CE 2251 – SOIL MECHANICS

UNIT = I

[Father of soil mechanics] → Karl von Terzaghi (1925)

Soil – Solum – Latin word

The loose material on the earth's crust consisting of disintegrated rock with an admixture of organic matter, which supports plant life.

Soil mechanics: –

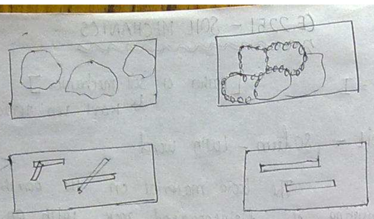
Soil mechanics is the study of engineering behaviour of soil when it is used either as a construction material (or) as a foundation material.

Field of application of soil mechanics:

1. Foundations
2. Underground and Earth retaining structures.
3. Pavement design
4. Excavations, embankments and dams.
5. Formation of soil base material.

Structure of soils: -

1. Single grained structure
2. Honey comb structure
3. Flocculent structure.



card house structure
of Flaky practises

major soil deposits of india;

1. Black cotton soils –
maharashtra, Gujarat, madhya pradesh Karnataka.
There are expansive in nature.
high swelling and shrinkage and potential – very difficult to deal the foundation design.

2. Marine soils:
occuring in a narrow bolt all along the coast, very soft.

3. Desert soils – uniformly graded.

4. Alluvial soils –

Laterite – deep brown – by air
load – sand, silt, clay
Bentonite – decomposed volcanic ash.

Basic Terminology:.

The basic terminology in soil mechanics.

V_a = Volume of air
V_w = Volume of water
V_v = Volume of voids
V_s = Volume of solids
V = Total volume of Soil mass

W_a = weight of air
W_w = weight of water
W_v = weight of materials occupying voids
W_s = weight of solids
W = Total weight of solid mass

$$W_v = W_s$$

In soil Phase diagrame, The volume phases are represented on the left side and the weight phases are represented on the right side,

Porosity:-

The porosity of a soil mass is the ratio of the volume ~~mass~~ of voids to the total volume of the soil mass, It is denoted by (n).

$$n = \frac{V_v}{V} \times 100$$

$$V_v = V_a + V_w$$

So; Total volume $\Rightarrow V = V_a + V_w + V_s$

voids ratio;

The ratio of the volume of voids to the volume of solids in the soil mass. (e)

$$e = V_v / V_s$$

$$V_v = V_a + V_w$$

degree of saturation;

Degree of saturation of a soil mass is defined as the ratio of the volume of water in the voids to the volume of voids. (S)

$$S = \frac{V_w}{V_v} \times 100$$

For a fully saturated soil mass; $V_w = V_v$

Saturated soil mass $S = 100\%$.

For dry sample; $V_w = 0$

$$S = 0$$

percent air voids;

percent air voids of soil mass is defined as the ratio of the volume of air voids to the total volume of the soil mass (n_a) in %.

$$n_a = \frac{V_a}{V} \times 100.$$

air content;

The ratio of the volume of air voids to the total volume of voids (a_c)

$$a_c = \frac{V_a}{V_v} \times 100$$

water content; (or) moisture content;

It is defined as the ratio of the weight of water to the weight of solids (in dry wt) of the soil mass. (w)

$$w = \frac{W_w}{W_s \text{ (or) } W_d} \times 100$$

$$w = \frac{(W - W_d)}{W_d} \times 100$$

Bulk unit weight;

(or) mass unit weight of a soil mass is defined as weight per unit volume of the soil mass. (γ)

$$\gamma = W/V$$

$W = W_w + W_s$ $\qquad$ $V = V_a + V_w + V_s$

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unit weight of solids;

weight of soil solids per unit volume of solids alone. (γ_s)

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

unit weight of water;

weight per unit volume of water.

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

The value of unit weight of water (γ_0)

$$\gamma_0 = 1000\ Kg/m^3 \ (or)\ 9.81\ KN/m^3$$

Submerged unit weight;

The submerged unit weight of a soil is unit weight in the submerged condition.

$(W_s)_{sub}$ per unit of total volume

$$\gamma' = \frac{(W_s)_{sub}}{V}$$

$$(W_s)_{sub} = W_s - (V_s \cdot \gamma_w)$$

$$(W_s)_{sub} = W - W_w - V_s \cdot \gamma_w$$

$$= W - V_w \cdot \gamma_w - V_s \cdot \gamma_w$$

$$= W - \gamma_w (V_w + V_s)$$

$$(W_s)_{sub} = W - V \cdot \gamma_w$$

Dividing by (V)

$$\frac{(W_s)_{sub}}{V} = \frac{W}{V} - \gamma_w$$

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

Dry unit weight;

ratio of weight of soil solids per unit of total volume

$$\gamma_d = \frac{W_s \ (or)\ W_d}{V}$$

mass Specific Gravity; (or) bulk unit weight;

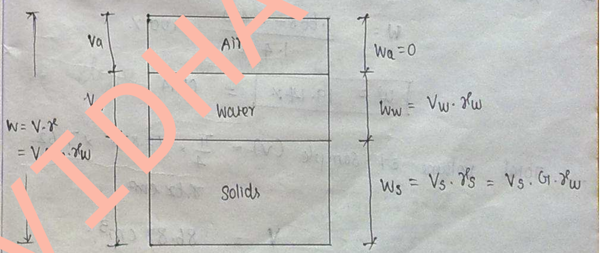
ratio of mass (or) bulk unit weight of soil to the unit weight of water (G_m)

$$G_m = \gamma / \gamma_0$$

Specific gravity of water;

ratio of unit weight of water to the unit weight of water

$$G_w = \gamma_w / \gamma_0$$



(2) determine the (i) water content (ii) dry density (iii) Bulk density (iv) voids ratio (v) degree of saturation from the following data:

Sample size = 3.81 cm dia × 7.62 Height.

wet weight = 1.668 N

oven - dry weight = 1.400 N

$G = 2.7$

Solu:

Wet weight (W) = 1.668 N.

Oven-dry weight (Wd) = 1.400 N.

⇒ water content (w)

$$w = \frac{1.668 - 1.400}{1.400} \times 100\,\%$$

$$\boxed{w = 19.14\%} = 0.1914$$

Total volume of sample $(V) = \frac{\pi}{4} \times (3.81)^2 \times 7.62$

$$V = 86.87\ cm^3.$$

Bulk unit weight; $\gamma = W/V$

$$\gamma = \frac{1.668}{86.87}$$

$$= 0.0192\ N/cm^3$$

$$\boxed{\gamma = 18.84\ kN/m^3.}$$

⇒ Dry density $(\gamma_d) = \frac{\gamma}{1+w}$

$$= \frac{18.84}{1 + 0.1914}$$

$$\boxed{\gamma_d = 15.81\ kN/m^3.}$$

⇒ Specific gravity of solids $G = 2.70$

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

$$15.81 = \frac{2.70 \times 9.81}{1+e}$$

$$\boxed{e = 0.675}$$

⇒ degree of saturation, (s)

$$S.e = w.G$$

$$S = \frac{w.G}{e} \times 100$$

$$= \frac{0.1914 \times 2.70}{0.675} \times 100$$

$$\boxed{S = 76.56\,\%}$$

(13)

③ A soil has bulk density of 20.1 KN/m³ and water content of 15%. calculate the water content if the soil partially dries to a density of 19.4 KN/m³ and voids ratio remains unchanged.

Bulk density = $\gamma = 20.1$ KN/m³.

$w = 15\%$

Dry density $(\gamma_d) = \frac{\gamma}{1+w}$

$= \frac{20.1}{1+0.15}$

$\gamma_d = 17.5$ KN/m³

If the voids ratio remains unchanged while drying takes place, the dry unit weight also remains unchanged since "G" and γ_w do not changed.

$\gamma = 19.4$ KN/m³.

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

(14)

$\therefore \gamma = \gamma_d (1+w)$

$1+w = \frac{19.4}{17.5}$

$w = 0.1086$

hence the water content after partial drying = 10.86%

④ porosity of a soil sample is 35% and the specific gravity of its particles is 2.7. calculate is voids ratio, dry density, saturated density and submerged density.

porosity $(n) = 35\%$ $\gamma_w = 9.81$ KN/m³

voids ratio $(e) = \frac{n}{1-n}$

$= \frac{0.35}{1-0.35}$

$e = 0.54$

dry density (γ_d)

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

$= \frac{2.7 \times 9.81}{1.54}$

$\gamma_d = 17.20$ KN/m³

(15)

Saturated unit weight (γ_{sat})

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

$$= \frac{2.7 + 0.54}{1 + 0.54} \times 9.81$$

$$\boxed{\gamma_{sat} = 20.64 \ kN/m^3}$$

Submerged unit weight ;

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

$$= 20.64 - 9.81$$

$$\boxed{\gamma' = 10.83 \ kN/m^3}$$

(5) A dry soil has a voids ratio of 0.65 and its grain specific gravity is = 2.80 what is it's unit weight.

i) weight is added to the sample so that its degree of saturation is 60 % without any change in voids ratio. determine the water content and unit weight.

(ii) The sample is next placed below water determine the true unit weight

i) if the degree of saturation is 95 and 100 % respectively.

(i) Dry soil,

voids ratio = $e = 0.65$

Grain ; $G = 2.80$

unit weight $\gamma_d = \dfrac{G \cdot \gamma_w}{1+e}$

$= \dfrac{2.8 \times 9.81}{1 + 0.65}$

$\boxed{\gamma_d = [illegible] \ kN/m^3}$

(ii) partial saturation of the soil;

degree of saturation = $S = 60\%$.

$e = 0.65$ (voids ratio unchang

water content ; $w = \dfrac{S \cdot e}{G}$

$= \dfrac{0.60 \times 0.65}{2.80}$

$w = 13.33\%$.

unit weight =>

$\gamma_{sat} = \dfrac{G + S \cdot e}{1+e} \cdot \gamma_w$

$$\gamma_{sat} = \frac{2.80 + 0.65 \times 0.65}{1.65} \times 9.81$$

$$= 18.97 \ KN/m^3.$$

(iii) Sample below water;

high degree of saturation;

$S = 95\%$.

unit weight;

$$\gamma_{sat} = \frac{G + Se}{1+e} \cdot \gamma_w$$

$$= \frac{2.80 + 0.95 \times 0.65}{1.65} \times 9.81$$

$$\gamma_{sat} = 20.32 \ KN/m^3.$$

(iv) Full saturation;

$S = 100\%$.

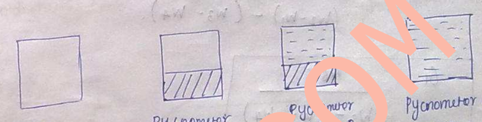
$S = 1$

$$\gamma_{sat} = 20.51 \ KN/m^3.$$

Specific gravity of soil solids.

Specific gravity of the soil solids in the determination of voids ratio, degree of saturation, critical hydraulic gradient, zero air voids in compaction.

Also it is useful in computing the weight of the soil under different conditions and also in the determination of particle size by wet analysis.



(a) empty pycnometer. W_1 — Pycnometer + Dry soil W_2 — Pycnometer + soil + water — Pycnometer + water. W_4

From the readings,

weight of the solids $W_s = W_2 - W_1$

weight of water $W_w = W_3 - W_2$

weight of distilled water $W_{d.w} = W_4 - W_1$

⇒ weight of water having the same volume as that of soil solids $= (W_4 - W_1) - (W_3 - W_2)$

by Archimedes principle (G).

$$G = \frac{\text{weight of soil solids}}{\text{weight of water of volume equal to that of solids}}$$

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

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

$$\boxed{G = \frac{W_s}{W_s - (W_3 - W_4)}}$$

W_s = dry weight of the soil solids

Density index;

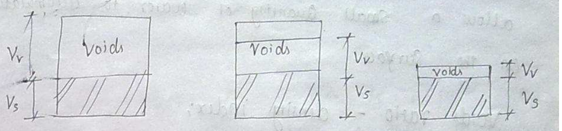
(or) relative density:

→ Indicates the relative compactness of the soil mass.

→ deals with the soil voids ratio.

→ In dense condition, the voids ratio is low and loose condition the voids ratio is high.

It is a comparative study of soil mass in the condition of loose and dense stage.



loosest stage voids ratio = e_{max} | Intermediate stage : e_0 | Densest condition voids ratio : e_{min}

$$I_D = \frac{e_{max} - e_0}{e_{max} - e_{min}}$$

Specified by IS 2720 (part 14) – 1983

→ more efficient packing only achived by vibratory forces.

Method of computing density index

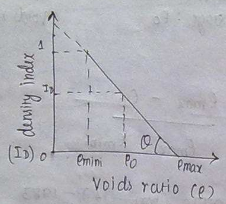
→ In dry method

mould with sample is placed on a vibratory table and vibrated for 8 min. at a frequency of 60 vibrations / seconds.

In wet method;

The mould filled with wet sample and sufficient quantity of water added to allow a small quantity of water to accumulate on the surface.

Voids ratio - density index;

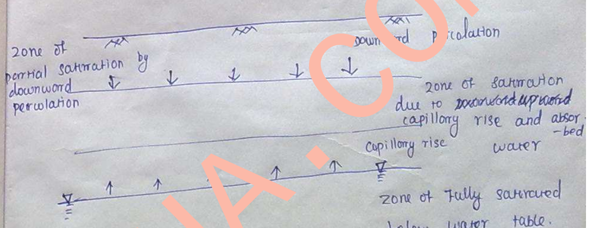


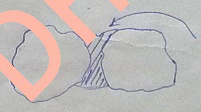
$$e_{max} = \frac{V_v \text{ max. condition}}{V_s \text{ mini. condition}}$$

Capillary rise in soil

The rise of waters in soils above the ground water table is analoge to the rise of water into capillary tubes placed in a source of water.

The voids spaces is a soils are irregular in shape and size, as they interconnect in all direction.





The large voids ratio represent interference to an upward capillary flow and would not be filled.

particle size distribution;

i) seive analysis, for the coarse fraction

ii) sedimentation analysis (or) wet analysis for the fine fraction.

Nomenclature of grain sizes;

Gravel - 80mm to 4.75mm

Sand - 4.75 to 0.075 mm

Silt = 0.075 mm to 0.002

Clay - less then 0.002 mm.

By sieve analysis;

set of sieves for coarse grained soils

IS 100 mm; 63mm; 20 mm; 10mm; 4.75;

set of sieves for fine grained soil

2mm; 1 mm; 600 μ; 425 μ; 300 μ; 212 μ

For fine grain soil = take about 1 kg.

For coarse grain soil = take about 3kg.

wet analysis;-

The soil partides less than 75 μ.

Terminal velocity of sphere falling through an infinite ligwd medium.

$$V = (1/18) \cdot [(\gamma_s - \gamma_L)/\mu_L] \cdot D^2$$

γ_s = unit weight of the material g/cm³.

γ_L = unit weight of the liquid g/cm³.

μ_L = viscosity of liquid g/sec/cm².

D = diameter of the spherical particle in cm.

$$V = \frac{1}{180} \cdot \frac{\gamma_m}{\mu_w} (G-1) D^2$$

If the particle falls through "H" cm in "t" min

$$D = \sqrt{\frac{180 \mu_w \cdot H}{\gamma_w (G-1) \cdot 60t}}$$

$$K = \sqrt{\frac{3\mu_w}{\gamma_w (G-1)}}$$

Consistency limits:

Liquid limits (LL)

Liquid limit is defined as the arbitrary limit of water content at which the soil is just about to pass from the plastic state into the liquid state.

Plastic limits; (PL)

Plastic limit is defined as the arbitrary limit of water content at which the soil tends to pass from the plastic state to the semi solid state of consistency.

Shrinkage limit; (SL)

Shrinkage limit is the arbitrary limit of water content at which the soil tends to pass from the semi-solid to the solid state.

Plasticity index; (PI)

Plasticity index is the range of water content within which the soil exibits plastic properties, That is diff. between L_L and P_L.

$$PI \text{ (or) } I_P = L_L - P_L =$$

Shrinkage index; (SI) (or) I_S

Shrinkage index (SI) is defined as the difference between the plastic limit and shrinkage limits of a soil

$$SI \text{ (or) } I_S = P_L - S_L$$

Consistency (limits) Index; (CI (or) I_C)

Consistency index (or) Relative consist. is defined as the ratio of the difference b/w liquid limit and natural water content to the plasticity index of soil.

$$CI \text{ (or) } I_C = \frac{L_L - w}{P_I}$$

Liquidity index (LI (or) I_L)

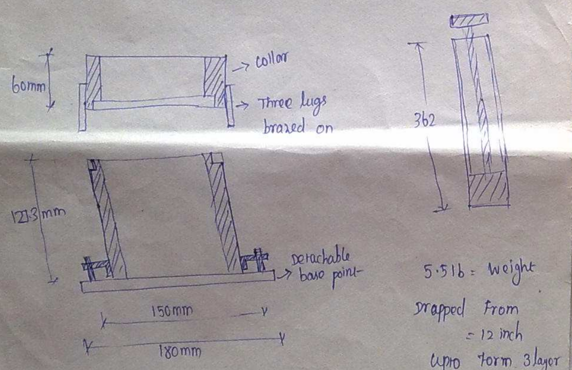
(or) water plasticity ratio is the ratio of the difference between the natural water content and plastic limit to the plasticity index:

$$LI \text{ (or) } I_L = \frac{w - P_L}{P_I \text{ (or) } I_P}$$

Compaction

Compaction is a process by which the soil particles are artifically re-arranged and packed together into a closer state of contact by mechanical means in order to increase the porosity may be accomplished by rolling, tamping (or) vibration.

Proctor's compaction test;



$\rho = \frac{M}{V}$ (g/cm³) ; $\rho_d = \frac{\rho}{1+w}$ (g/cm³).

(1) The dry unit weight of a sand Samp[le in] the loosest state is 13.34 kN/m³. and the dense state it is 21.19 kN/m³. dete[rmine] the density index of this sand when has a porosity of 33%. $G = 2.68$.

$\gamma_{mini} = 13.34$ kN/m³.

$\gamma_{max} = 21.19$ kN/m³.

$n = 33\%$.

Voids ratio;

$$e_0 = \frac{n}{1-n}$$

$$= \frac{0.33}{1-0.33}$$

$$e_0 = 0.49$$

$$\gamma_0 = \frac{G \cdot \gamma_w}{1+e_0} = \frac{2.68 \times 9.81}{1+0.49}$$

$$I_D = \frac{e_{max} - e_0}{e_{max} - e_{mini}}$$

$$\gamma_{mini} = \frac{G \cdot \gamma_w}{1+ \dots} \qquad \gamma_{mini} = \frac{G \dots}{1+ \dots}$$

(i) Relationship involving porosity, void ratio, degree of saturation, water content, percent air content and air voids.

(i) Voids ratio:

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

(ii) porosity;

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

(iii) specific gravity; ($S.e = w.G$).

w = water content.

S = degree of saturation

$$S = \frac{w.G}{e}$$

(iv). air content;

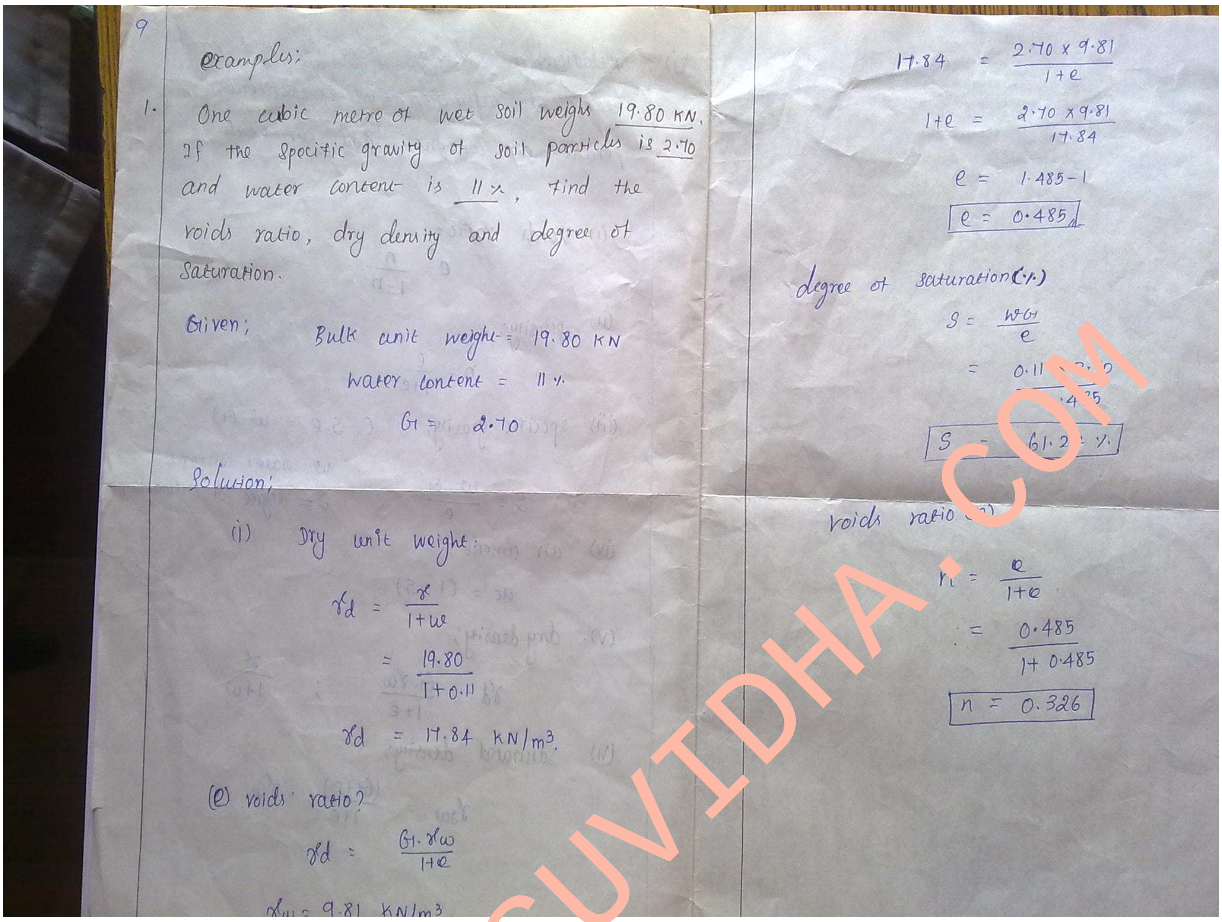
$$a_c = (1 - S)$$

(v). dry density;

$$\gamma_d = \frac{G.\gamma_w}{1+e} \quad ; \quad \frac{\gamma}{1+w}$$

(vi) saturated density;

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



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examples:

1. One cubic metre of wet soil weighs 19.80 KN. If the specific gravity of soil particles is 2.70 and water content is 11%, find the voids ratio, dry density and degree of saturation.

Given; Bulk unit weight = 19.80 KN

water content = 11 %

G = 2.70

Solution;

(i) Dry unit weight:

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

$= \frac{19.80}{1+0.11}$

$\gamma_d = 17.84 \ kN/m^3$

(2) voids ratio?

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

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

$17.84 = \frac{2.70 \times 9.81}{1+e}$

$1+e = \frac{2.70 \times 9.81}{17.84}$

$e = 1.485 - 1$

$e = 0.485$

degree of saturation (%)

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

$= \frac{0.11 \times 2.70}{0.485}$

S = 61.2[illegible] %

voids ratio (n)

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

$= \frac{0.485}{1+0.485}$

$n = 0.326$