CHAPTER 1

Properties of Soil

Question 1.1: The total unit weight of the glacial outwash soil is 16 kN/m^3. The specific gravity of soil particles of the soil is 2.67. The water content of the soil is 17%. Calculate

(a) Dry unit weight

(b) Porosity

(c) Void ratio

(d) Degree of saturation

Solution: Total unit weight γ = 16 kN/m^3

Specific gravity G = 2.67

Water content w =17%

Dry unit weight $\gamma_d = \gamma/(1+w) = 16/(1+0.17) = 13.675$ kN/m^3

Void ratio $e = (G\gamma_w/\gamma_d) - 1 = (2.67 \times 9.81/13.675) - 1 = 0.9153$

Porosity $n = e/(1+e) = 0.9153/(1+0.9153) = 47.79\%$

Degree of saturation $S = wG/e = 0.17 \times 2.67/.9153 = 49.59\%$

Question 1.2: The porosity (n) and the degree of saturation (S) of a soil sample are 0.7 and 40%, respectively. Determine the volume (in m^3) of air in 100 m^3 volume of the soil.

Solution: Porosity = $n = V_v/V = 0.7$

Volume of voids $V_v = 0.7 \times 100 = 70$ m^3

V_w/V_v = degree of saturation S = 0.4

Volume of water $V_w = 70 \times 0.4 = 28$ m^3

Volume of air $V_a = V_v - V_w = 70 - 28 = 42$ m^3

Volume of air = 42 m^3

Question 1.3: A soil sample has specific gravity of 2.60 and void ratio of 0.78. Determine the water content in percentage required to fully saturate the soil at that void ratio.

Solution: Degree of saturation S = 100%

Water content $w = Se/G$

$= 100 \times 0.78/2.60$

$= 30\%$

Question 1.4: A soil has mass unit weight γ, water content w (expressed as ratio). The specific gravity of soil solids G, unit weight of water = γ_w, then show that the degree of saturation of soil S is given by: $S = w/ [(\gamma_w/\gamma)(1+w) - 1/G]$

Solution: $\gamma = G(1+w)\gamma_w /(1+e)$

$1+e = G(1+w)\gamma_w/\gamma$

and $Gw = Se$

$Gw/S = [G(1+w)\gamma_w/\gamma] - 1$

Dividing both sides by G, we get

$w/S = [(1+w)\gamma_w/\gamma] - 1/G$

$S = w/ [(\gamma_w/\gamma)(1+w) - 1/G]$

Question 1.5: A sample of saturated sand has a dry unit weight 18 kN/m^3 and a specific gravity of 2.7. If the unit weight of water is 10 kN/m^3, determine the void ratio of soil sample.

Solution: Dry unit weight $\gamma_d = G\gamma_w/(1+e)$

Void ratio $e = (G\gamma_w/ \gamma_d) - 1$

$= 2.7 \times 10/18$

$= 0.5$

Question 1.6: The natural void ratio of sand sample is 0.6 and its density index is 0.6. If the void ratio in the loosest state is 0.9, then determine the void ratio in its densest state.

Solution: Density index $= (e_{max} - e)/(e_{max} - e_{min}) = 0.6$

Void ratio in loosest state,

$e_{max} = 0.9$

Void ratio in natural state,

$e = 0.6$

$0.9 - e_{min} = (0.9 - 0.6)/ 0.6$

$e_{min} = 0.9 - 0.5$

$= 0.4$

Question 1.7: What will be the relative density of saturated sand deposit having moisture content of 25%, maximum and minimum void ratio 0.95 and 0.45 respectively and specific gravity of particles 2.6?

Solution: At saturated moisture content void ratio is

$$e = Gs/S$$

$$= 2.6 \times 25/100 = 0.65$$

Relative density

$$D_r = (e_{max} - e) / (e_{max} - e_{min})$$

$$= (0.95 - 0.65)/(0.95 - 0.45) = 0.6$$

$$D_r = 60\%.$$

Question 1.8: 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 the mass density of water as 1000 kg/m^3 and G_s as 2.7;determine the relative density (in %) of the soil.

Solution: Given, soil with the field properties

Bulk density (ρ) = 1800 kg/m^3

Water content, w = 8% = 0.08

So dry density $\rho_d = \rho/(1+w) = 1800/(1+0.08)$

$$= 1666.67 \text{ kg/m}^3$$

So void ratio 'e' at the field condition can be determined by relation

$$\rho_d = G\rho_w/(1+e) \Rightarrow e = \{G\rho_w/(\rho_d)\} - 1$$

$$= \{(2.7 \times 1000)/(1666.67)\} - 1$$

$$e = 0.62$$

So $e_{max} = 0.85$, $e_{min} = 0.50$

Relative density $I_d = \{(e_{max} - e)/(e_{max} - e_{min})\} \times 100$

$$= \{(0.85-0.62)/(0.85-0.50)\} \times 100$$

$$I_d = 65.71\%$$

Question 1.9: What are the respective values of void ratio, porosity ratio and saturated unit weight (in kN/m^3) for a soil sample which has saturation moisture content of 20% and specific of grains 2.6. Take unit weight of water 10kN/m^3.

Solution:

Given, water content w = 20%,

Specific gravity G = 2.6,

Degree of saturation S = 100%

Void ratio $e = wG/S = (20\times2.6)/100 = 0.52$

Porosity $n = e/(1+e) = 0.34$

Saturated unit weight $\gamma_{sat} = [(G + e)/ (1 + e)]\ \gamma_w$

$= [(2.6 + 0.52)/(1 + 0.52)] \times10$

$= 20.53\ \text{kN/m}^3$

If unit weight of water is taken as 9.81 kN/m^3

Then $\gamma_{sat} = [(2.6 + 0.52)/(1 + 0.52)] \times9.81$

$= 20.14\ \text{kN/m}^3$

Question 1.10: What is the dry unit weight of clay soil when the void ratio of sample thereof is 0.50, the degree of saturation is 70% and specific gravity of soil grains is 2.7? Take the value of γ_w to be 9.81 kN/m^3.

Solution: Bulk unit weight

$\gamma_b = (G + Se)\ \gamma_w/ (1+ e)$

$= [(2.7 + 0.7 \times0.5) \times9.81]/(1+ 0.5)\ \text{kN/m}^3$

$= 19.947\ \text{kN/m}^3$

$Se = wG$

Water content $w = Se/G$

$w = 0.7 \times 0.5/2.7 = 0.1296 = 12.96\%$

Dry density $\gamma_d = \gamma_b/ (1 + w) = 19.947/ (1 + 0.1296)$

$= 17.658\ \text{kN/m}^3$.

Question 1.11: An earth embankment is to be constructed with compacted cohesionless soil. The volume of the embankment is 5000 m^3 and the target dry unit weight is 16.2 kN/m^3. Three nearly sites (see figure below) have been identified from where the required soil can be transported to the constructed site. The void ratios (e) of different sites are shown in the figure below. Assume the specific gravity of soil to be 2.7 for all three sites. If the cost of transportation per km is twice the cost of excavation per m^3 of borrow pits, which site would you choose as the most economical solution? Take unit weight of water = 10 kN/m^3.

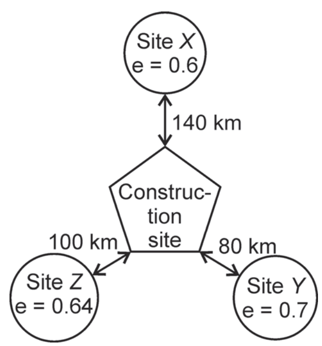

Figure 1.1

Solution:

Volume of solids at embankment,

Volume of solids $V_s = W_s / G_s\gamma_\omega$

$$V_s = \frac{(16.2 \times 5000)}{(2.7 \times 10)} m^3$$

$$V_s = 3000 \text{ m}^3$$

Volume of solids will remain constant

Also, total volume $V = V_v + V_s = eV_s + V_s$

$= V_s(1 + e)$

$V = 3000(1 + e)$

For site X; $V_x = 3000 \times 1.6 = 4800 \text{ m}^3$

For site Y; $V_y = 3000 \times 1.7 = 5100 \text{ m}^3$

For site Z; $V_z = 3000 \times 1.64 = 4920 \text{ m}^3$

Let cost of excavation be α/m^3,

$P_x = 4800\ \alpha + 140 \times \alpha \times 2$

$= 5080\ \alpha$

$P_y = 5100\ \alpha + 80 \times \alpha \times 2$

$= 5260\ \alpha$

$P_z = 4920\ \alpha + 100 \times \alpha \times 2$

$= 5120\ \alpha$

Here P_x is least.

Therefore, total cost for site X is the least.

Question 1.12: A fine-grained soil has 60% (by weight) silt content. The soil behaves as semi-solid when water content is between 15% and 28%. The soil behaves fluid-like when the water content is more than 40%. Determine the activity of the soil.

Solution: Using index properties of soil

Shrinkage limit $w_s = 15\%$

Plastic limit $w_p = 28\%$

Liquid limit $w_l = 40\%$

Plasticity index $I_p = W_l - W_p = 12\%$

Activity of soil, $A = I_p/c = 12/(100\text{-}60)$

$= 0.3.$

Question 1.13: A soil sample has shrinkage limit of 6% and the specific gravity of soil grains is 2.6. Determine the porosity of soil at shrinkage limit.

Solution: Shrinkage limit $w_s = 6\%$;

Specific gravity G = 2.6

At shrinkage limit, soil is fully saturated, hence S = 1

$$Se = wG$$

$$1 \times e = 0.06 \times 2.6$$

Void ratio e = 0.156

Porosity $n = e/(1 + e) = 0.156/(1 + 0.156)$

$= 0.1349$

$= 13.49\%$

Question 1.14: The plastic limit and liquid limit of soil are 30% and 42% respectively. The percentage volume change from liquid limit to dry state is 35% of dry volume. Similarly, the percentage volume change from plastic limit to dry state is 22% of the dry volume. Determine the shrinkage ratio.

Solution: Given data:

Plastic limit $w_p = 30\%$

Liquid limit $w_l = 42\%$

$$V_l - V_d = 0.35V_d$$

$$V_p - V_d = 0.22V_d$$

$$V_l = 1.35V_d$$

$$V_p = 1.22V_d$$

$$SR = [(V_1 - V_2)/V_d]/(w_1 - w_2) \times 100$$

$$= [(V_l - V_p)/V_d]/(w_l - w_p) \times 100$$

$$= [(1.35V_d - 1.22V_d)/V_d]/(42 - 30)$$

$$SR = (0.13/12) \times 100 = 1.083 \approx 1.1$$

Question 1.15: A sample of saturated soil has a water content of 40%. The specific gravity G of soil particles is 2.7. Determine

1. void ratio
2. porosity
3. saturated and dry unit weights.

Solution: Given data:

Water content w = 40% = 0.40,

Specific gravity G = 2.7

Void ratio, e

$$e = w_{sat}\, G$$
$$= 0.40 \times 2.7 = 1.08$$

Porosity, n

$$n = e/(1 + e)$$
$$= 1.081 / 2.081 = 0.519$$

Dry unit weight,

$$\gamma_d = (1 - n)\, G\, \gamma_w$$
$$= (1 - 0.519) \times 2.7 \times 9.81$$
$$= 12.74 \text{ kN/m}^3$$

Saturated unit weight, $\gamma_{sat} = \gamma_d + n\, \gamma_w$

$$= 12.74 + 9.81 \times 0.519 = 17.831 \text{ kN/m}^3.$$

Question 1.16: A certain sample of saturated soil with watch glass weighs 65.42g. On oven drying, the sample with watch glass is 60.85 g. The weight of watch glass is 35.45 g. The specific gravity of solid is 2.8. Determine

1. void ratio
2. water contents
3. porosity
4. unit weights

Solution: Given data:

Mass of wet soil, M = 65.42 – 35.45 = 29.97 g

Mass of dry soil, M_d = 60.85 – 35.45 = 25.40 g

Specific gravity, G = 2.8

Water content w $= [(M/M_d) - 1] \times 100\%$

$$= [(29.97/25.40) - 1] \times 100\%$$
$$= 17.99\%$$

Void ratio, $e = w_{sat}\, G$

$$= 0.1799 \times 2.8$$
$$= 0.504$$

Porosity, $n = e/(1 + e)$

$$= 0.504/1.504$$
$$= 0.335$$

Bulk unit weight, $\gamma = \gamma_w(G + Se)/(1 + e)$

$= 9.81\times (2.8+0.504\times1)/(1 +0.504)$

$= 21.551$ kN/m^3.

Dry unit weight, $\gamma_d = G\gamma_w(1 - n)$

$= 9.81\times2.8 (1 - 0.335) = 18.266$ kN/m^3.

Unit weight of solids, $\gamma_s = G\gamma_w$

$= 9.81\times2.8= 27.468$ kN/m^3.

Saturated unit weight, $\gamma_{sat} = \gamma_d + n\gamma_w$

$= 18.266+9.81\times0.335= 21.552$ kN/m^3.

Submerged unit weight, $\gamma' = \gamma_{sat} - \gamma_d$

$= 21.552- 9.81= 11.742$ kN/m^3.

Questions

Question 1: Soil is to be excavated from a borrow pit which has density of 1.75 g/cm^3 and water content of 12%. The specific gravity of soil particles is 2.7. The soil is compacted so that water content is 18% and dry density is 1.65 g/cm^3. For 1000 m^3 of soil in fill, estimate:

1. Quantity of soil to be excavated from the pit in m^3.
2. Amount of water to be added.
3. Void ratio of soil in borrow pit and fill.

(ESE: 1995)

Question 2: The values of liquid limit, plastic limit and shrinkage limit of a soil were reported as $w_l = 60\%$, $w_p = 30\%$, $w_s = 20\%$. If a sample of this soil at liquid limit has a volume of 40 cm^3 and its volume measured at shrinkage limit was 23.5 cm^3, determine the specific gravity of solids. What is the shrinkage ratio and volumetric shrinkage?

(ESE: 1996)

Question 3: 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 water content. What would be the water content for complete saturation, the void ratio remaining the same?

(ESE: 1999)

Question 4: A sample of sand above water table was found to have a natural moisture content of 15% and a unit weight 18.84 kN/m^3. Laboratory tests on a drained sample indicated values of 0.5 and 0.85 for minimum and maximum void ratio respectively for the densest and the loosest states. Determine the degree of saturation and relative density. Assume G = 2.65.

(ESE: 2000)

Question 5: A solid sample has a porosity of 40%. The specific gravity of solid is 2.7. Calculate the (a) void ratio (b) dry density (c) unit weight if soil is 50% saturated and (d) unit weight if the solid is completely saturated.

(ESE: 2012)

Question 6: An oven-dry soil sample of volume 225 cm^3 weighs 390 g. If the specific gravity of soil is 2.72, determine the void ratio and shrinkage limit. What will be the water content which will fully saturate the sample and cause an increase in volume equal to 8% of the original dry volume?

(ESE: 2011)

Question 7: A solid sample has a porosity of 40%. The specific gravity of solid is 2.7. Calculate (a) void ratio (b) dry density (c) unit weight if the soil is 50% saturated and (d) unit weight if the solid is completely saturated.

(ESE: 2012)

Question 8: The mass of saturated soil sample is 150 g and its mass when oven dried is 90 g; find the water content. Suppose that the sample used in triaxial test has a diameter 38 mm and height 76 mm, determine the void ratio. (ESE: 2013)

Question 9: A soil deposit has a void ratio of 0.9. Its void ratio is reduced to 0.6 by compaction. Determine the percentage reduction of volume due to the compaction.

(ESE: 2014)

Question 10: A sampler with a volume of 45 cm^3 is filled with a soil sample. When the soil is poured into a graduated cylinder, it displaces 25 cm^3 of water. What is the porosity and void ratio of the soil?

(ESE: 1998)

Question 11: 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, determine the saturated unit weight and the void ratio of the soil.

Question 12: Soil has been compacted is an embankment at 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.

Question 13: A soil has a void ratio of 0·70, degree of saturation 50% and Gs = 2·7. Find the water content, porosity, bulk density and dry density. By how much can the water content be increased without changing the volume.

Question 14: A proposed earthen dam will have a volume of 5000000 m^3 of compacted soil. The soil is to be taken from a borrow pit and will be compacted to a void ratio of 0·8. The void ratio of soil in the borrow pit is 1·15. Estimate the volume of soil that must be excavated from the borrow pit for the construction of the above dam.

Question 15: A soil deposit has a void ratio of 0·9. Its void ratio is reduced to 0·6 by compaction. Determine the percentage reduction of volume by this compaction.

Question 16: The mass of the saturated soil sample is 150 gm and its mass when oven dried is 90 gm, find the water content. Suppose that the sample, used for triaxial test, has a diameter of 38 mm and the height of 76 mm, find the void ratio.