KUPPAM ENGINEERING COLLEGE

DEPARTMENT OF CIVIL ENGINEERING

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INDEX PROPERTIES, RELATIONSHIPS AND TESTS

TOPICS TO BE COVERED

1. Phase diagram
2. Basic terms and definition
3. Functional relationships
4. Determination of index properties
5. Relative density

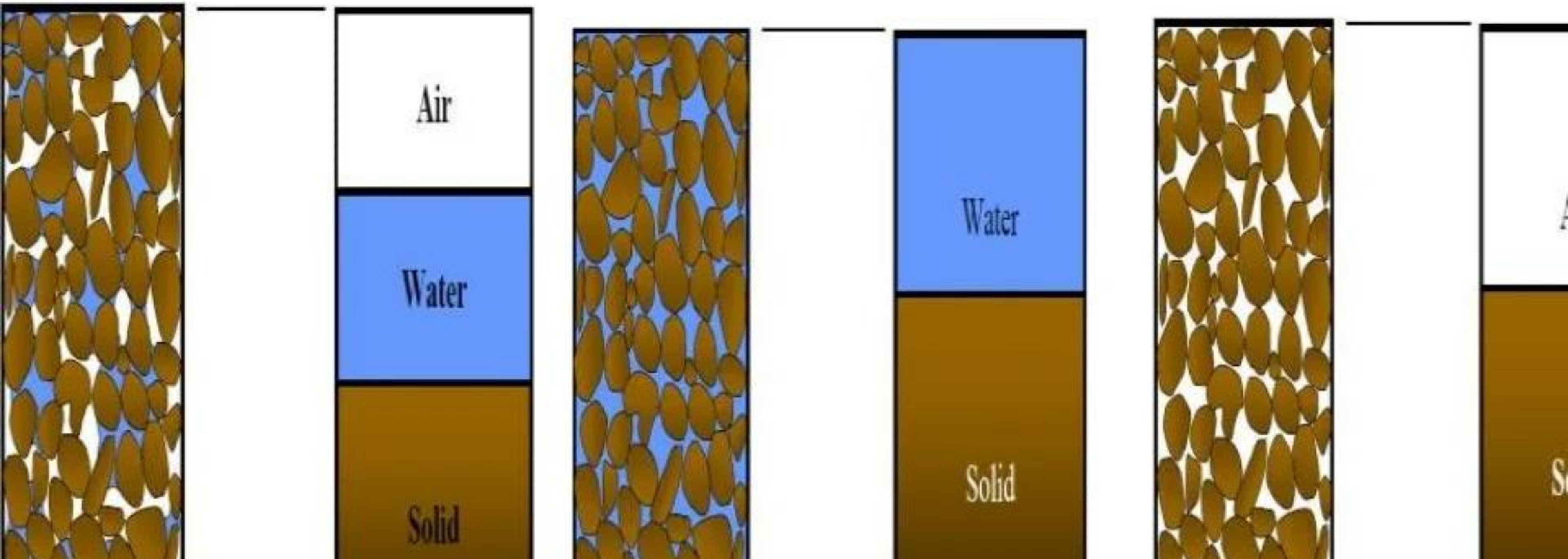
PHASE DIAGRAMS

Soil mass consist of solid particles, water, air. In soil mass volume of solid particles is highest. The voids may be filled of water or air.

SOME ASSUMPTIONS ARE MADE

- Mass of air in soil is zero.
- All soil particles are of same size

PHASE DIAGRAMS



THREE PHASE DIAGRAM

In this case soil is partially dry and partially saturated. Here,

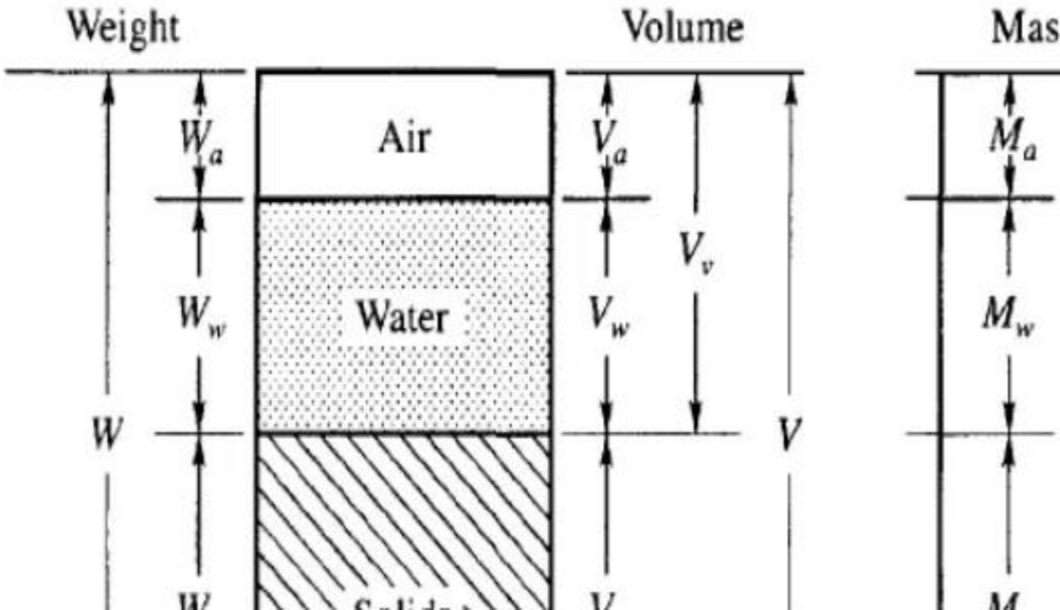
V_a=volume of air

V_w=volume of water

V_s=volume of solids

V_t=total volume of soil

From fig;



TWO PHASE DIAGRAM FOR FULLY DRY SO

In this case ,two phases ,solids and air are present. Water is absent and void are filled with the air.

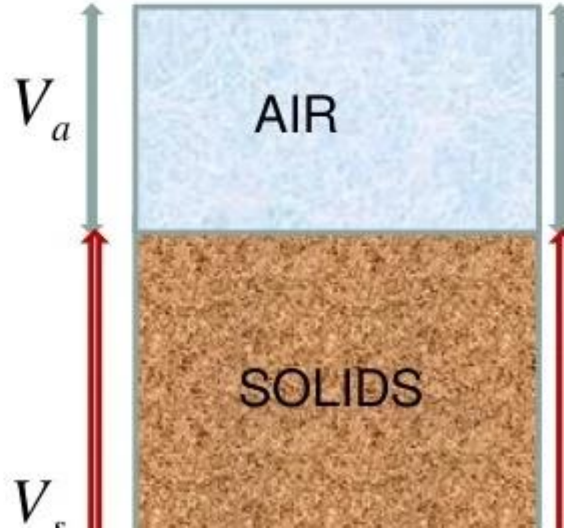
From, fig;

V=Vs+Va

Now,

$W = W_v + W_s$

$$\therefore W = W_a + W_s \qquad \text{but; } W_a = 0$$



TWO PHASE DIAGRAM FOR FULLY SAURATED SOIL

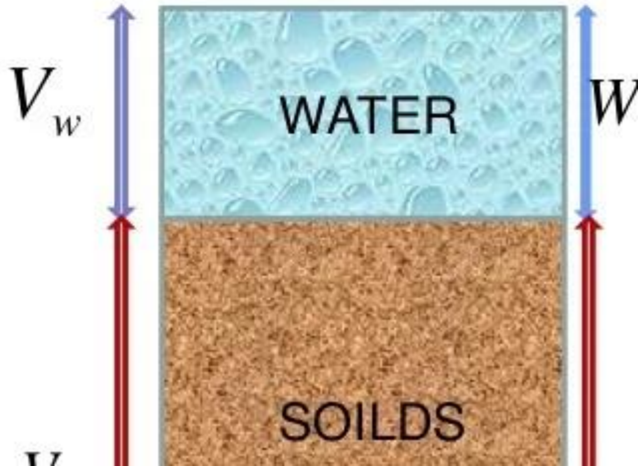
In this case two phases , solid , water are present. Air is absent. Voids are filled with water only.

$$V = V_v + V_s$$

$$but,\ V_v = V_w$$

$$\therefore V = V_w + V_s$$

Similarly,



FUNDAMENTAL DEFINATION

1. WATER CONTENT OR MOISTURE CONTENT

- The water content is defined as the ratio of mass of water to the mass of soils.

- Water content=(weight of water / weight of dry soil)*100%

$$w = \frac{M_w}{M_s} * 100\%$$

or

2. BULK UNIT WEIGHT (γ_b)

- Bulk unit weight is defined as the total weight of soil mass per unit of total volume.
- Bulk unit weight = (total weight of soil mass / total volume of soil mass) * 100 %

$$\gamma_b = \frac{W}{V} \quad \cdots \mathrm{N/m^3} \ \text{ or } \ \mathrm{kN/m^3}$$

3.DRY UNIT WEIGHT (γ_d)

Dry unit weight is defined as the weight of soil solids per unit of total volume of the soil mass.

4. SATURATED UNIT WEIGHT (γ_{SAT})

- When soil mass is saturated, its bulk unit weight is called the saturated unit weight.
- Saturated unit weight = (total weight of saturated soil mass / total volume of soil mass)
- $\gamma_{sat} = (W_{sat} / V)$… k N/m^3

5. UNIT WEIGHT OF SOLIDS(γ_s)

•Unit weight of solids is the ratio of weight of solids to the

6. SUBMERGED UNIT WEIGHT (γ_{sub} OR γ)

- Submerged unit weight is defined as the ratio of submerged weight of soil solids to the total volume of the soil mass.
- Submerged unit weight = (submerged weight of soil solids / total volume of soil mass)

$$\gamma_{sub} = \frac{(W_d)_{sub}}{V} \quad \cdots \mathrm{kN/m^3}$$

- When dry soil is submerged in water, it displaces an equal volume of water. Thus the net weight of soil is

7. SPECIFIC GRAVITY (G)

- Specific gravity is defined as the ratio of the weight of a given volume of soil solids to the weight of an equal volume of distilled water.
- Specific gravity = (weight of a given volume of soil solid / weight of an equal volume of distilled water)

$$G = \frac{W_s}{W_w} = \frac{\gamma_s}{\gamma_w} \text{ no unit}$$

SPECIFIC GRAVITY

• GRAVEL	2.65 - 2.68
• SAND	2.65 - 2.68
• SILTY SAND	2.66 - 2.70
• SILTS	2.66 - 2.70
• INORGANIC CLAYS	2.70 – 2.80
• ORGANIC SOILS	VARIABLE, MAY FALL BELOW
• SOILS HIGH IN MICA, IRON	2.75 - 2.85

8. VOID RATIO (e)

- It is defined as the ratio of the volume of voids to the volume of solids.

∴ Void ratio = (volume of voids / volume of solids)

- $e = V_v/V_s$.

9. POROSITY(n)

- It is defined as the ratio of volume of voids to the total volume.

10. DEGREE OF SATURATION(S_r)

- It is defined as the ratio of the volume of water to the volume of voids.

∴ Degree of saturation = (volume of water / volume of voids)

- $S_r = (V_w/V_v)$
- In case of fully saturated soil, voids are completely filled with water. There is no air.

∴ $V_w = V_v$

∴ $S_r = 1$

- In case of fully dry soil, voids are completely filled with

11. AIR CONTENT(a_c)

- It is defined as the ratio of the volume of air to the volume of voids.
- Air content = (volume of air/ volume of voids)

$\therefore a_c = (V_a/V_v)$

12. PERCENTAGE AIR VOIDS(n_a)

- It is defined as the ratio of the volume of air to the total volume.
- Percentage air voids = (volume of air/ total volume)

13. DENSITY INDEX OR RELATIVE DENSITY

- The density index is defined as,

  $I_D = (e_{max} – e / e_{max} – e_{min})$

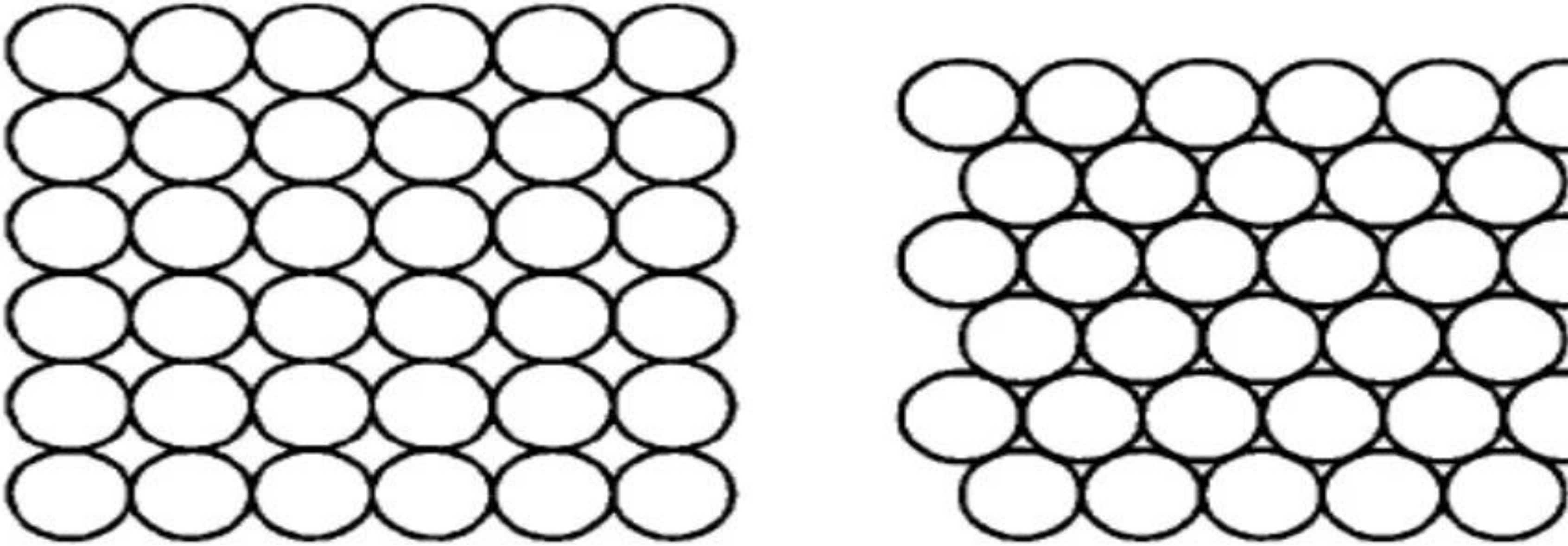
Where,

e_{max} = void ratio in the loosest state

e_{min} = void ratio in the densest state

e = natural void ratio of the deposit

- This term is used for cohesion less soils only



(a) Loosest state

(b) Densest state

Figure 3.8 Packing of grains of uniform size

Table 3.8 Classification of sandy soils

Relative density, D_r %	Type of soil

VOLUME - MASS RELATIONSHIP

1)BULK DENSITY (ρ_b)

The bulk density is defined as the total mass per unit volume.

$$\therefore \rho_b = \rho = (m/v)$$

- It is expressed as kg/m^3.
- $1cm^3 = 1ml$

2)DRY DENSITY (ρ_d)

3.SATURATED DENSITY

- The saturated density is the bulk density of soil when it is fully saturated.

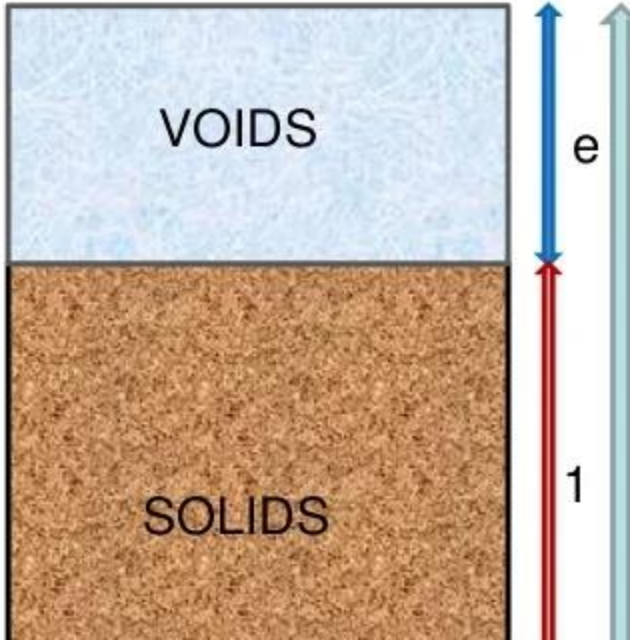
$\therefore \rho_{sat} = (M_{sat} / V)$ ….. Kg/m^3

4.SUBMERGED DENSITY

- When the soil exist below water , it is in a submerged condition. When a volume v of soil is submerged in water, it displaces an equal volume of water. Thus the net mass of soil when submerged is reduced.
- The submerged density of the soil is defined as the submerged mass per unit total volume.
- $\rho_{sub} = \rho' = (m_{sub} / v) = (\rho_{sat} - \rho_w)$

FUNCTIONAL RELATIONSHIPS

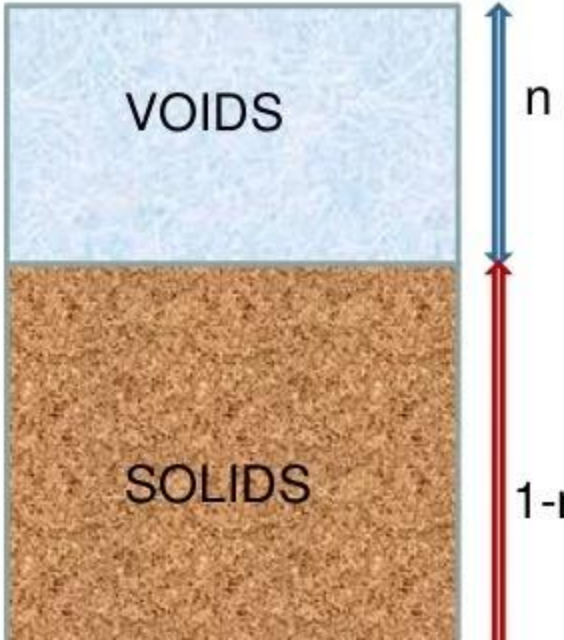
If volume of void is taken as “e”, the volume of solids by definition of porosity will be “1” and total volume is “1+e”.



$$\therefore n=\frac{V_v}{V}=\frac{e}{1+e}$$

If volume of voids is taken as "n", the volume of solids, by definition of void ratio will be "1-n" and total volume equal to "1".

$$\therefore e = \frac{V_v}{V_s} = \frac{n}{1-n}$$



combining the above two eqution we get,

RELATION BETWEEN e,G,w& S_r

Fig shows the soil element.

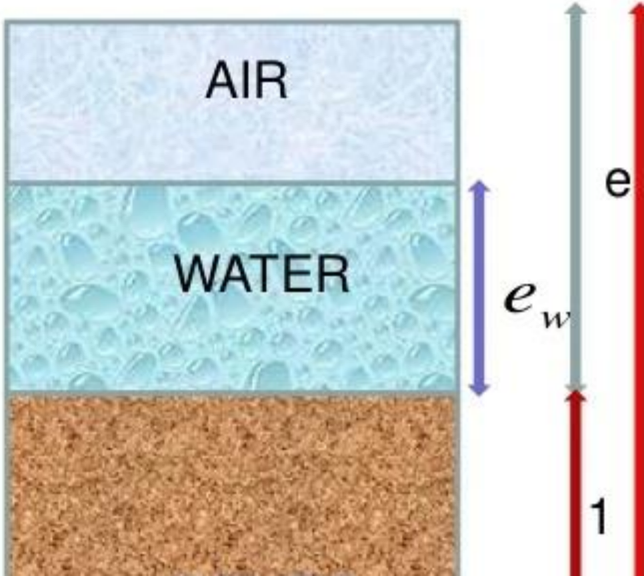
Where, e_w = water void ratio

e = void ratio

Vs=1= volume of solids

We, know

$$w = \frac{M_w}{M_s} = \frac{\rho_w . V_w}{\rho_s . V_s} \quad \text{------} \quad (A)$$



Now

putting the value of equ. (1) & (2) in equ. (A)

$$\therefore w = \frac{\rho_w . S V_v}{\rho_w . G V_s} = \frac{S V_v}{G V_s} = \frac{S}{G} e$$

$$\therefore Se = wG$$

In case of fully saturated soil S=1. So, e=w G

DERIVE : $\rho_b = \frac{(G + e.S_r)\gamma_w}{1+e}$

We know that,

$$\gamma_b = \frac{W}{V} = \frac{W_s + W_w}{V}$$

$$\therefore \gamma_b = \frac{\gamma_s . V_s + \gamma_w . V_w}{V} \quad (\because \gamma_s = \frac{W_s}{V_s} \& \gamma_w = \frac{W_w}{V_w})$$

Now,

$$\gamma_b = \frac{G.\gamma_w + e_w.\gamma_w}{1+e} \qquad (\because G = \frac{\gamma_s}{\gamma_w} \;\&\; e_w = e.S_r)$$

$$\gamma_b = \frac{(G+e_w)\gamma_w}{1+e}$$

$$\therefore \gamma_b = \frac{(G+e.S_r)\gamma_w}{1+e}$$

- If soil is fully dry, $S_r = 0$ and $\gamma_b = \gamma_d$

$$\therefore \gamma_d = \frac{G.\gamma_w}{\ldots}$$

DERIVE : $\rho_{dry} = \frac{\rho_b}{1+w}$

We know that,

$$\rho_b = \frac{\mathbf{M}_t}{\mathbf{V}} = \frac{M_s + M_w}{V}$$

$$\therefore \rho_b = \frac{M_s + wM_s}{V} \qquad (\because w = \frac{M_w}{M_s})$$

$$\therefore \rho_b = \frac{\mathbf{M}_s(1+w)}{V} \qquad \text{But, } \rho_{dry} = \frac{M_s}{V}$$

Table 3.1 Various Forms of Relationships for γ, γ_d, and γ_{sat}

Moist unit weight (γ)		***Dry unit weight*** (γ_d)		***Saturated unit weight*** (γ	
Given	**Relationship**	**Given**	**Relationship**	**Given**	**Relationshi**
w, G_s, e	$\frac{(1+w)G_s\gamma_w}{1+e}$	γ, w	$\frac{\gamma}{1+w}$	G_s, e	$\frac{(G_s+e)\gamma_w}{1+e}$
S, G_s, e	$\frac{(G_s+Se)\gamma_w}{1+e}$	G_s, e	$\frac{G_s\gamma_w}{1+e}$	G_s, n	$[(1-n)G_s + n$
w, G_s, S	$\frac{(1+w)G_s\gamma_w}{1+\frac{wG_s}{S}}$	G_s, n	$G_s\gamma_w(1-n)$	G_s, w_{sat}	$\left(\frac{1+w_{sat}}{1+w_{sat}G_s}\right)G$
w, G_s, n	$G_s\gamma_w(1-n)(1+w)$	G_s, w, S	$\frac{G_s\gamma_w}{1+\left(\frac{wG_s}{S}\right)}$	e, w_{sat}	$\left(\frac{e}{w_{sat}}\right)\left(\frac{1+w}{1+e}\right.$
S, G_s, n	$G_s\gamma_w(1-n) + nS\gamma_w$	e, w, S	$\frac{eS\gamma_w}{(1+e)w}$	n, w_{sat}	$n\left(\frac{1+w_{sat}}{w_{sat}}\right)\gamma_w$

DETERMINATION OF INDEX PROPERTIES O
SOIL

Those properties of soil which are used in the identification and classification of soil are known as INDEX PROPERTIES.

- Various index properties of soils are:-

a. Water content
b. In-situ density
c. Specific gravity

METHODS OF WATER CONTENT DETERMINATION

The water content can be determined by any of the given methods:-

a) Oven drying method
b) Sand bath method
c) Alcohol method
d) Calcium carbide method
e) Nuclear probe method

SAND BATH METHOD

This is a field method of determining rough value of the water content. The container with the soil is placed on a sand bath. Heated over a kerosene stove. The soil become dry within ½ to 1 hrs. It should

Water contain can be determined as;

$$w = \frac{M_2 - M_3}{M_3 - M_1} * 100\%$$

Where, M_1= mass of empty container

M_2= mass of container + wet soil

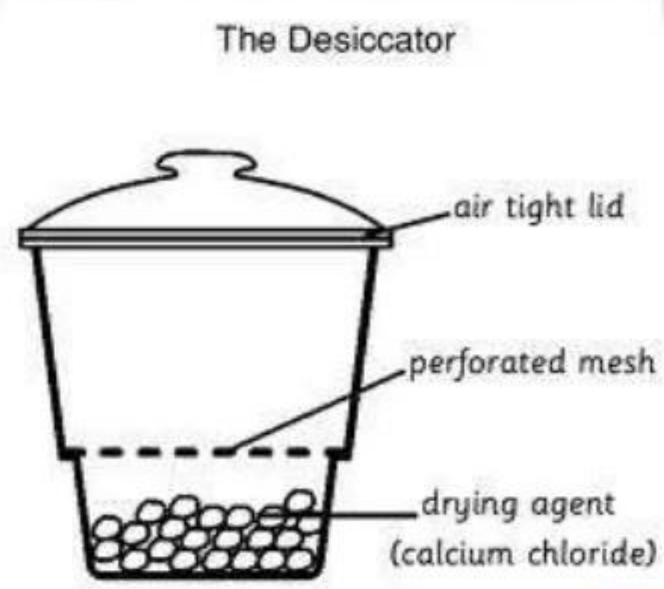
OVEN DRYING METHOD

Equipments:-

- Containers
- Desiccator with any suitable desiccating agent
- Thermostatically controlled oven
- Weighing balance with accuracy of 0.01 gm.

PROCEDURE:-

1. Clean the container, dry it and weight it with the lid. (W1)
2. Take the required quantity of the wet soil specimen in the container & weight it with the lid.(W2)
3. Place the container with its lid removed, in the oven till its weight become constant.
4. When the soil has dried, remove the container from the oven using tongs.
5. Find the weight W3 of the container with the lid and the


The Desiccator
air tight lid
perforated mesh
drying agent
(calcium chloride)


PC-210K


large pore

Now, water content can be calculated as;

$$w = \frac{M_2 - M_3}{M_3 - M_1} * 100\ \%$$

SPECIFIC GRAVITY DETERMINATIO

•The specific gravity of solids is frequently required for computation of several soil properties such as void ratio, degre of saturation, unit weigh of solids, fine soil particle size, etc.

•Laboratory using the following methods:

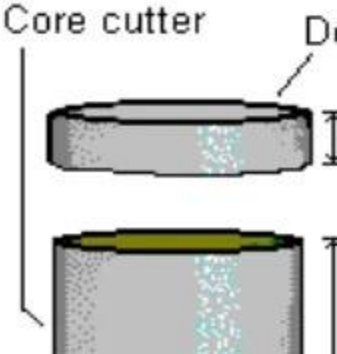
1. Pycnometer bottle method
2. Density bottle method
3. Measuring flask method
4. Gas jar method

PYCNOMETER BOTTLE METHOD

1. Clean and dry the pycnometer. Find its mass with cap as M1.
2. Place about 200 gm of oven dried soil passing through 4.75 mm sieve.
3. Determine mass of pycnometer with dry soil as M2.
4. Add sufficient amount of de-aired water to the soil in the pycnometer. Thoroughly mix it. Determine mass of pycnometer with soil and water as M3.
5. Empty the pycnometer, clean it and wipe it try.
6. Fill the pycnometer with distilled water and find its

DETERMINATION OF DRY DENSITY BY CORE CUTTER

1. Measure the inside dimensions of the core cutter
2. Determine empty weight of core cutter (W1)
3. Level the surface, about 300 mm square in area.
3. Place the dolly over the top of the core cutter and press the core cutter into the soil mass using the rammer.
4. Stop the process of pressing when about 15 mm of the dolly protrudes above the soil surface.
5. Remove the soil surrounding the core cutter and take out the core cutter.
6. Remove the dolly. Trim the top and bottom surface of the core cutter carefully using a straight edge.



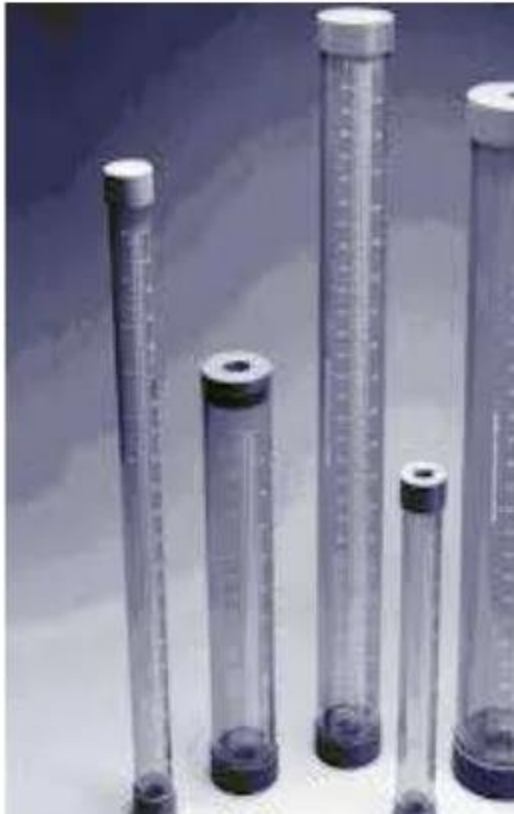
DETERMINATION OF FIELD DRY-DENSITY

- The test procedure is divided in to two parts.

1. Calibration of cylinder.
2. Determination of bulk density of the soil.

PART – 1 : Calibration of cylinder

1. Fill the sand pouring cylinder with sand, within about 10 mm from its top. Determine the weight of cylinder with sand and lid (W1) gm.
2. Place the sand-pouring cylinder vertically on the calibrating container.
3. Lift the pouring cylinder, weigh the sand collected in the tray used in filling the cone as (W2).



PART – 2 : Determination of bulk density of soil:

1. Expose an area of about 450 mm 450 mm on the surface of the soil mass. Trim the surface down to a level surface, using scraper tool.
2. Place the metal tray on the levelled surface surface.
3. Excavate the soil through the central hole of the tray. The depth of the excavated hole should be about 150 mm.
4. Collect all the excavated soil in a metal tray and weigh it as W4.
5. Now place the sand pouring cylinder in the metal tray over the excavated hole. Remember that weight of sand pouring cylinder with sand at this time is W3.
6. Allow the sand to run out of the cylinder by opening the shutter. Close the shutter when the hole is completely filled and no further movement of sand is observed.

7. Weigh the sand pouring cylinder with sand and lid as W5.

8.Weigh of sand in the excavated hole W6 = W3 – W2 – W5

9. Density of sand in hole = weight of sand in hole / volume of hole

volume of hole = weight of sand in hole / density of sand in hole

$v = W6 / \gamma s$

10. Bulk density of soil = weight of soil collected from hole / volume of hole

$\gamma b = W4 / V$

11. Determine water content of soil collected from the hole as w.

12. Dry density of soil, $\gamma d = \gamma b / 1 + w$.

RELATIVE DENSITY

The relative density is generally used to indicated the in situ (on site) denseness or looseness of soil. It is define by;

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$$

where, e_{max} = void ratio of the soil in loosest state

$$I_D = \frac{\rho_{max}}{\rho_d}\left(\frac{\rho_d - \rho_{min}}{\rho_{max} - \rho_{min}}\right)$$

$$here, \rho_{min} = \frac{M_{min}}{V_m}$$

$$M_{min} = mass \text{ of dry soil}$$

$$\mathrm{V_m} = \text{volume of mould}$$

similarly;

REFERENCE

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  by-Dr. R.P. Rethaliya


THANK