_d = \left( \frac{G}{1+e} \right) \rho_w$$

$$1.73 = \left( \frac{2.69}{1+e} \right) \times 1$$

$$\Rightarrow e = 0.55$$

$$\text{Porosity, } n = \frac{e}{1+e} = \frac{0.55}{1.55} = 0.3548 = 35.48\%$$

If embankment gets fully saturated and no volume change takes place, then 'e' remains same.

$$S \cdot e = w' \cdot G$$

$$\text{or, } 1 \times e = w' \cdot G$$

$$\text{or, } w' = \frac{0.55}{2.69} = 0.2045 = 20.45\%$$

$$\text{increase in water content} = w' - w = (20.45 - 6)\% = 14.45\%$$

Now bulk density = Saturated density

$$\rho_{\text{sat}} = \left( \frac{G+e}{1+e} \right) \rho_w = \frac{2.69+0.55}{1.55} \times 1 = 2.09 \text{ gm/cc}$$

bulk unit weight = saturated unit weight

$$= \gamma_{\text{sat}}$$

$$= \rho_{\text{sat}} \times g = 2.09 \times \frac{10^{-3}}{10^{-6}} \times 9.81 \times 10^{-3} \text{ kN/m}^3 = 20.5029 \text{ kN/m}^3$$