GEOTECHNICAL ENGINEERING

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Soil Formation

Soil forms when weathered parent material interacts with *environment.*

SOILS OF INDIA

- Loose material and uppermost layer of earth’s crust.
- Important natural resource.
- Formed due to weathering of rocks.
- Provides nutrients & water to plants.

- Factors affecting soil formation:
    - Climate
    - Vegetation
    - Age of rock
    - Relief and
    - Parent rock

TYPES OF SOILS

- Eight major types according to Indian Council of Agricultural Research (ICAR).
  - Alluvial soils
  - Black soils
  - Red soils
  - Laterite soils
  - Desert soils
  - Mountain soils
  - Saline and Alkaline soils
  - Peaty and Marshy soils

ALLUVIAL SOIL

- Formed by deposition of alluvium by rivers.
- Occupies 15 Lakh sqkm area in India.
- Contribute greatly in agricultural development.

- Two types: *KHADAR & BHANGAR*
- **KHADAR**: Newer alluvium.
  - Sandy, pale brown composition.
  - Found in lower areas.
  - Flooded every year.

ALLUVIAL SOIL

- **BANGAR**: Older alluvium.
  - Clayey & dark in colour.
  - Coarse in nature.
  - Contains ***Kankar*** (lime nodules), Pebbles and Gravels.
  - Represents riverine alluvium of Himalayan rivers.
  - The regions of alluvial soil are thickly populated and intensively cultivated

ALLUVIAL SOIL

- **Characteristics**: Transported soils.
  - Coarser in upper section and finest in delta.
  - Light to dark in colour.
  - Rich in Potash & Humus.
  - Poor in Phosphorous and Nitrogen.
  - Highly fertile, good for all crops (kharif & rabi).
  - **Crops**: *Rice, Wheat, Sugarcane, Cotton, Jute*.
  - **Areas**: *Punjab, Haryana, U.P, Bihar, W.B, Assam, Parts of Orissa, delta regions of S.India*

BLACK SOIL

- Also known as Regur or Black Cotton soil.
- Dark grey to Black in colour.
- High clay content.
- Highly moist retentive.
- Develops cracks in summer.
- Covers 5.4 lakh sqkm.
- Highly suitable for cotton.
- Rich in iron, lime, calcium, Magne carbonates, and alumina.

BLACK SOIL

- Poor in Phosphorous, Nitrogen and Organic matter.
- The soil is black in colour because it is volcanic in origin
- Created from igneous rocks, and is called **‘regur soil’**
- **Areas:** *Deccan Trap which includes: Maharastra, W^n M.P, Parts of A.P, N^n Karnataka, Parts of T.N and Rajasthan.*
- **Crops**: *Cotton, Sugarcane, Groundnut, Millets, Rice, Wheat, Oilseeds*.

RED SOIL

- Formed due to weathering of old crystalline rocks in the areas of low rainfall.
  - More sandy and less clayey.
  - Rich in iron, small amount of Humus.
  - Poor in phosphorus, nitrogen and lime.
  - Slightly acidic and do not retain moisture.
  - 3.5 lakhs sq.km area.
  - Porous and Friable.

RED SOIL

- Area :
  - *Tamil Nadu, Southern Karnataka, parts of Madhya Pradesh, Maharashtra, West Bengal, Eastern Rajasthan, North eastern States.*
- **Crops :**
  - *Ragi, Groundnut, millet, Tobacco, Potato, Rice, Wheat, Sugarcane.*

LATERITE SOIL

- Latin word meaning brick.
  - Formed under high temperature and rainfall with wet and dry spell.
  - Silica is leached due to high rainfall.
  - Remnants of iron and aluminum oxides left behind is know as Laterite.
  - Brown to Yellowish colour.
  - Becomes hard when exposed to atmosphere.
  - Used as building material.

Laterite Soil

LATERITE SOIL

- Rich in Iron.
- Poor in Lime, Potash, & Magnesium.
- Occupies 2.4 Lakh sqkm.
- The humus content in the laterite soil is less because the micro-organisms and decomposers get destroyed in the high temperature.

• **Areas**: *Parts of Assam, Karnataka, T.N, A.P, M.P, Kerala*.

• **Crops**: After taking soil conservation measures, this soil is suitable for *Tea, Coffee, Cashew, Rubber and Coconut.*

DESERT SOIL

- Contains soluble salts.
- Red to brown in colour.
- Originated by Mechanical disintegration & wind deposit.
- Porous and coarse.
- 90% sand & 5% clay.
- Rich in Nitrates & Phosphates.
- Poor in Nitrogen & Humus.
- Friable, sandy & low moist content.
- 1.4 Lakh sqkm.

DESERT SOIL

- **Areas**: *Arid and Semi arid regions of Rajasthan, S^n Haryana, Punjab, N^n Gujarat.*

- Due to high temperature, dry climate, evaporation is faster and the soil lacks humus and moisture.

- After taking proper irrigation measures, this soil can be used for agriculture.

Crops: *Drought resistant crops like millets and barley*

MOUNTAIN SOIL

- – Found in hill slopes.
  - – Formed by deposition of organic matter from forest.
  - – Rich in humus.
  - – Poor in Potash and Lime.
- **Areas:** *Assam, Kashmir, Sikkim & Arunachal Pradesh.*
- **Crops:** *Tea, Coffee, Spices & Tropical Fruits.*

SALINE & ALKALINE SOIL

- – Contains salts like Sodium, Magnesium, Calcium.
- – Infertile, unfit for cultivation.
- – Sandy to loamy in texture.

- **Areas:**
  - – *Parts of Gujarat, Rajasthan, Punjab, Haryana, U.P & Maharashtra.*

PEATY AND MARSHY SOIL

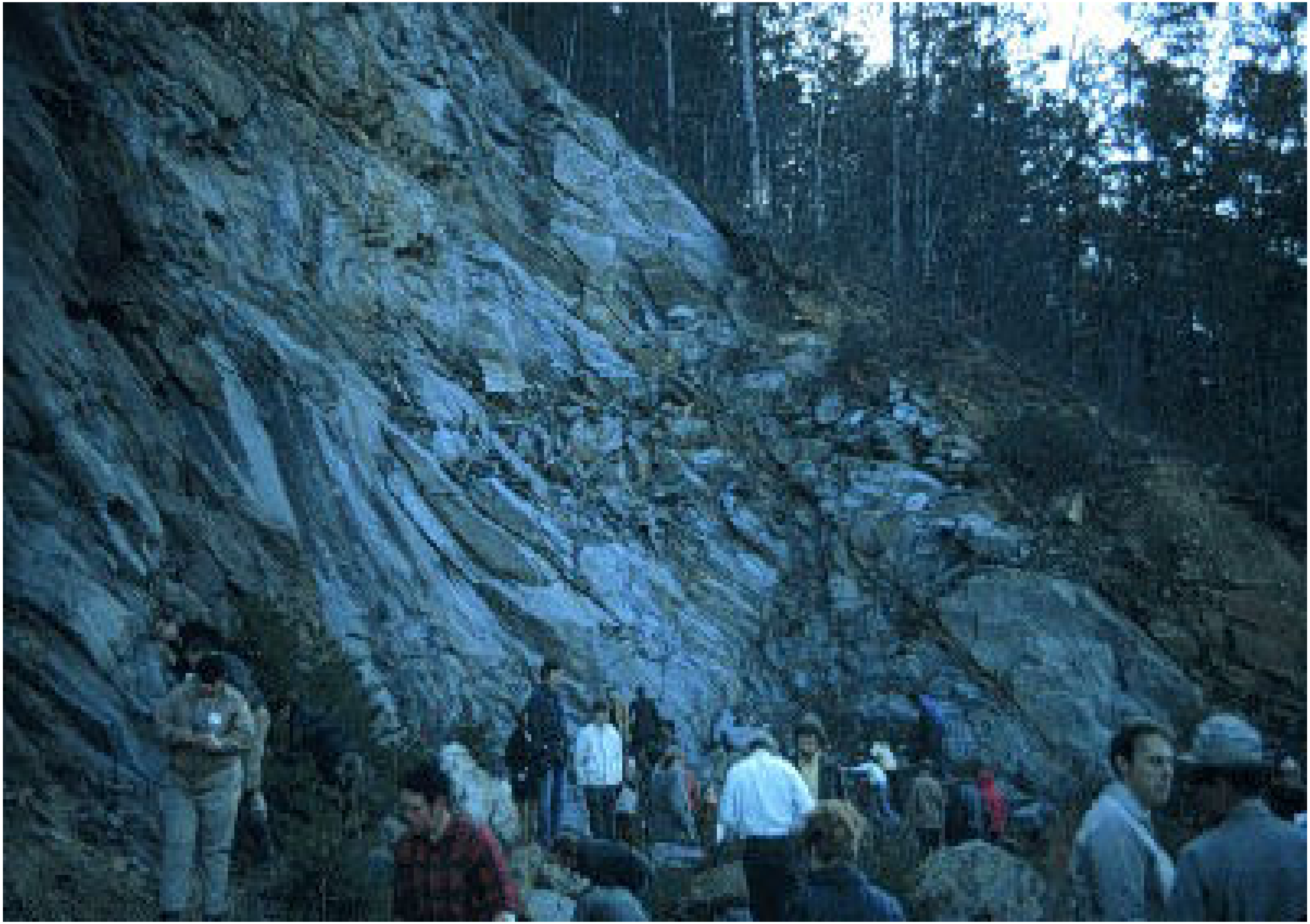
  - Occur in Humid region.
  - Formed by accumulation of organic matter.
  - Black in colour.
  - Highly acidic and heavy.
- **Areas:**
  - *Kottayam & Alleppey in Kerala, Coastal Orissa, Sundarbans of W.B*

Freeze / Thaw

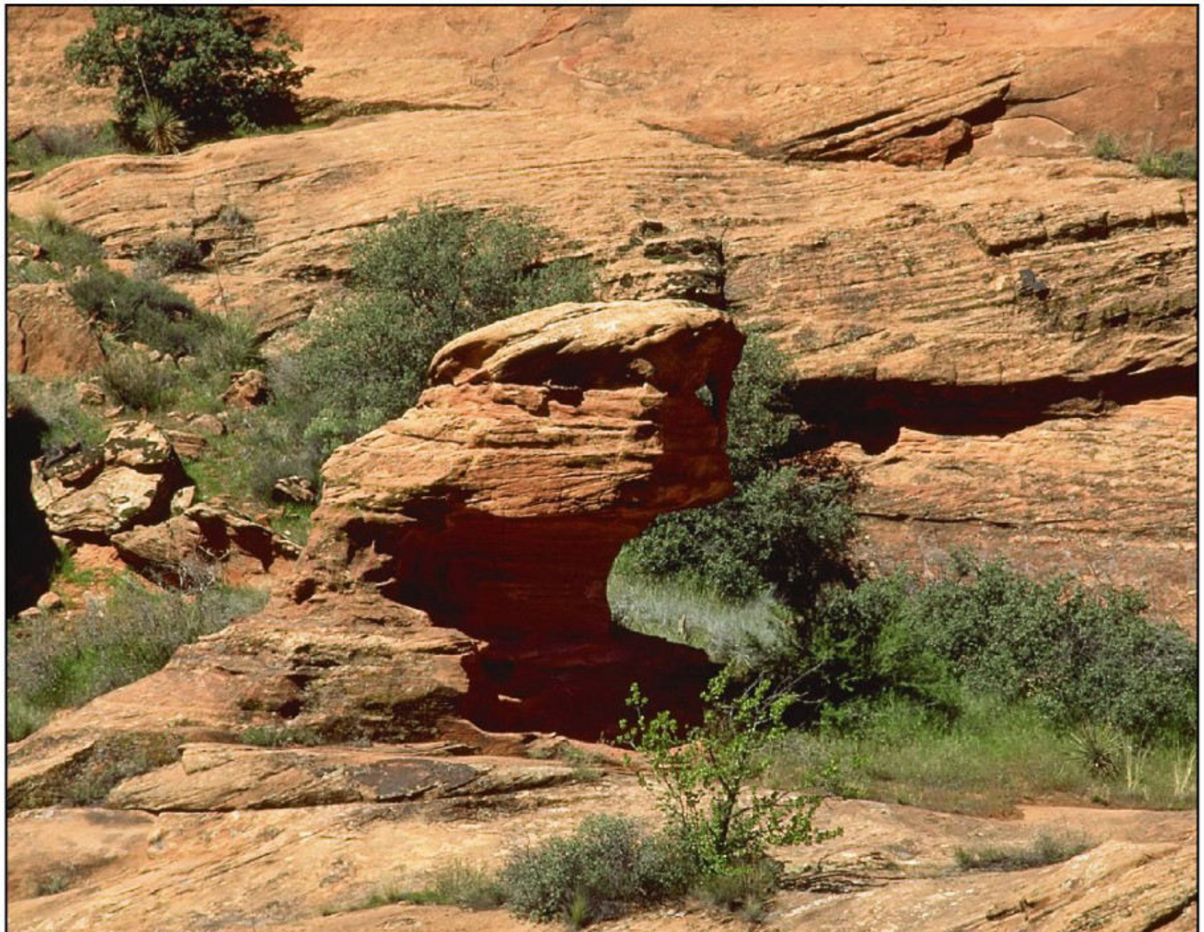
(a)

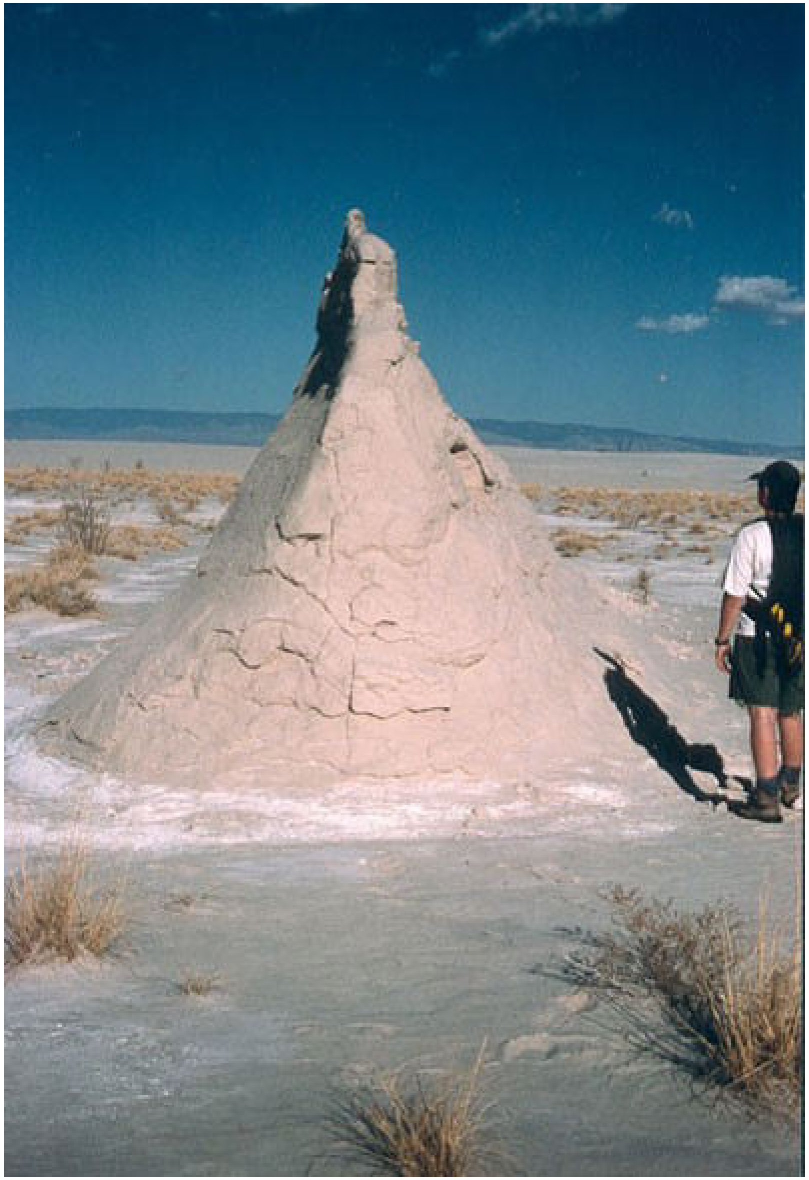
2. Exfoliation

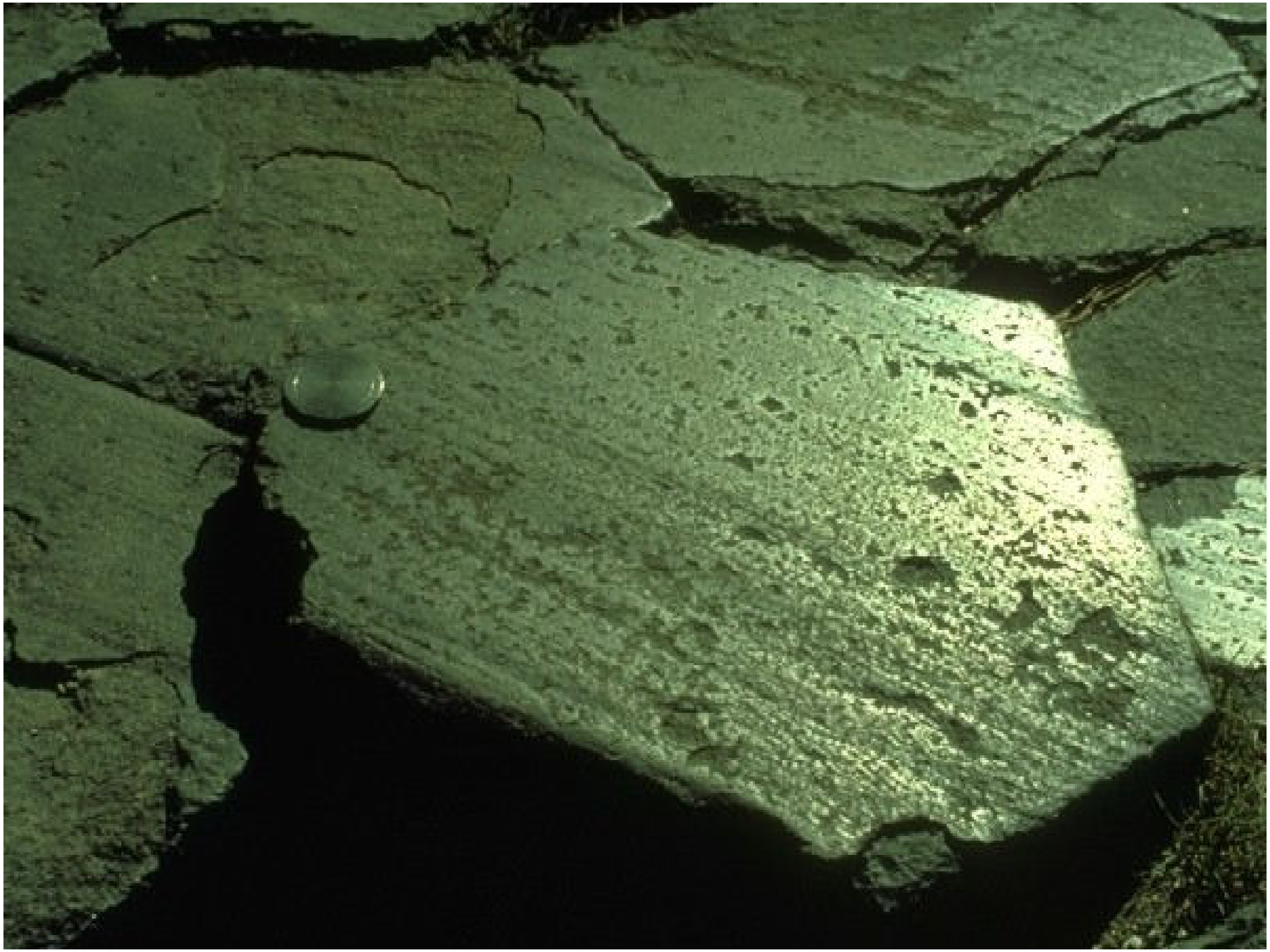
(b)



3. Abrasion (wind, water, ice)







4. Salt Wedging

INDEX PROPERTIES, RELATIONSHIPS AND TEST

TOPICS TO BE COVERED

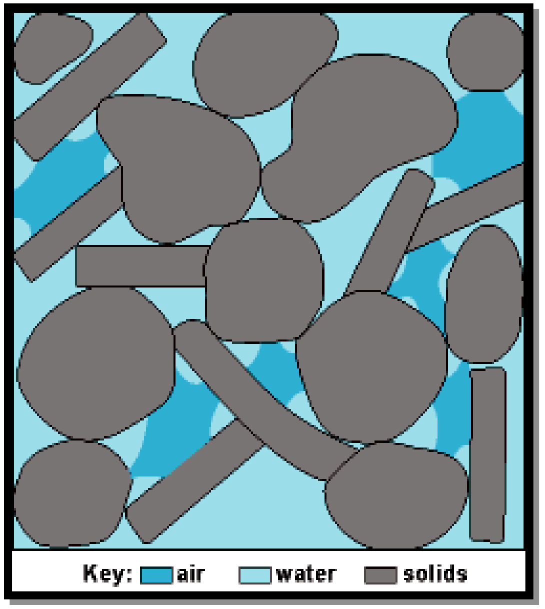
1. Phase diagram
2. Basic terms and definition
3. Functional relationships
4. Determination of index properties
5. Relative density

PHASE DIAGRAMS

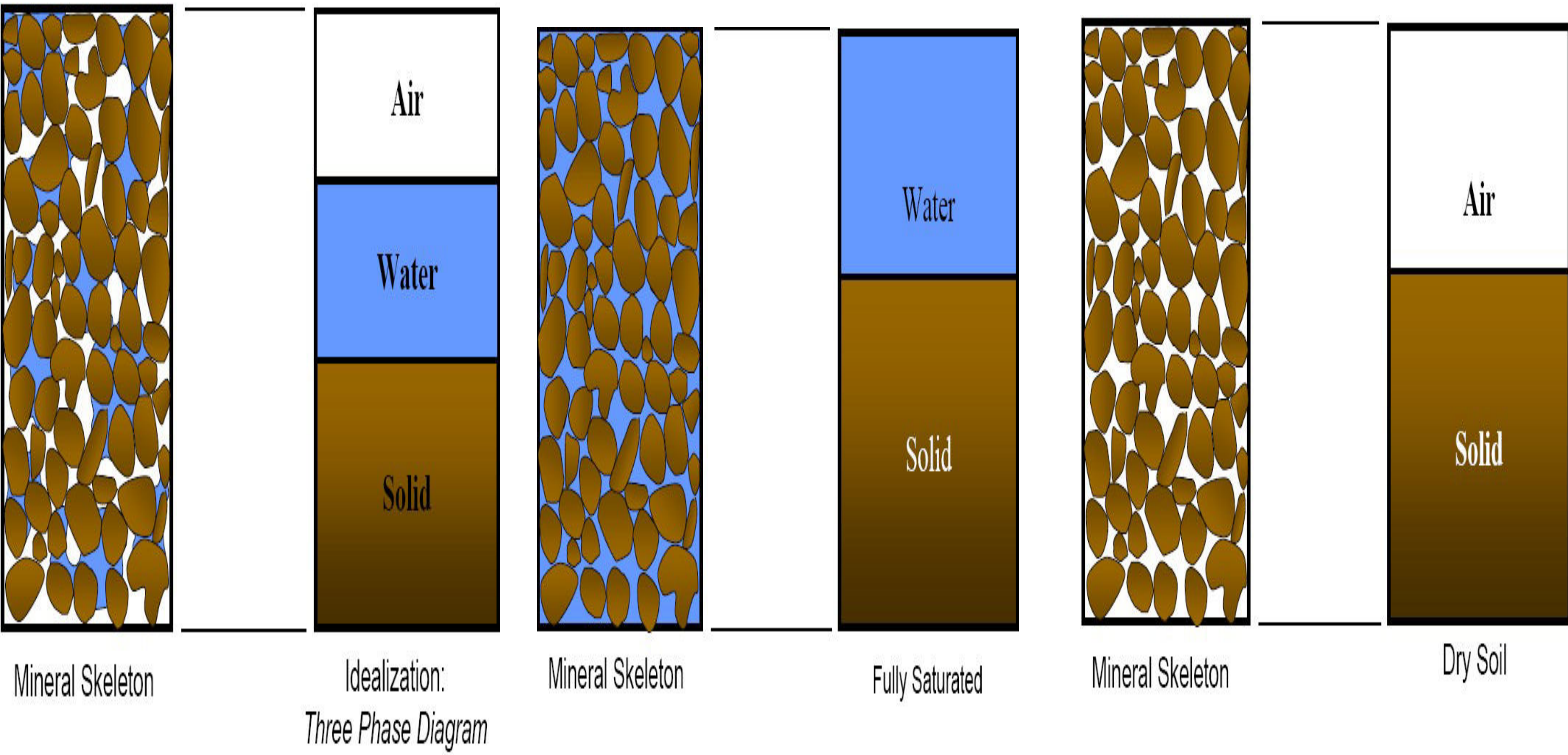
Soil mass consist of solid particles, water, air. In soil mass volume of solid particles is highest. The voids may be filled of water or air.

SOME ASSUMPTIONS ARE MADE

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



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

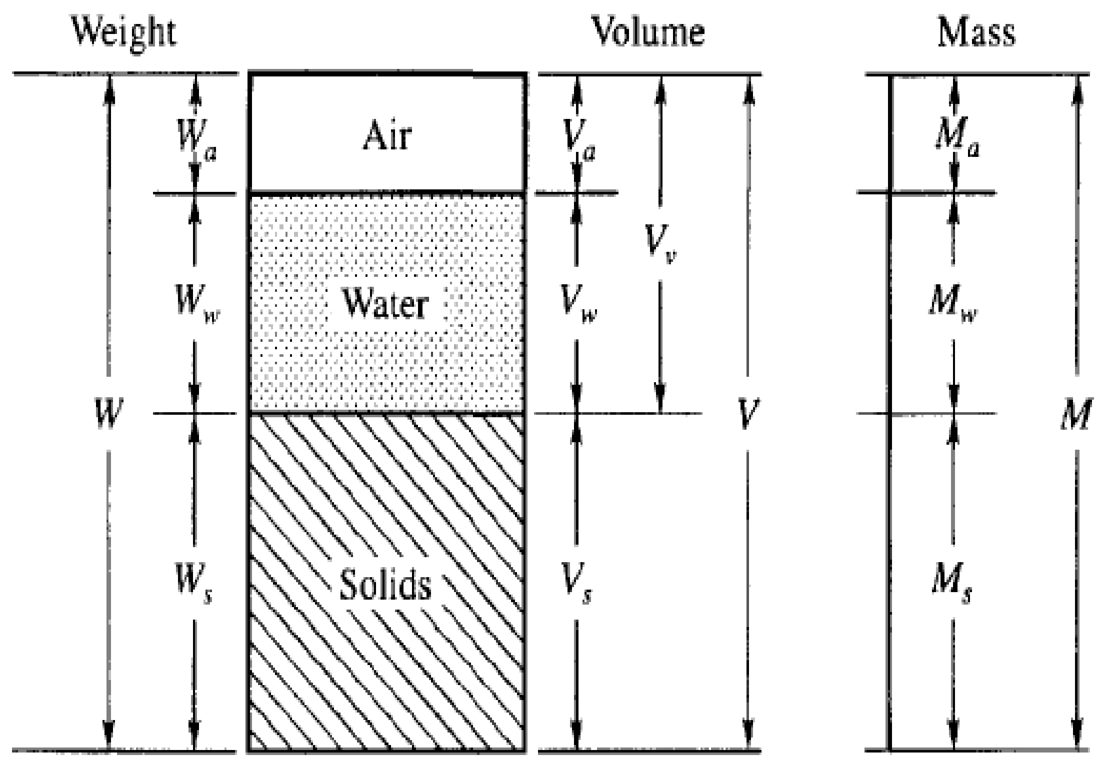
From fig;

$V_t=V_s+V_w+V_a$

Similarly;

$M_t=M_s+M_w+M_a$ (but $M_a=0$)

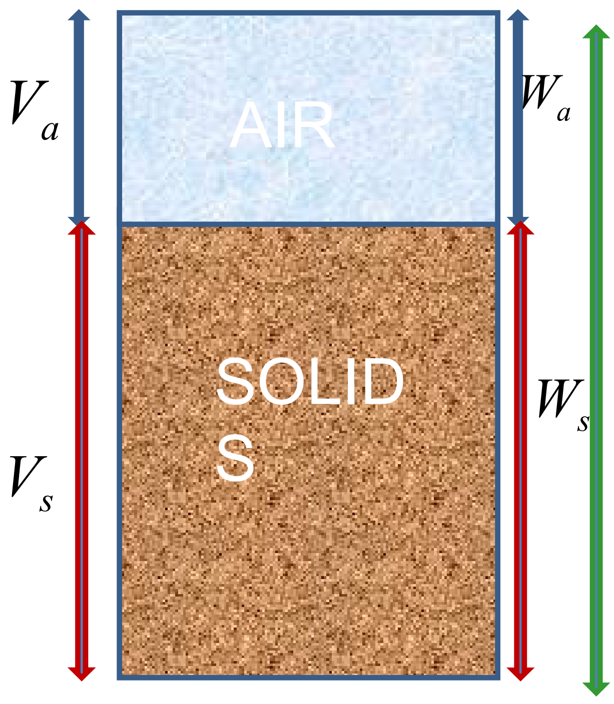
$M_t=M_s+M_w$



TWO PHASE DIAGRAM FOR FULLY DRY SOIL

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

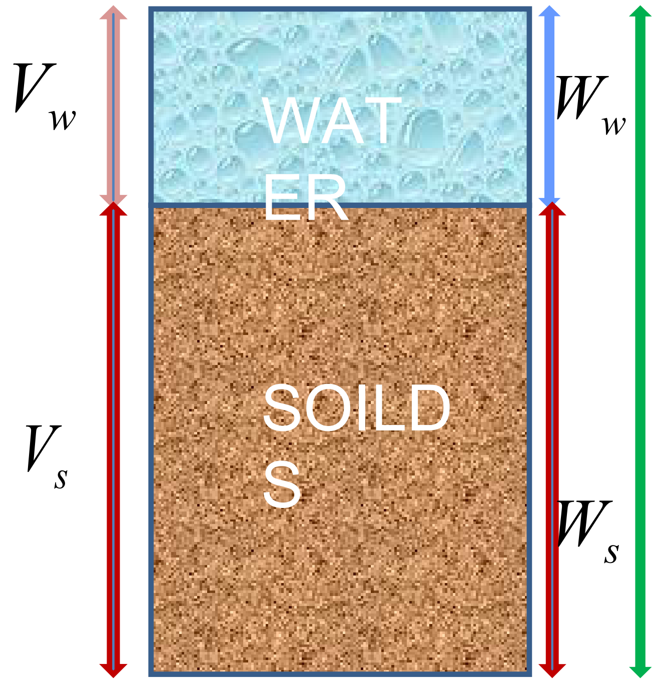
$$\therefore W = W_s$$



TWO PHASE DIAGRAM FOR FULLY SAURATED SOIL

$$V = V_v + V_s$$
$$but,\ \mathrm{V_v} = V_w$$
$$\therefore V = V_w + V_s$$

$$W = W_v + W_s$$
$$but,\ \mathrm{W_v} = W_w$$
$$\therefore W = W_w + W_s$$



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

$$\mathrm{w} = \frac{\mathrm{M_w}}{\mathrm{M_d}} * 100\%$$

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 %

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

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.

Dry unit weight = (total weight of soil solids / total volume of soil mass) * 100%

$$\gamma_d = \frac{W_d}{V} \quad \cdots \mathrm{kN/m^3}$$

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/m³

5. UNIT WEIGHT OF SOLIDS(γ_s)

-

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

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 reduced.

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

$$where,$$

$$\gamma_w = \text{unit weight of water} = 10\ \mathrm{kN/m^3}$$

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 2.0
- 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.
- Porosity = (volume of voids/ total volume)

  $n = (V_v/V)$

10. DEGREE OF SATURATION(S_r)

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

$\therefore$ 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.

$\therefore V_w = V_v$

$\therefore S_r = 1$

- In case of fully dry soil, voids are completely filled with air. There is no water.

$\therefore V_w = 0$

$\therefore S_r = 0.$

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)

-
-

$\therefore$

13. DENSITY INDEX OR RELATIVE DENSITY

- The density index is defined as,

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

Where,

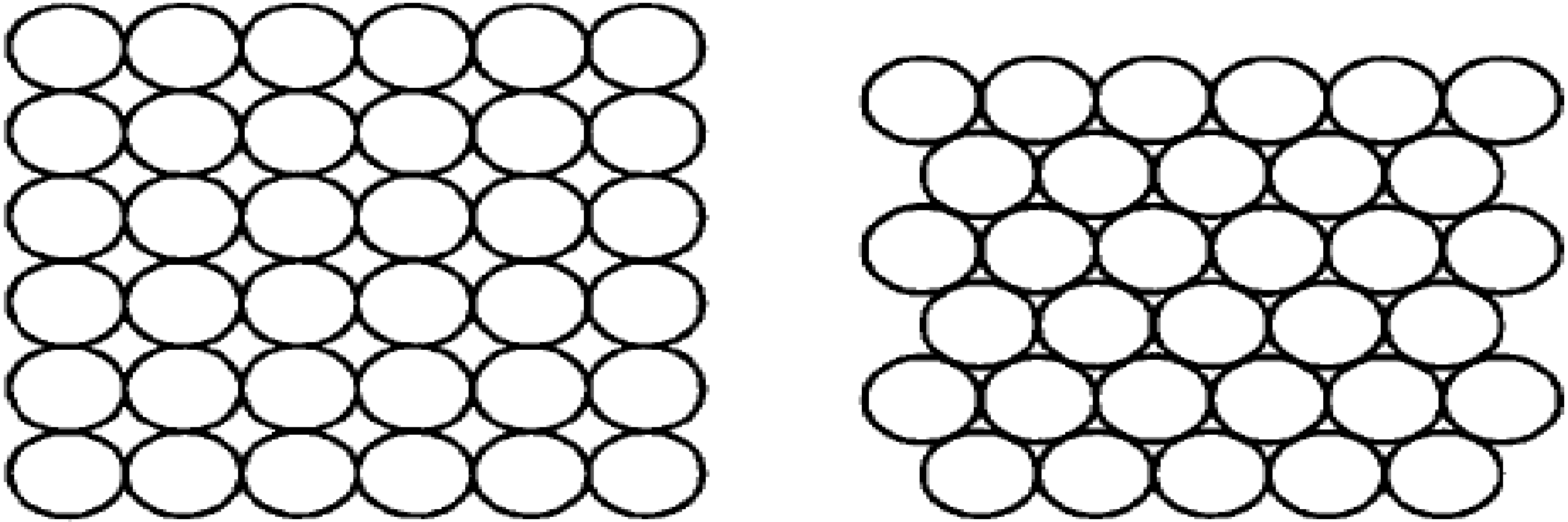
e_{max} = void ratio in the loosest state

e_{min} = void ratio in the densest state

e = natural void ratio of the deposit

- This term is used for cohesion less soils only.
- When the natural state of the cohesionless soil is in the loosest form,

$e_{max} = e$.



(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
0–15	Very loose
15–50	Loose
50–70	Medium dense
70–85	Dense
85–100	Very dense

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

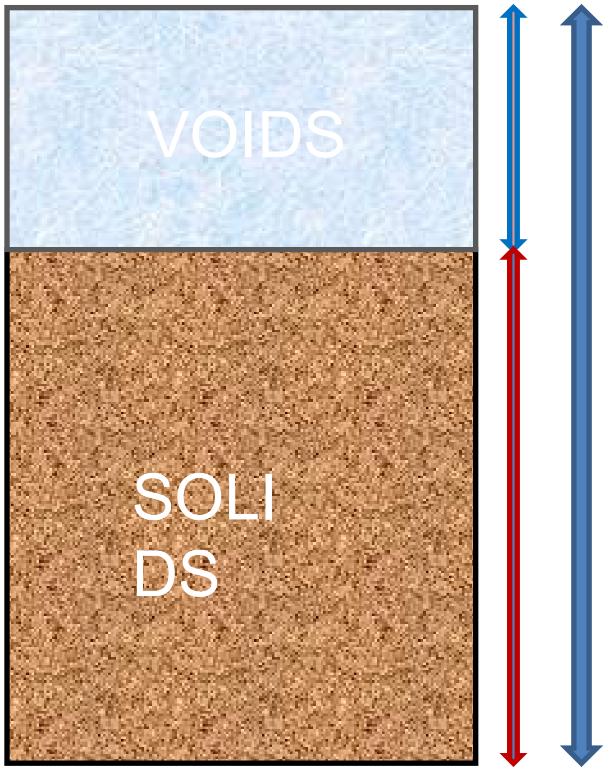
4.SUBMERGED DENSITY

- 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".

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



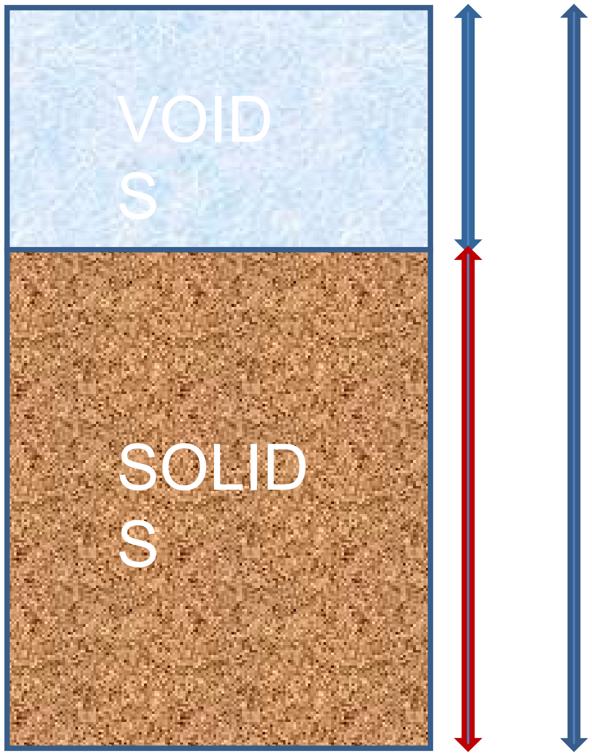
If volume of voids is taken as "n", the volume of solids, by definition of void ratio will be "1-n" and total volume equal to "1".

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

combining the above two eqution we get,

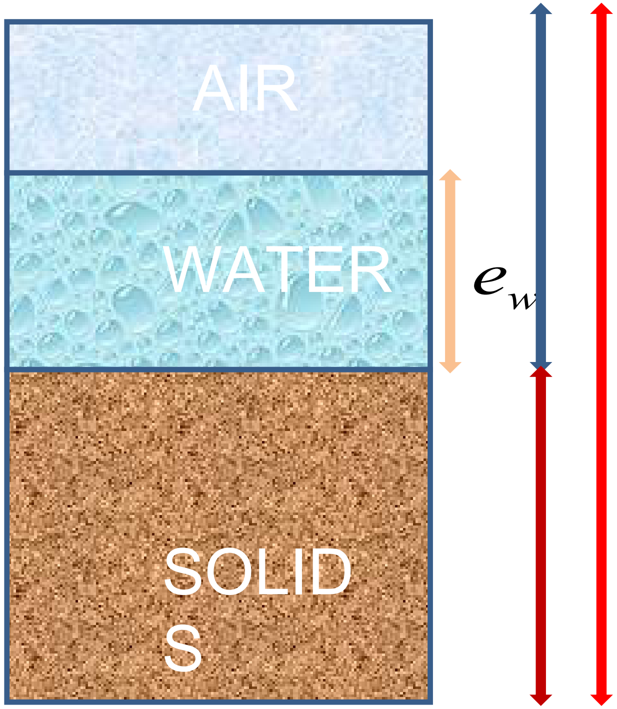
$$n = \frac{e}{1+e} = e(1-n) \qquad (\because n = \frac{e}{1+e})$$

$$\therefore (1-n) = \frac{1}{1+e}$$



RELATION BETWEEN e,G,w& S_r

$$w = \frac{M_w}{M_s} = \frac{\rho_w \, . \, \mathrm{V_w}}{\rho_s \, . \, \mathrm{V_s}} \quad \text{------}$$



$$S = \frac{V_w}{V_v} \qquad \mathrm{G} = \frac{\rho_s}{\rho_w} \qquad \therefore \rho_s = G\,\rho_w$$

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

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

$$\therefore \mathrm{Se} = \mathrm{wG}$$

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

DERIVE : $\rho_b = \dfrac{(G + e\,.\,\mathrm{S_r})\,\gamma_{\mathrm{w}}}{1+\mathrm{e}}$

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

$$\therefore\ \gamma_{\mathrm{b}} = \frac{\gamma_s\,.\,\mathrm{V_s} + \gamma_w . V_w}{V} \qquad (\because \gamma_{\mathrm{s}} = \frac{\mathrm{W_s}}{\mathrm{V_s}}\ \&\ \gamma_{\mathrm{w}} = \frac{\mathrm{W_w}}{\mathrm{V_w}})$$

$$\therefore \gamma_{\mathrm{b}} = \frac{\gamma_s . 1 + \gamma_{\mathrm{w}} . e_w}{1+e} \qquad \cdots \text{ from fig } \mathrm{V_s} = 1, \mathrm{V_w} = e_w, \mathrm{V} = 1 + \mathrm{e}$$

Now,

$$\gamma_{\mathrm{b}} = \frac{G.\gamma_w + e_w.\gamma_w}{1+e} \qquad \left(\because \mathrm{G} = \frac{\gamma_{\mathrm{s}}}{\gamma_w} \;\&\; \mathrm{e_w} = \mathrm{e.S_r}\right)$$

$$\gamma_{\mathrm{b}} = \frac{(G+e_w)\gamma_w}{1+e}$$

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

- If soil is fully dry, $\mathrm{S_r} = 0$ and $\gamma_{\mathrm{b}} = \gamma_d$

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

- If soil is fully saturated, $\mathrm{S_r} = 1$ and $\gamma_{\mathrm{b}} = \gamma_{sat}$

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

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

We know that,

$$\rho_b = \frac{\mathrm{M_t}}{\mathrm{V}} = \frac{M_s + M_w}{V}$$

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

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

$$\therefore \rho_b = \rho_{dry}.(1+w)$$

$$\therefore \rho_{dry} = \frac{\rho_b}{(1+w)}$$

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_{sat})	
Given	**Relationship**	**Given**	**Relationship**	**Given**	**Relationship**
w, G_s, e	$\dfrac{(1+w)G_s\gamma_w}{1+e}$	γ, w	$\dfrac{\gamma}{1+w}$	G_s, e	$\dfrac{(G_s+e)\gamma_w}{1+e}$
S, G_s, e	$\dfrac{(G_s+Se)\gamma_w}{1+e}$	G_s, e	$\dfrac{G_s\gamma_w}{1+e}$	G_s, n	$[(1-n)G_s+n]\gamma_w$
w, G_s, S	$\dfrac{(1+w)G_s\gamma_w}{1+\dfrac{wG_s}{S}}$	G_s, n	$G_s\gamma_w(1-n)$	G_s, w_{sat}	$\left(\dfrac{1+w_{sat}}{1+w_{sat}G_s}\right)G_s\gamma_w$
w, G_s, n	$G_s\gamma_w(1-n)(1+w)$	G_s, w, S	$\dfrac{G_s\gamma_w}{1+\left(\dfrac{wG_s}{S}\right)}$	e, w_{sat}	$\left(\dfrac{e}{w_{sat}}\right)\left(\dfrac{1+w_{sat}}{1+e}\right)\gamma_w$
S, G_s, n	$G_s\gamma_w(1-n)+nS\gamma_w$	e, w, S	$\dfrac{eS\gamma_w}{(1+e)w}$	n, w_{sat}	$n\left(\dfrac{1+w_{sat}}{w_{sat}}\right)\gamma_w$
		γ_{sat}, e	$\gamma_{sat}-\dfrac{e\gamma_w}{1+e}$	γ_d, e	$\gamma_d+\left(\dfrac{e}{1+e}\right)\gamma_w$
		γ_{sat}, n	$\gamma_{sat}-n\gamma_w$	γ_d, n	$\gamma_d+n\gamma_w$
		γ_{sat}, G_s	$\dfrac{(\gamma_{sat}-\gamma_w)G_s}{(G_s-1)}$	γ_d, S	$\left(1-\dfrac{1}{G_s}\right)\gamma_d+\gamma_w$
				γ_d, w_{sat}	$\gamma_d(1+w_{sat})$

DETERMINATION OF INDEX PROPERTIES OF 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
d. Particle size
e. Consistency
f. Density index

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
f) Pycnometer method
g) Infra-red 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 not be used for organic soil or soil containing higher percentage of gypsum.

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

M_3= mass of container + dry soil

OVEN DRYING METHOD

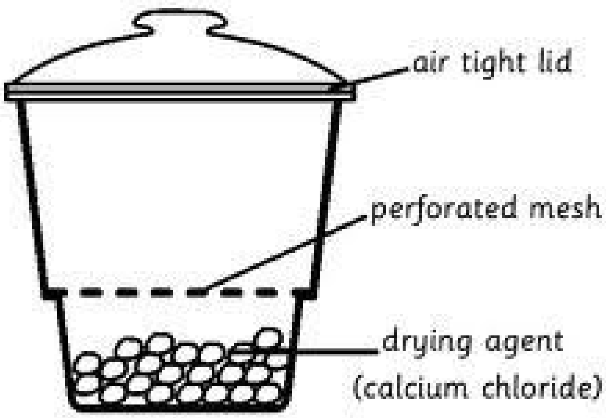
Equipments:-

- 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 dry soil sample.

The Desiccator



Now, water content can be calculated as;

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

SPECIFIC GRAVITY DETERMINATION

- The specific gravity of solids is frequently required for computation of several soil properties such as void ratio, degree 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
5. Shrinkage limit method

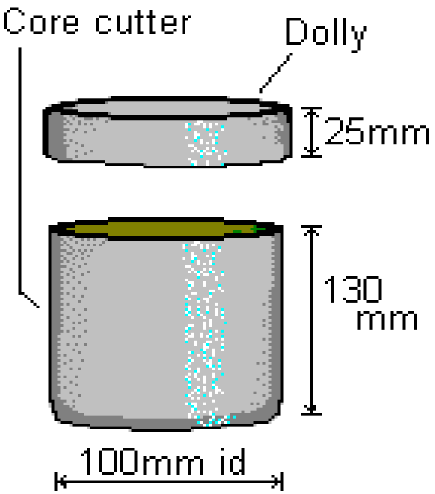
PYCNOMETER BOTTLE METHOD

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 mass as M4.
7. Now, calculate the specific gravity of soil solids as under :

$$G = (M2-M1) / (M4-M1) – (M3-M2)$$

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.
7. Weight the core cutter filled with the soil (W2).
8. Remove the core of the soil from the cutter. Determine the water content.



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).
4. Weigh the pouring cylinder with sand (W3) after filling the cone and the calibration container.
5. Weight of sand in the calibration container Ws = W1 – W2 –W3

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

e_{min} = void ratio of the soil in the densest state

e = void ratio for in situ.

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

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

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

$\mathrm{V_m}$ = volume of mould

similarly;

$$\rho_{\max} = \frac{M_{\max}}{V_m}$$

ATTERBERG LIMITS

- Liquid limit test:

  A soil is place in the grooving tool which consists of a brass cup and a hard rubber base. A groove is cut at the center of the soil pat using a standard grooving tool. The cup is then repeatedly drooped from a height of 10 mm until a groove closure of 12.7 mm. The soil is then removed and its moisture content is determined. The soil is said to be at its liquid limit when exactly 25 drops are required to close the groove for a distance of 12.7 mm (one half of an inch)

- Plastic limit test:

  A soil sample is rolled into threads until it becomes thinner and eventually breaks at 3 mm. it is defined as the moisture content in percent at which the soil crumbles when rolled into the threads of 3.0 mm. If it is wet, it breaks at a smaller diameter; if it is dry it breaks at a larger diameter.

- Shrinkage limit test:

  It is performed in the laboratory with a porcelain dish approximately 45 mm in diameter and about 12.7 mm high. The dish is completely filled with wet soil. The mass and volume of the wet soil is then recorded. The dish is then oven dried, then the mass and volume of the oven dried soil is also recorded.

- Shrinkage limit test:

The moisture content in percent at which the soil mass ceases to change is known as the **shrinkage limit.**

$$\boldsymbol{S.L.} = \frac{(\boldsymbol{m_1} - \boldsymbol{m_2})}{\boldsymbol{m_2}}(\mathbf{100}) - \frac{(\boldsymbol{V_1} - \boldsymbol{V_2})}{\boldsymbol{m_2}}\boldsymbol{\rho_W}(\mathbf{100})$$

Where:

$$m_1 = mass\ of\ the\ wet\ soil\ in\ the\ dish$$
$$m_2 = mass\ of\ the\ dry\ soil\ in\ the\ dish$$
$$V_1 = initial\ volume\ of\ wet\ soil$$
$$V_2 = final\ volume\ of\ dry\ soil$$
$$\rho_W = density\ of\ water$$

- **Plasticity Index**

Is the difference between liquid limit test and plastic limit test. It is measured of the range of moisture content that encompasses the plastic state.

$$P.I. = LL - PL$$

- **Liquidity Index**

Is a ratio which signifies the relative consistency of a cohesive soil in the natural state. When the liquidity index is 0 it means the soil is at its plastic limit and when it is equal to 1 the soil is at its liquid limit.

$$L.I. = \frac{\omega - PL}{LL - PL}$$

If I give you a bag of 1-Kg soil taken from an under construction site and ask you the following questions.

1. What is the most basic classification of soil?
2. What are the methods of soil gradation or grain size distribution?
3. How do you define the soil types? Clay, Silt, Sand, Gravel or cobble and boulder
4. Calculate **D_{10}, D_{30} and D_{60}** of this soil using the sieve analysis?
5. Calculate both the **C_u and C_c** of this soil?
6. Is this soil poorly, gap or well graded, Liquid limit and Plastic limit? How do you define theses terms?

You will learn in today's practical class

Answer all the above questions in your first report.

Purpose:

- This test is performed to determine the percentage of different grain sizes contained within a soil.
- The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles.

Significance:

- The distribution of different grain sizes affects the engineering properties of soil.
- Grain size analysis provides the grain size distribution, and it is required in classifying the soil.

Major Soil Groups

Cohesive soils

Granular soils or **Cohesionless** soils

Clay	Silt	Sand	Gravel	Cobble	Boulder
	0.002	0.075	4.75		

Grain size (mm)

Fine grain soils

Coarse grain soils

Grain Size Distribution

Significance of GSD:

- To know the relative proportions of different grain sizes.

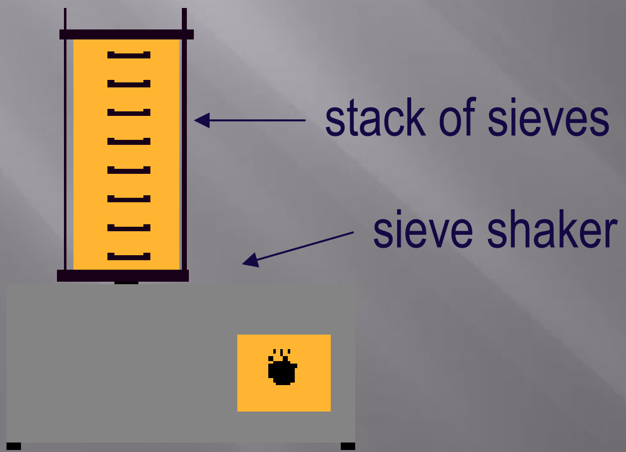
- An important factor influencing the geotechnical characteristics of a **coarse** grain soil.

- Not important in fine grain soils.

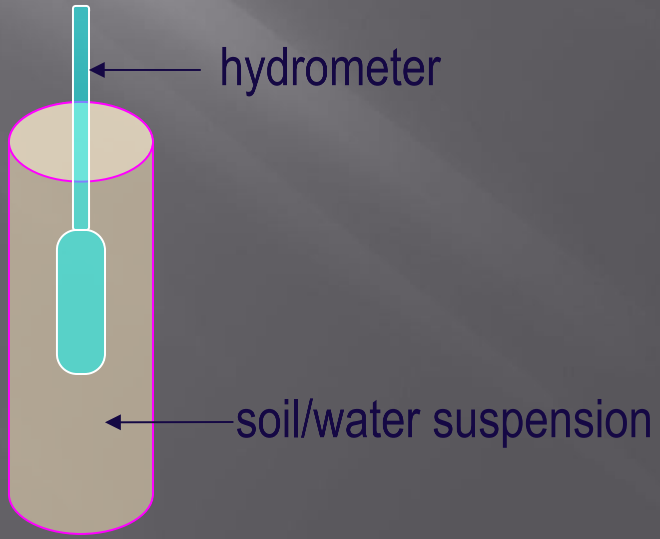
Grain Size Distribution

Determination of GSD:

- In coarse grain soils …… By sieve analysis
- In fine grain soils …… By hydrometer analysis

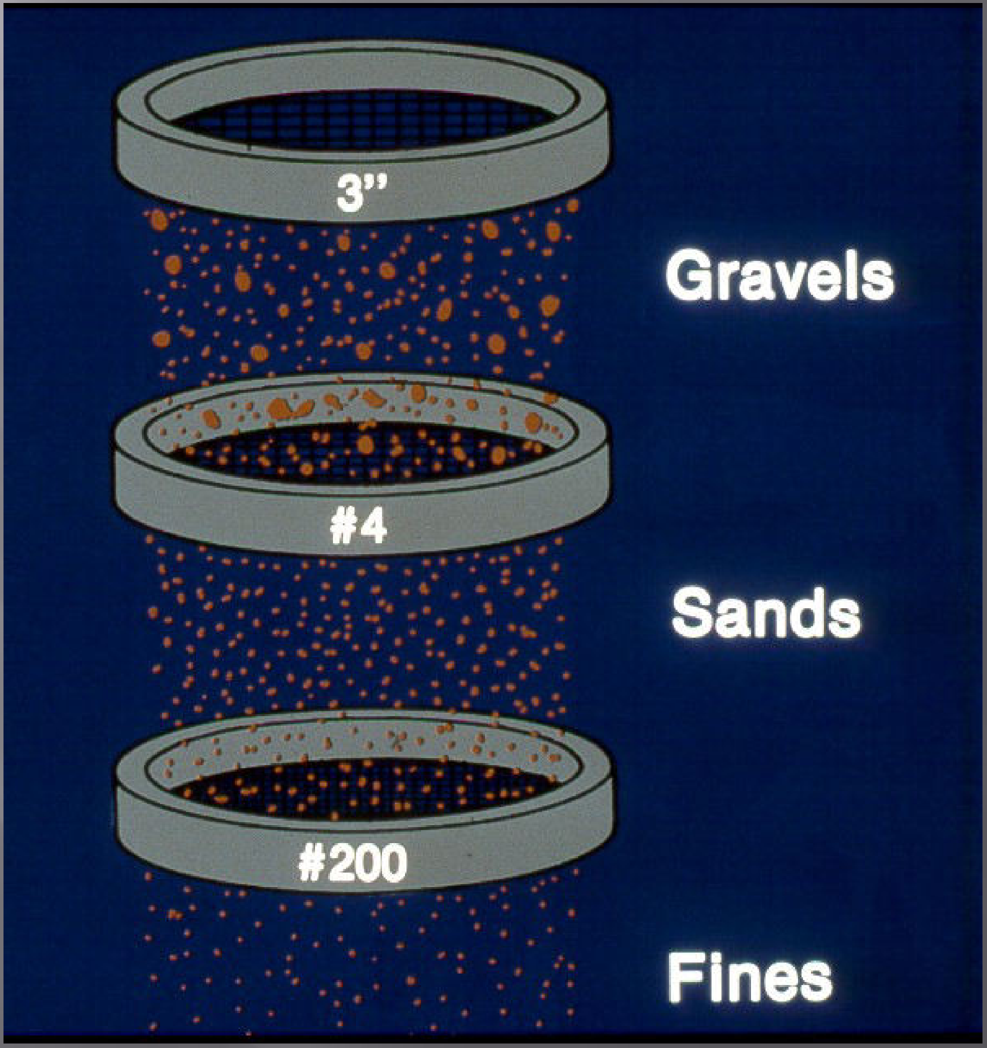


Sieve Analysis



Hydrometer Analysis

Sieve Analyses

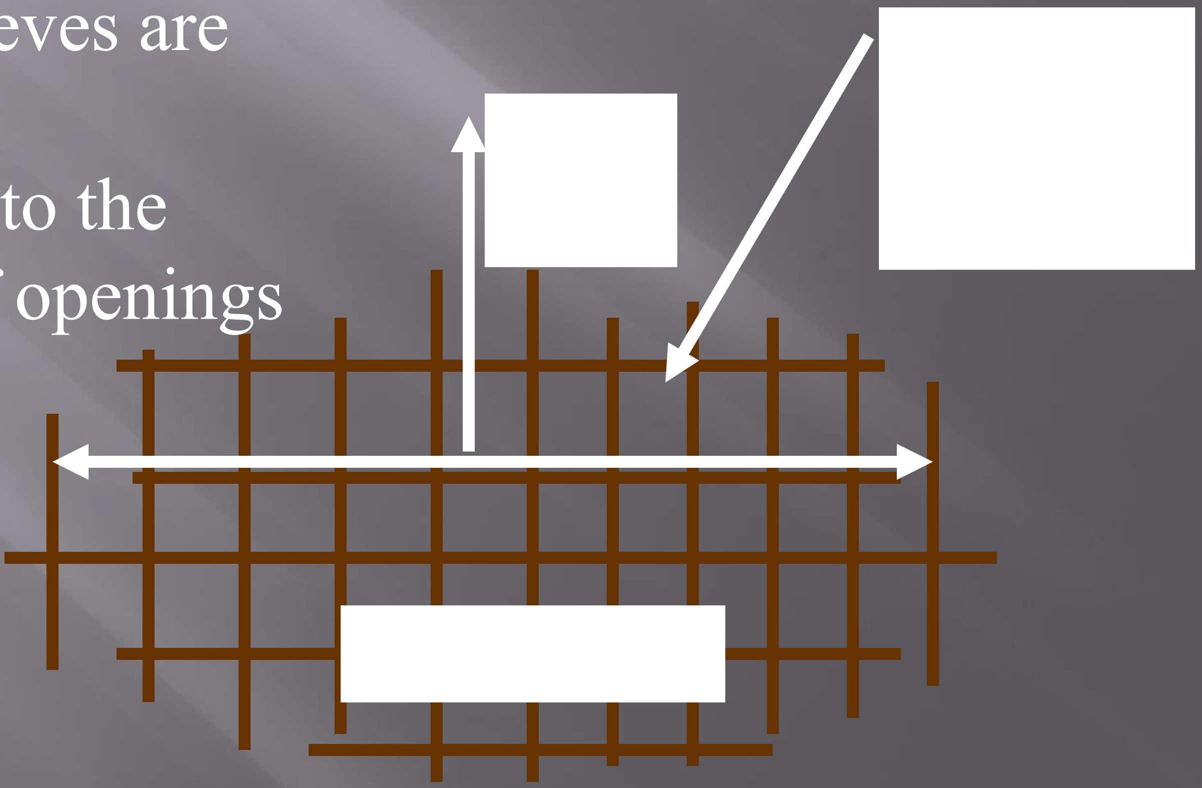


Sieve Analysis

Sieve Designation - Large

Sieve Designation - Smaller

Smaller sieves are numbered according to the number of openings per inch



Sieving procedure

(1) Write down the weight of each sieve as well as the bottom pan to be used in the analysis.

(2) Record the weight of the given dry soil sample.

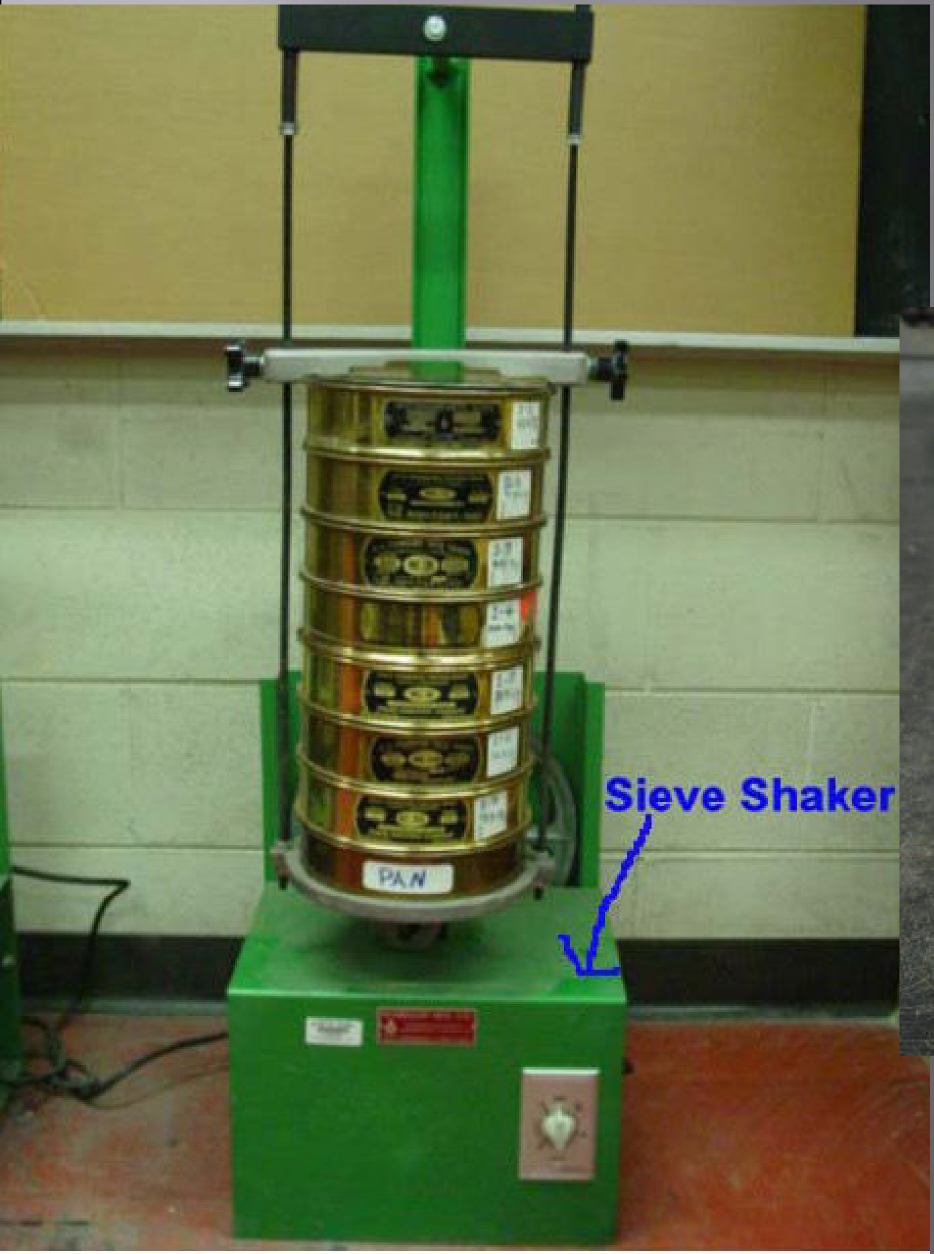
(3) Make sure that all the sieves are clean, and assemble them in the ascending order of sieve numbers (#4 sieve at top and #200 sieve at bottom). Place the pan below #200 sieve. Carefully pour the soil sample into the top sieve and place the cap over it.

(4) Place the sieve stack in the mechanical shaker and shake for 10 minutes.

(5) Remove the stack from the shaker and carefully weigh and record the weight of each sieve with its retained soil. In addition, remember to weigh and record the weight of the bottom pan with its retained fine soil.


Set of Sieves
Soil Specimen
Balance
PAN


PAN


Sieve Shaker
PAN

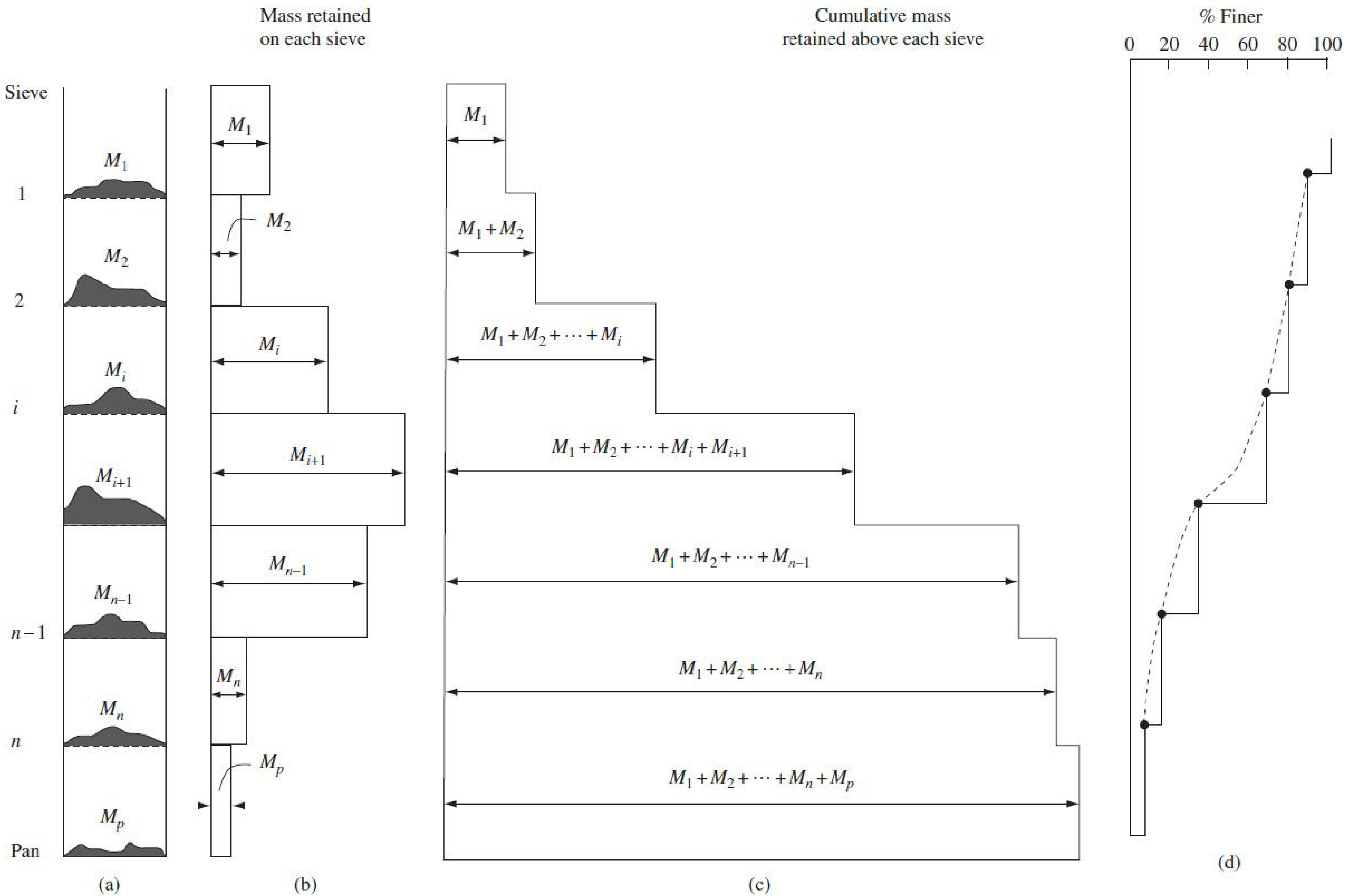

GEOTEST ELECTRONIC SOLUTION BALANCE U-1027
0.824
lb
lb/oz
kg
MODE
OFF
SAMPLE
SET
ON
ZERO-TARE
PCS

Data Analysis:

(1) Obtain the mass of soil retained on each sieve by subtracting the weight of the empty sieve from the mass of the sieve + retained soil, and record this mass as the weight retained on the data sheet. The sum of these retained masses should be approximately equals the initial mass of the soil sample. A loss of more than two percent is unsatisfactory.

(2) Calculate the percent retained on each sieve by dividing the weight retained on each sieve by the original sample mass.

(3) Calculate the percent passing (or percent finer) by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure.



Mass retained
on each sieve
Cumulative mass
retained above each sieve
% Finer
0 20 40 60 80 100
Sieve
1
2
i
$n-1$
n
Pan
M_1
M_2
M_i
M_{i+1}
M_{n-1}
M_n
M_p
$M_1 + M_2$
$M_1 + M_2 + \cdots + M_i$
$M_1 + M_2 + \cdots + M_i + M_{i+1}$
$M_1 + M_2 + \cdots + M_{n-1}$
$M_1 + M_2 + \cdots + M_n$
$M_1 + M_2 + \cdots + M_n + M_p$
(a)
(b)
(c)
(d)

Sieve Number	Diameter (mm)	Mass of Empty Sieve (g)	Mass of Sieve+Soil Retained (g)	Soil Retained (g)	Percent Retained	Percent Passing
4	4.75	116.23	166.13	49.9	9.5	90.5
10	2.0	99.27	135.77	36.5	7.0	83.5
20	0.84	97.58	139.68	42.1	8.0	75.5
40	0.425	98.96	138.96	40.0	7.6	67.8
60	0.25	91.46	114.46	23.0	4.4	63.4
140	0.106	93.15	184.15	91.0	17.4	46.1
200	0.075	90.92	101.12	10.2	1.9	44.1
Pan	---	70.19	301.19	231.0	44.1	0.0
			Total Weight=	523.7		

For example: Total mass = 500 g,

Mass retained on No. 4 sieve = 9.7 g

For the No.4 sieve:

Quantity passing = Total mass - Mass retained

= 500 - 9.7 = 490.3 g

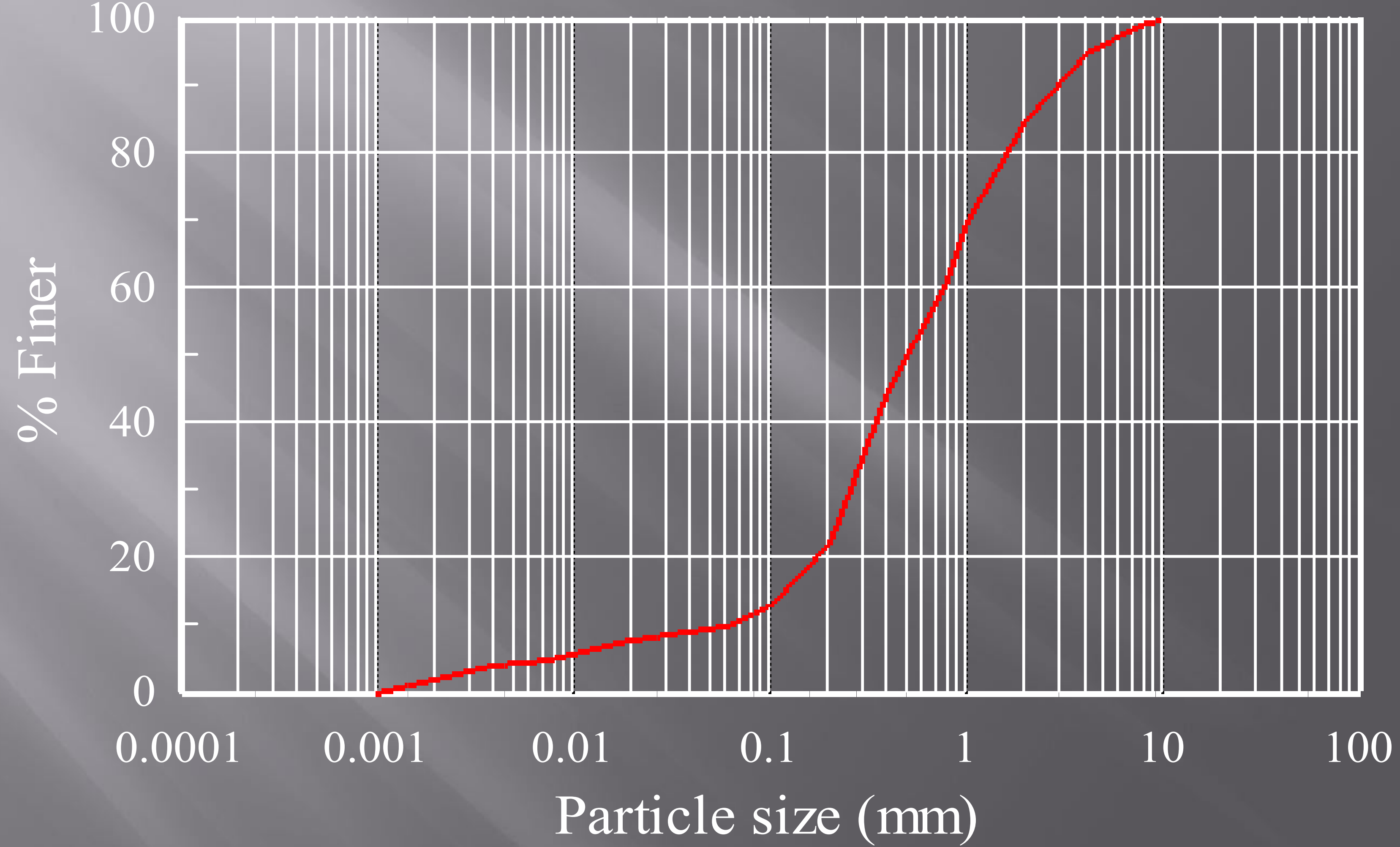
The percent retained is calculated as;

% retained = Mass retained/Total mass

= (9.7/500) X 100 = 1.9 %

From this, the % passing = 100 - 1.9 = 98.1 %

Grain size distribution



Unified Soil Classification

- Each soil is given a 2 letter classification (e.g. SW). The following procedure is used.

  - Coarse grained (>50% larger than 75 mm)

    - Prefix S if > 50% of coarse is Sand
    - Prefix G if > 50% of coarse is Gravel

    - Suffix depends on %fines

    - if %fines < 5% suffix is either W or P
    - if %fines > 12% suffix is either M or C
    - if 5% < %fines < 12% Dual symbols are used

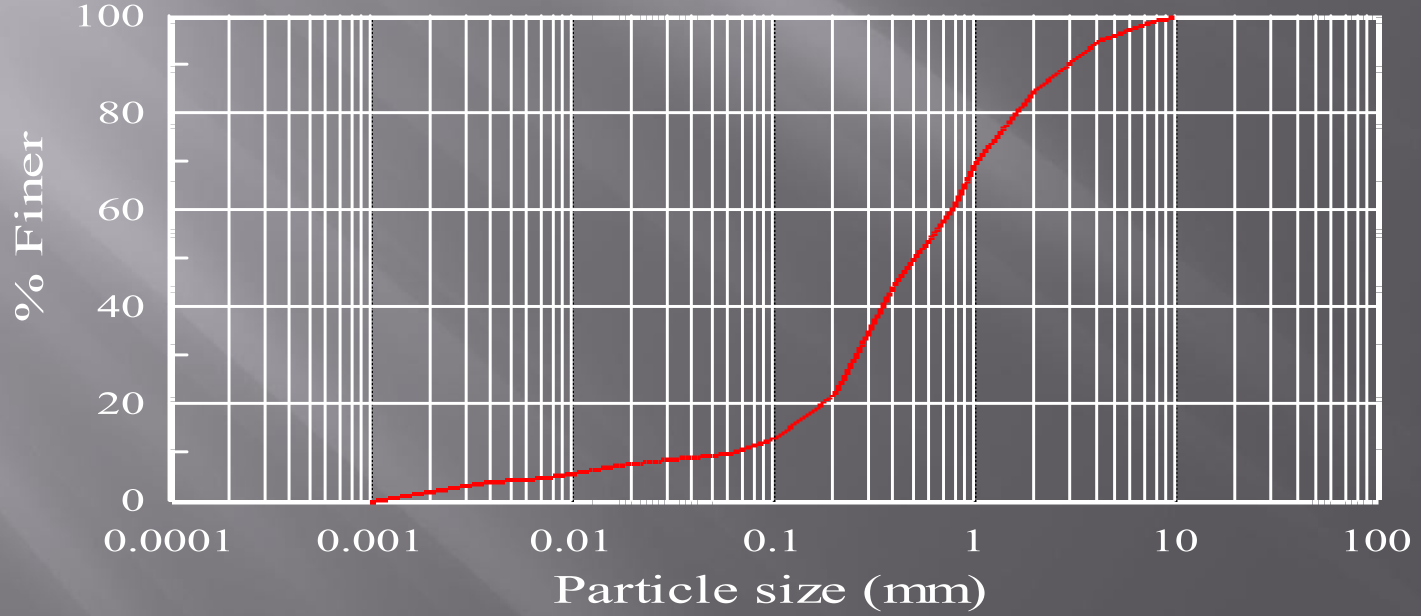
Unified Soil Classification

To determine W or P, calculate C_u and C_c

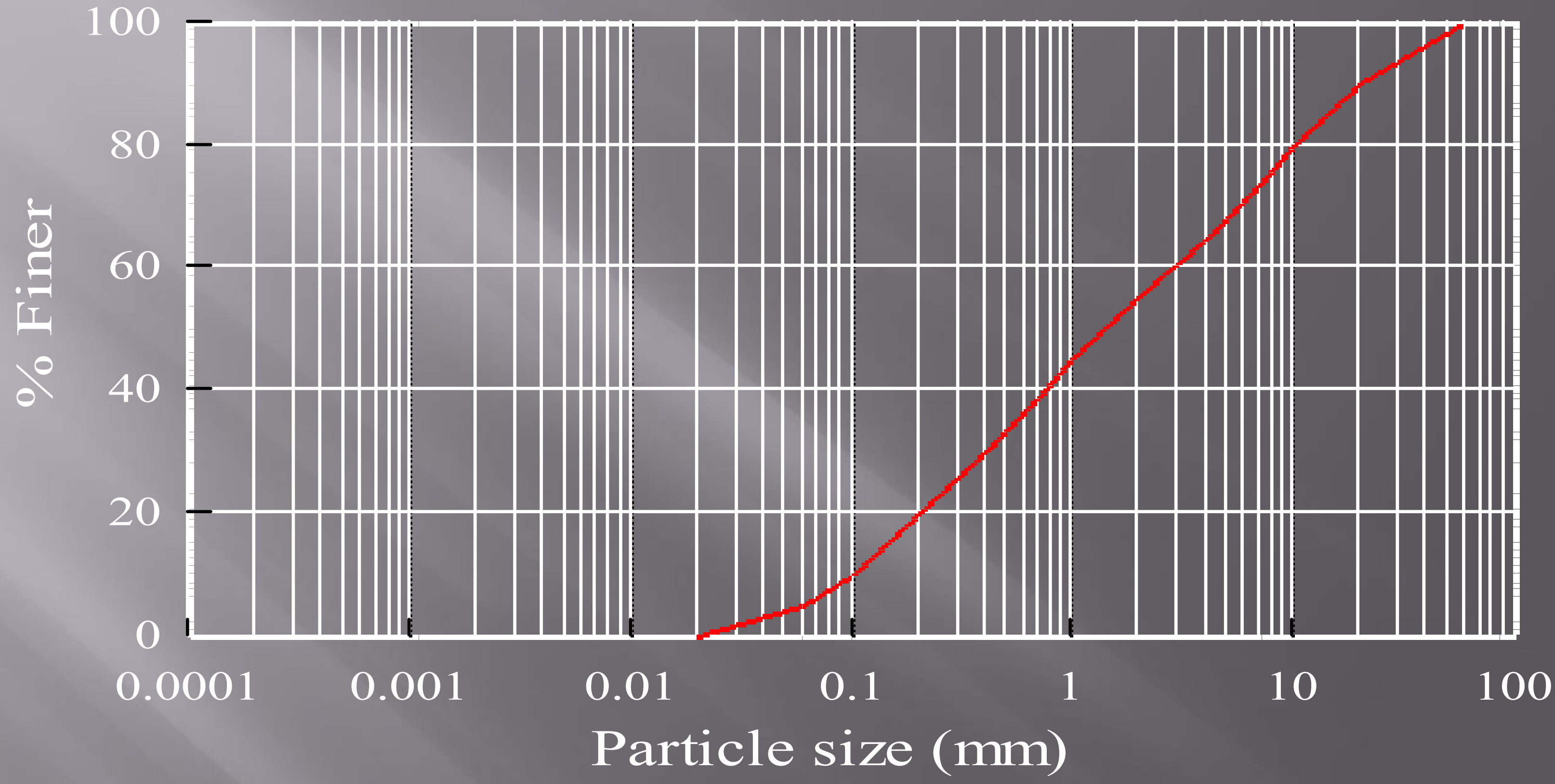
$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_c = \frac{D_{30}^2}{(D_{60} \times D_{10})}$$

x% of the soil has particles smaller than D_x

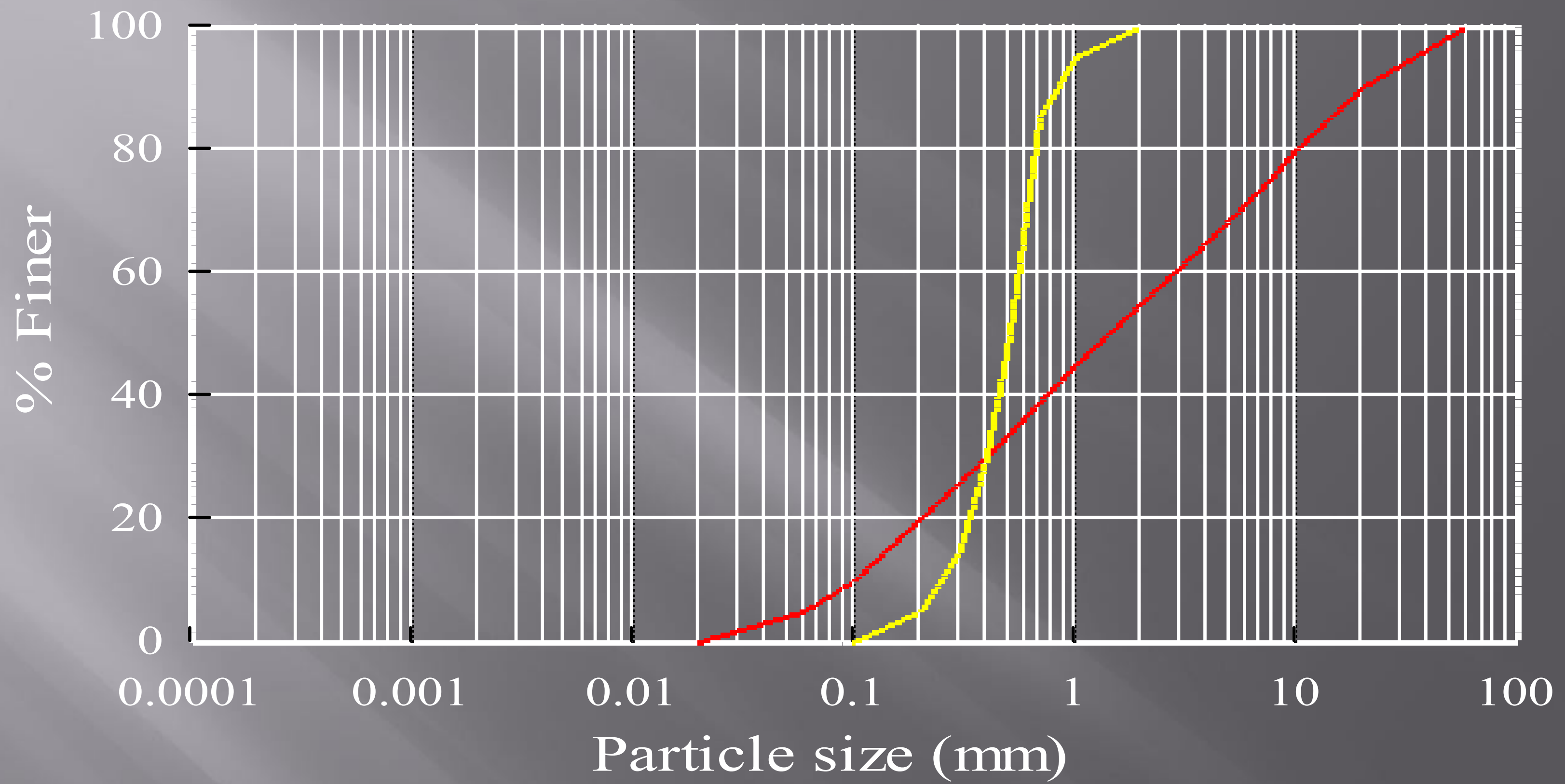


Grading curves



W Well graded

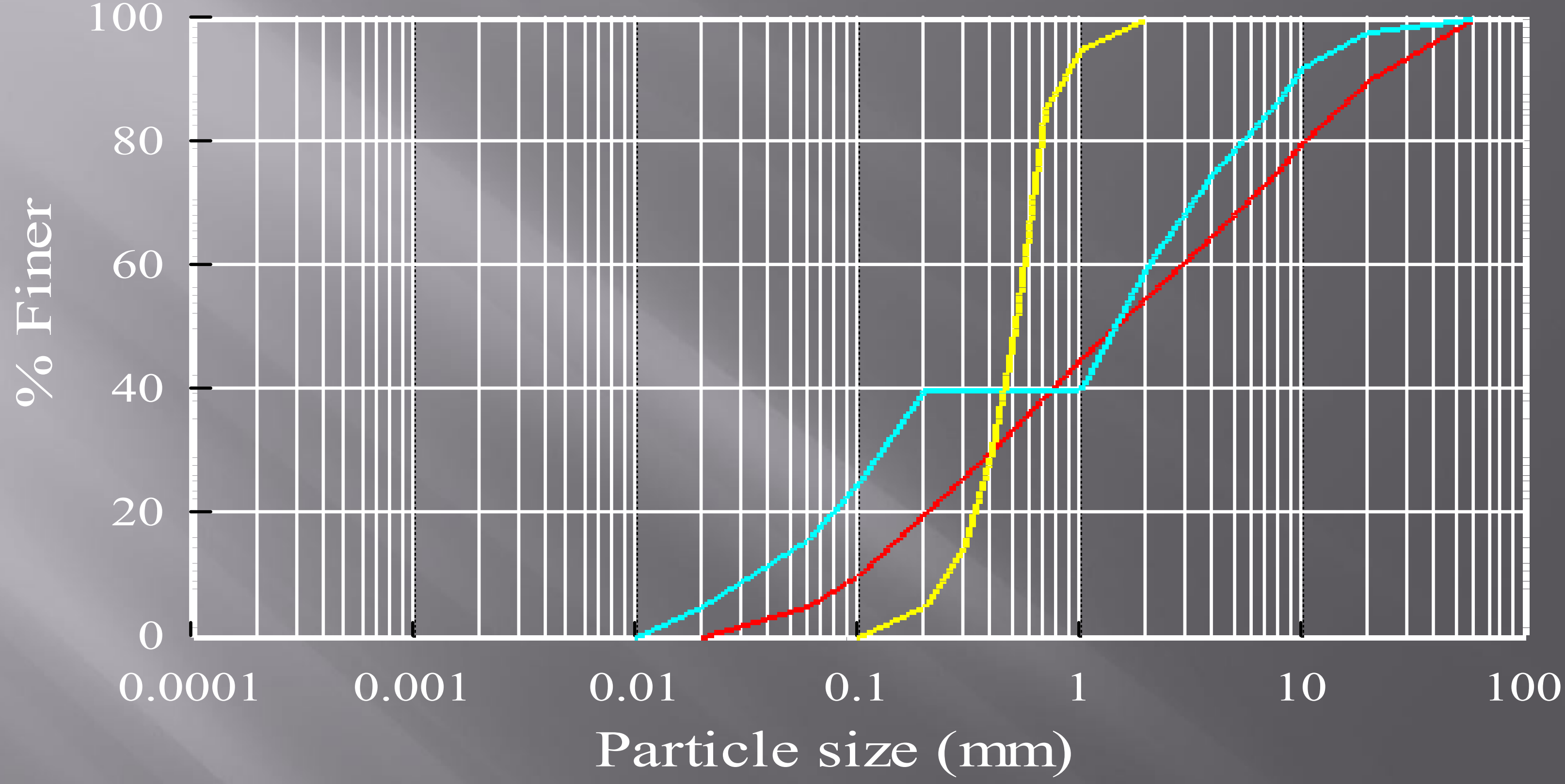
Grading curves



W Well graded

U Uniform

Grading curves

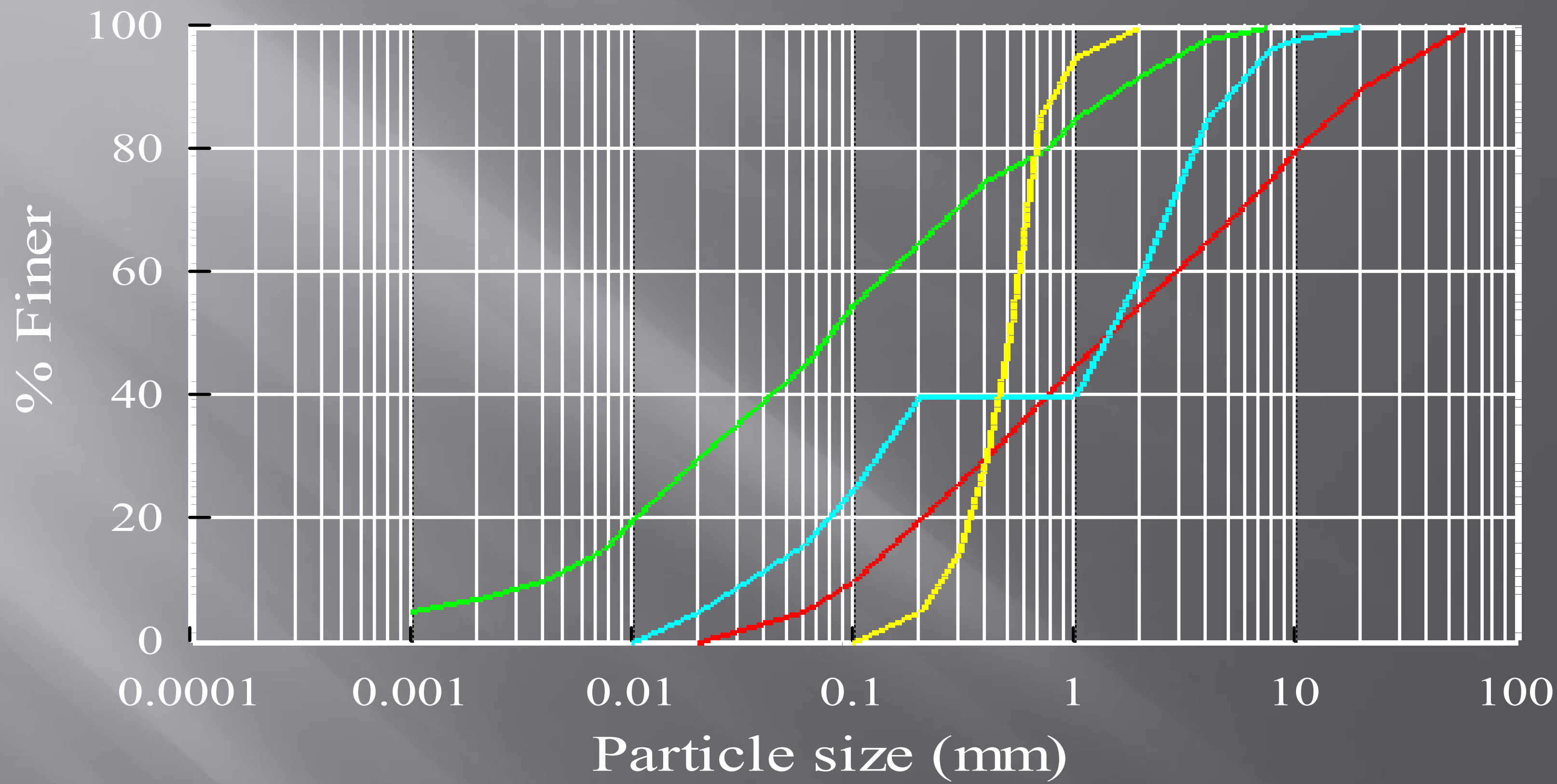


W Well graded

U Uniform

P Poorly graded

Grading curves



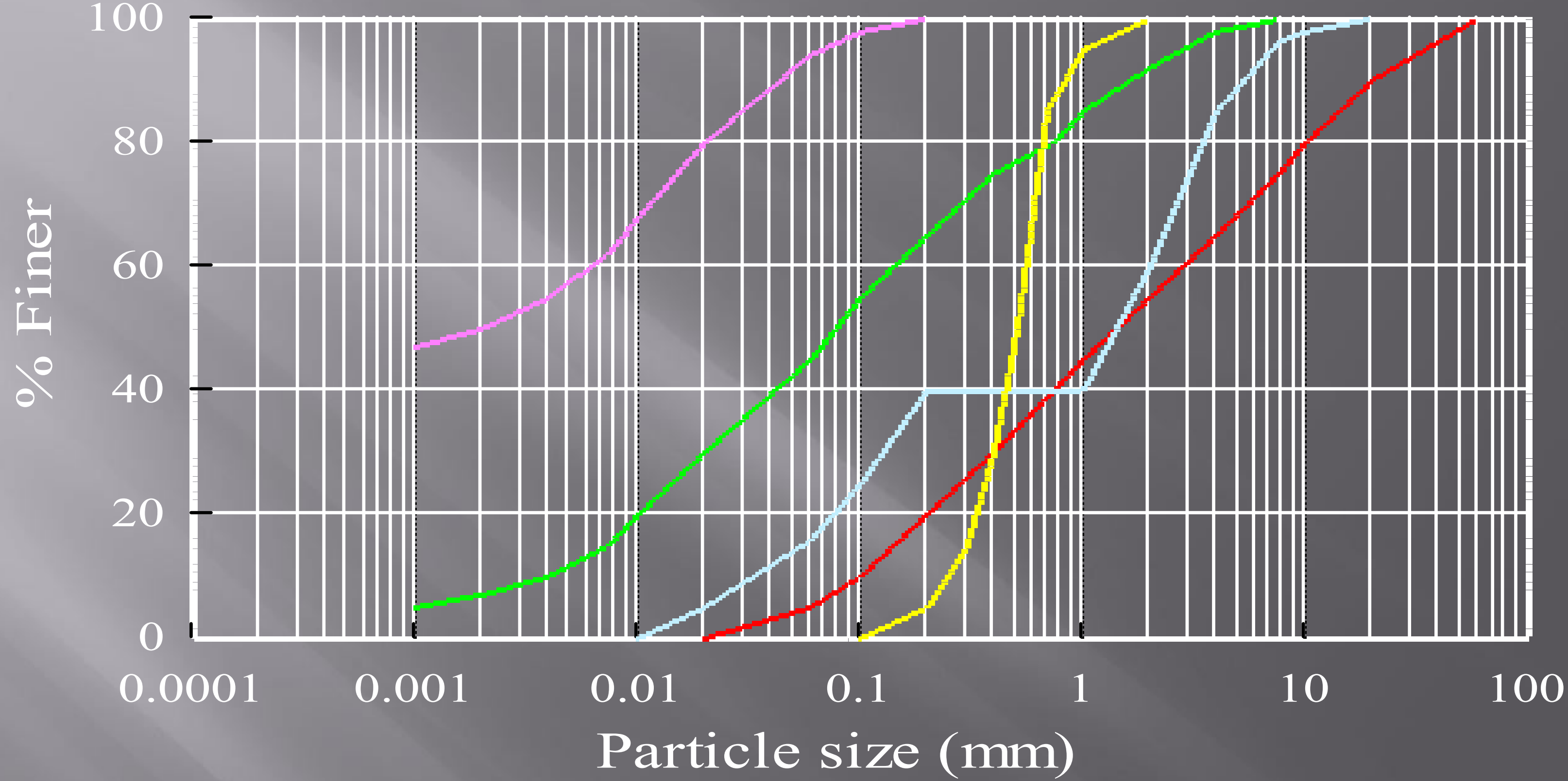
W Well graded

U Uniform

P Poorly graded

C Well graded with some clay

Grading curves

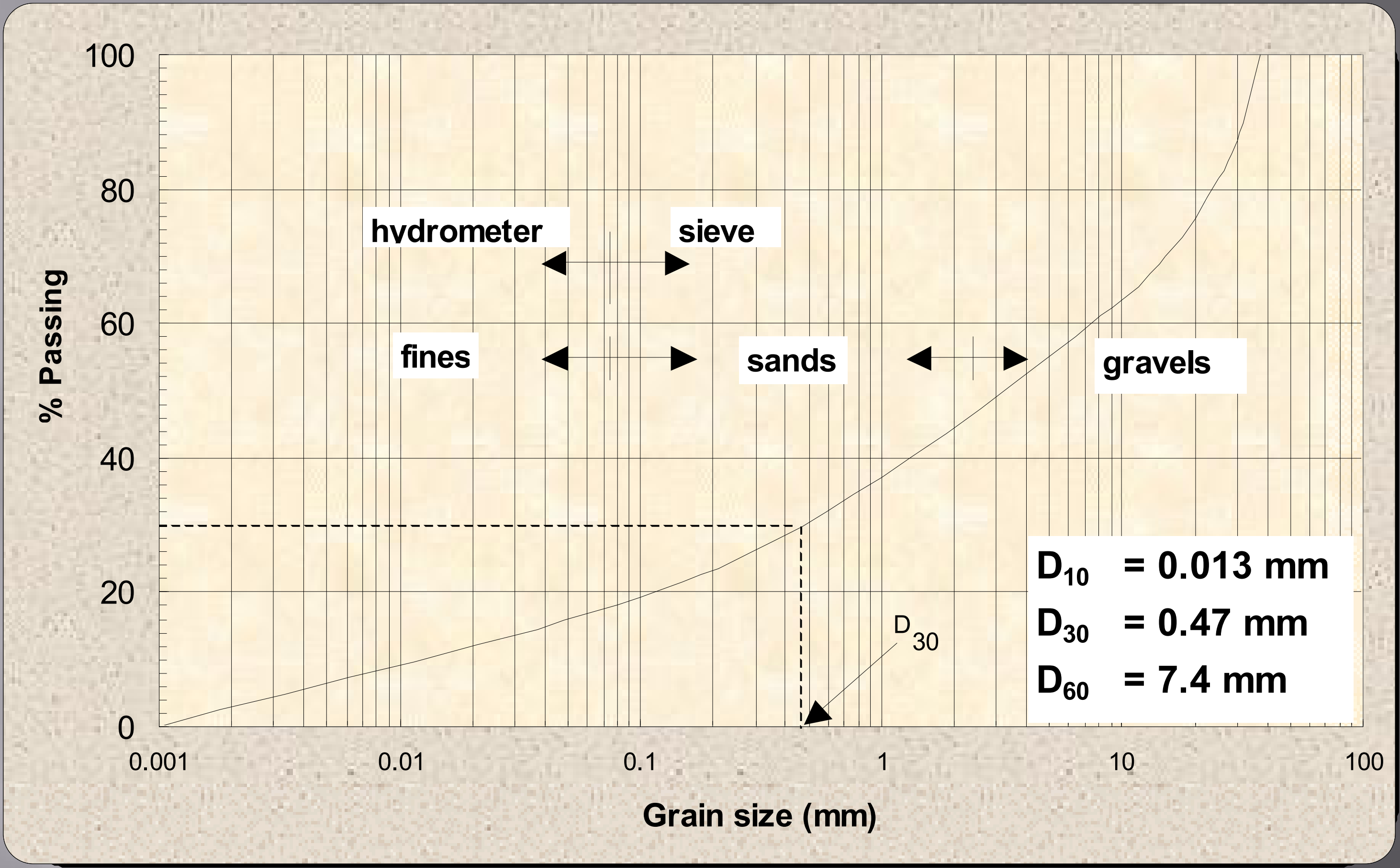


W Well graded

U Uniform

P Poorly graded

C Well graded with some clay



Grain Size Distribution Curve

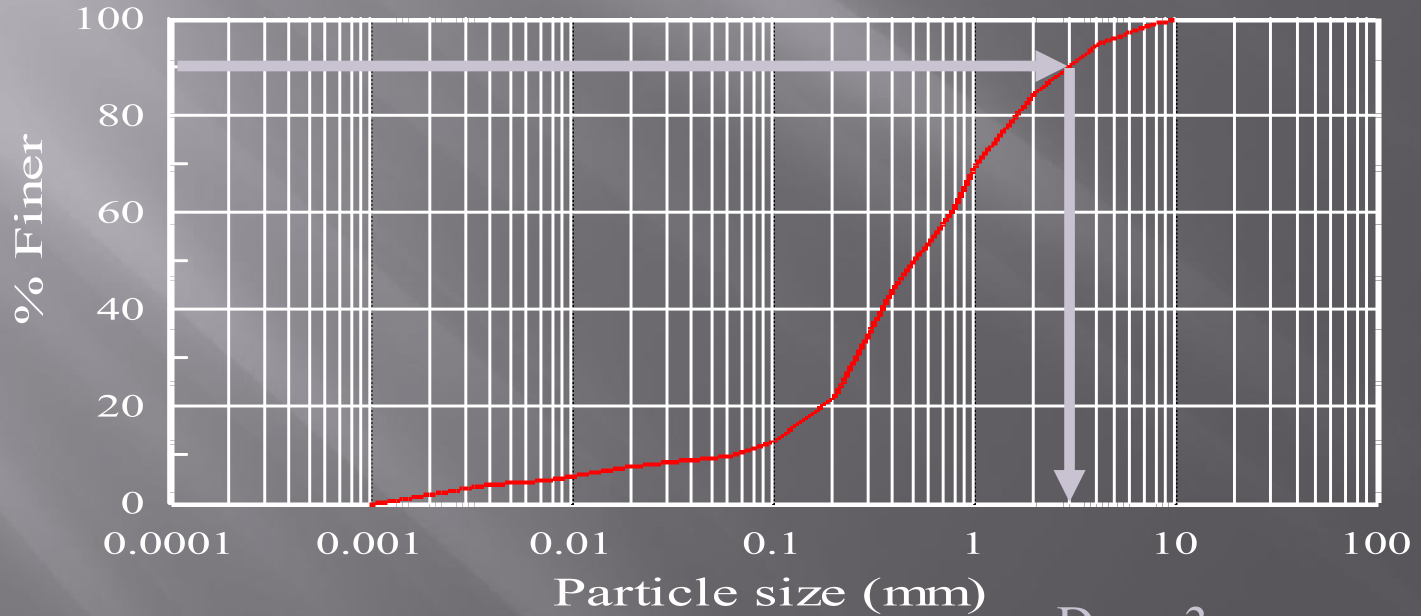
- can find % of gravels, sands, fines
- define D_{10}, D_{30}, D_{60}.. as above.

To determine W or P, calculate C_u and C_c

$$C_u = \frac{D_{60}}{D_{10}}$$

$$C_c = \frac{D_{30}^2}{(D_{60} \times D_{10})}$$

x% of the soil has particles smaller than D_x



$D_{90} = 3$ mm

Well or Poorly Graded Soils

Well Graded Soils

Wide range of grain sizes present

Gravels: C_c = 1-3 & C_u >4

Sands: C_c = 1-3 & C_u >6

Poorly Graded Soils

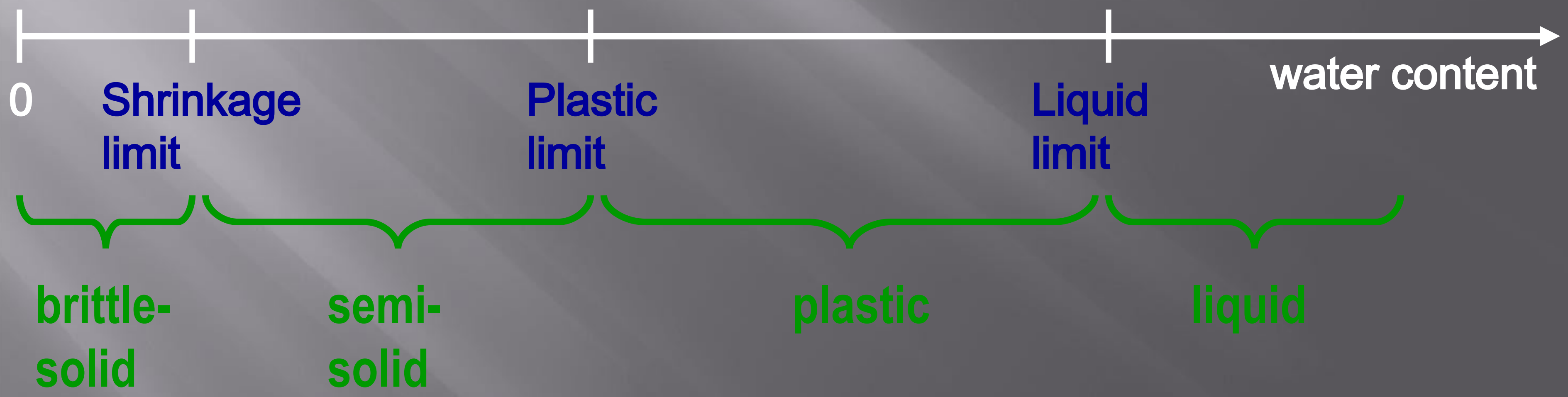
Others, including two special cases:

(a) Uniform soils – grains of same size

(b) Gap graded soils – no grains in a specific size range

Atterberg Limits

- Border line **water contents**, separating the different **states** of a fine grained soil



Purpose:

This lab is performed to determine the plastic and liquid limits of a fine grained soil. The Atterberg limits are based on the moisture content of the soil.

The plastic limit: is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state.

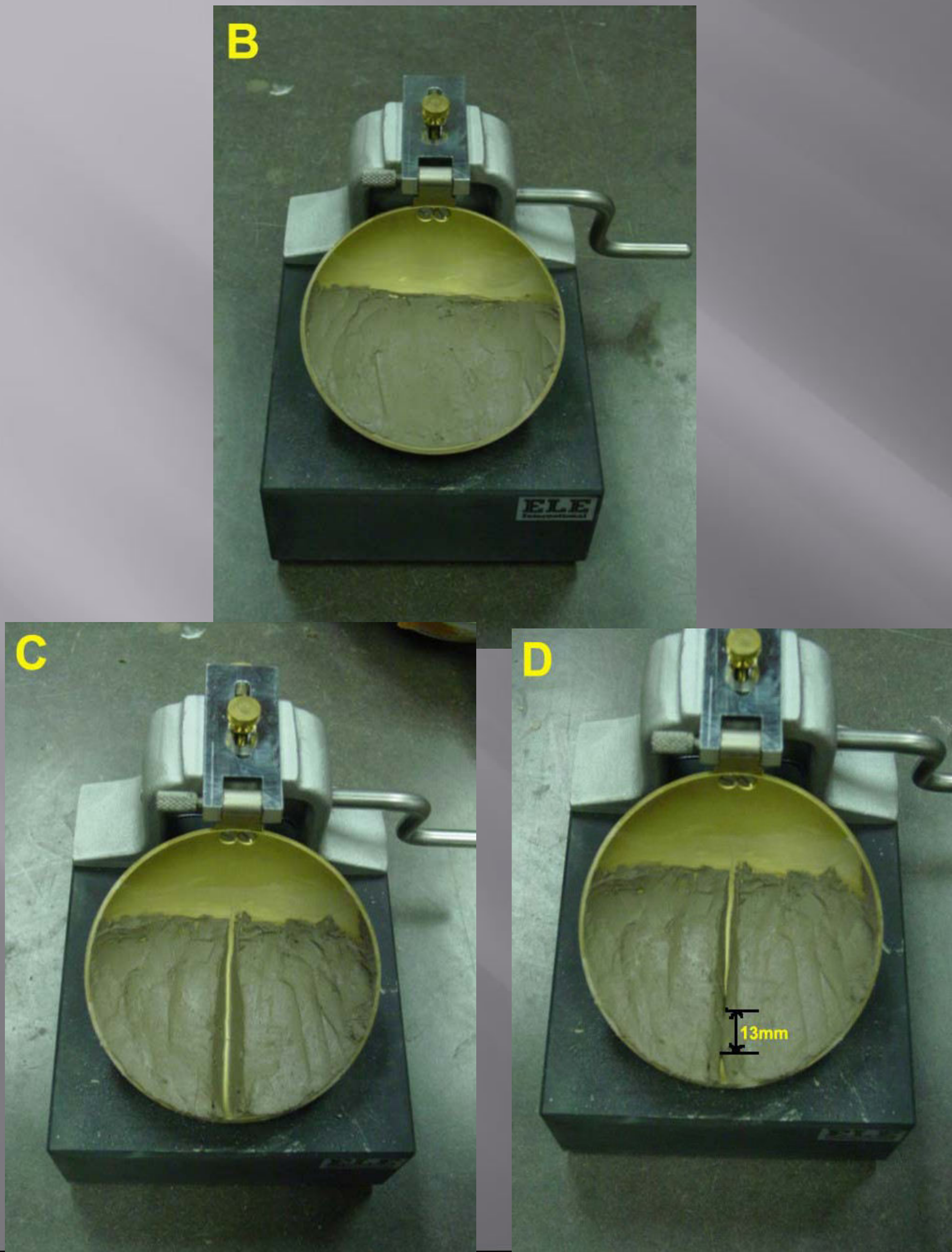
The liquid limit: is the moisture content that defines where the soil changes from a plastic to a viscous fluid state.


A
Spatula
Liquid limit device
Grooving tool
Soil specimen
Moisture cans

Liquid Limit Definition

- The water content at which a soil changes from a plastic consistency to a liquid consistency
- Defined by Laboratory Test concept developed by Atterberg in 1911.

ned by Laboratory Test concept developed by Atterberg in



The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a pat of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 12 mm under the impact of 25 blows in the devise.

The cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second.

Atterberg Limits

Liquid Limit (w_L or LL):

Clay flows like liquid when w > LL

Plastic Limit (w_P or PL):

Lowest water content where the clay is still plastic

Shrinkage Limit (w_S or SL):

At w<SL, no volume reduction on drying

LL Test Procedure

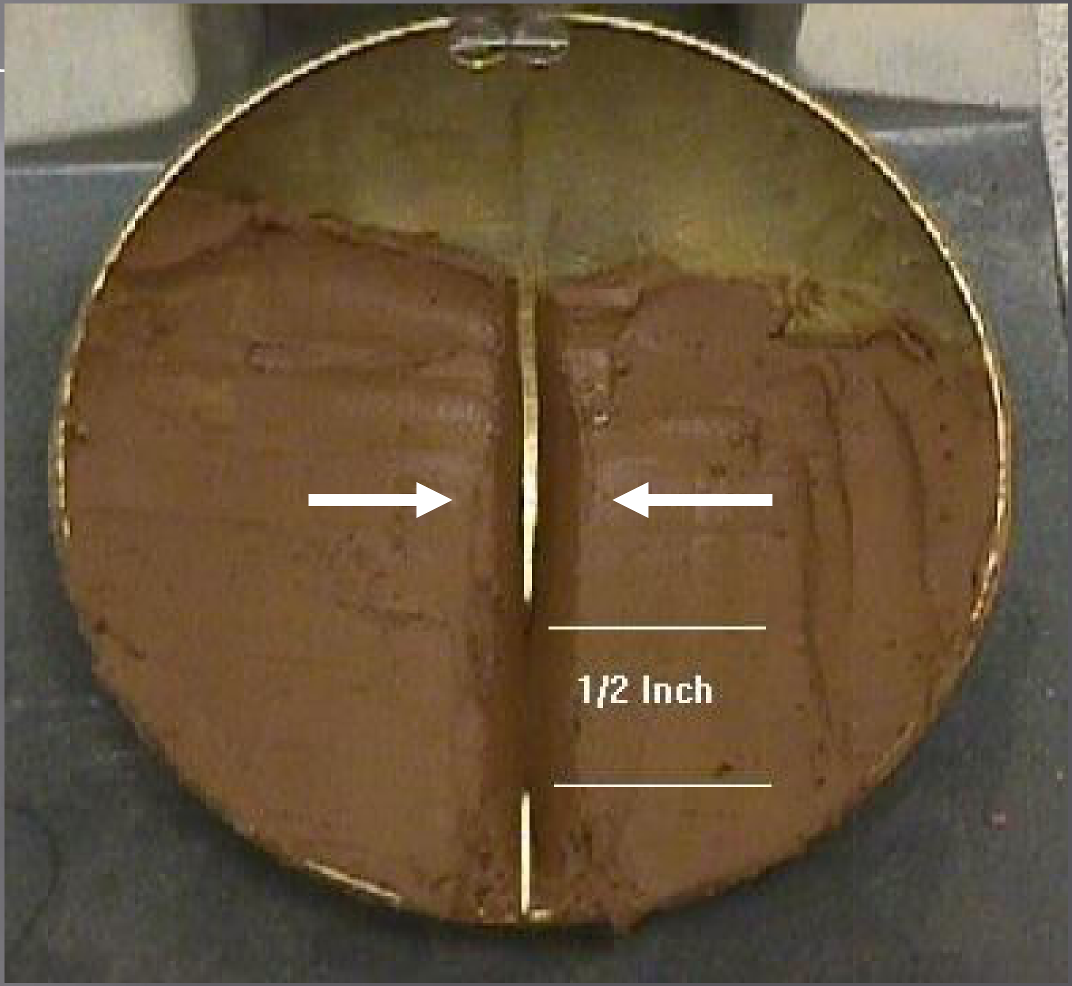
- Prepare paste of soil finer than 425 micron sieve
- Place Soil in Cup

LL Test Procedure

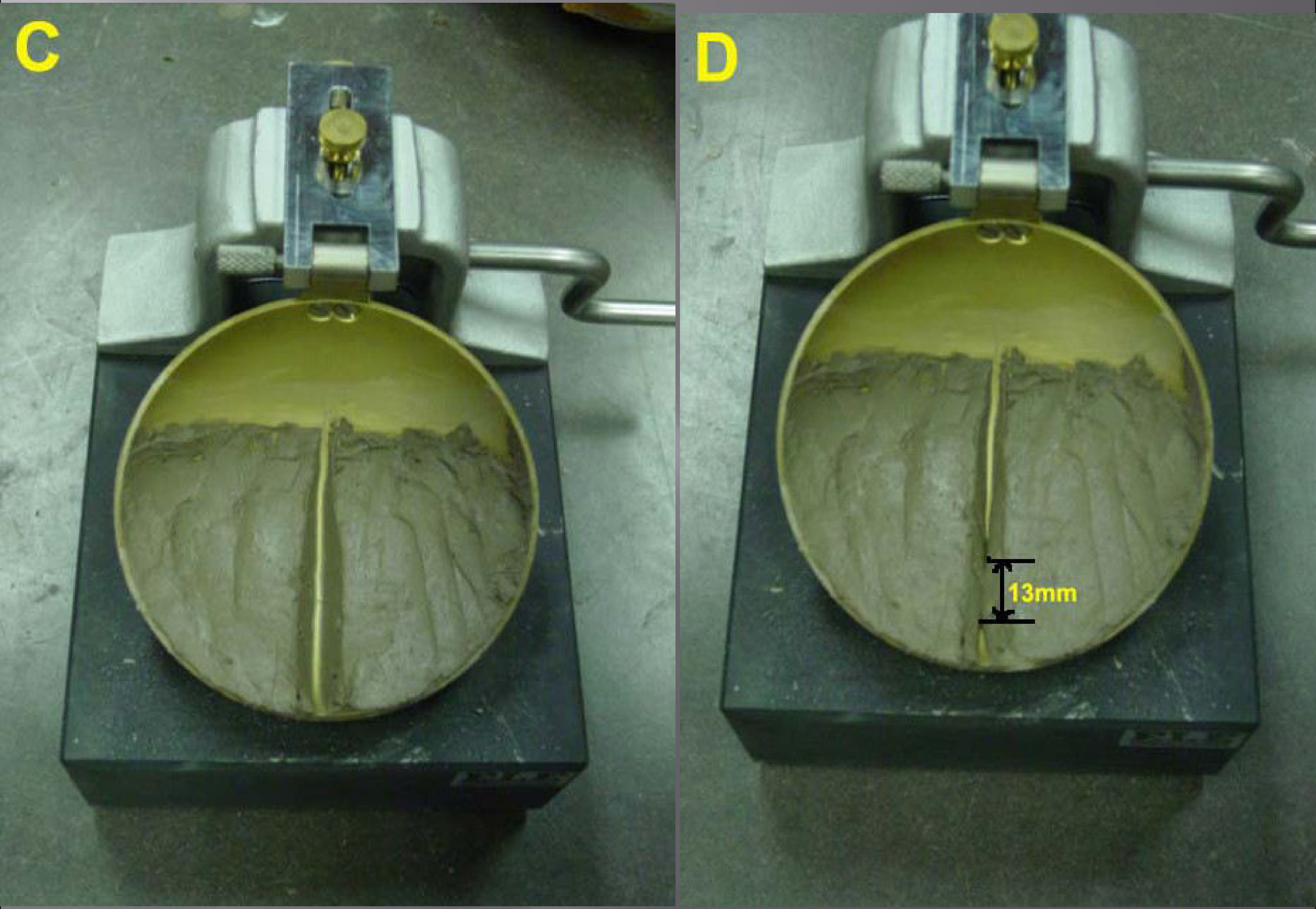
- Cut groove in soil paste with standard grooving tool

LL Test Procedure

- Rotate cam and count number of blows of cup required to close groove by 1/2”



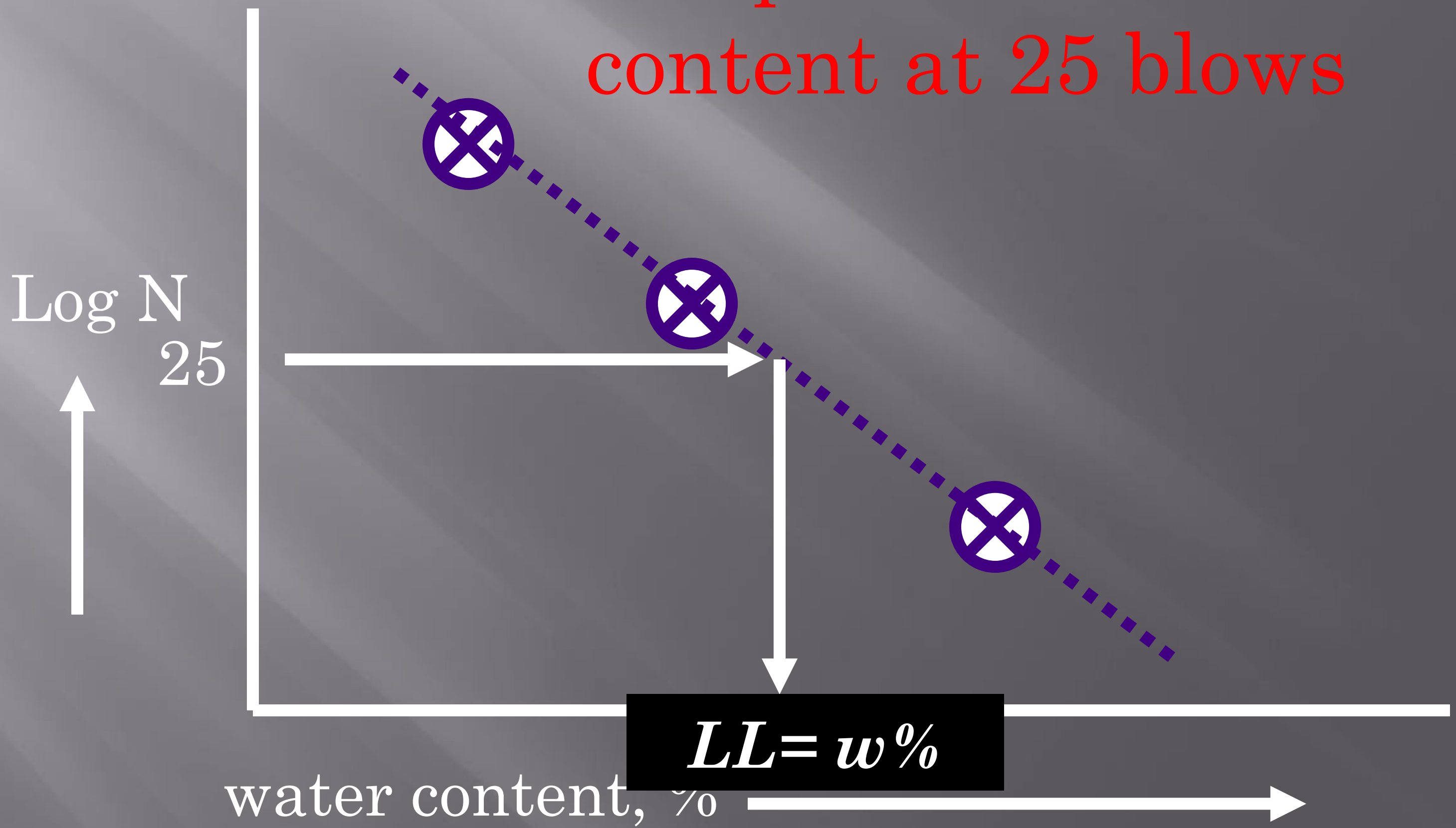

B
ELE


C
D
13mm

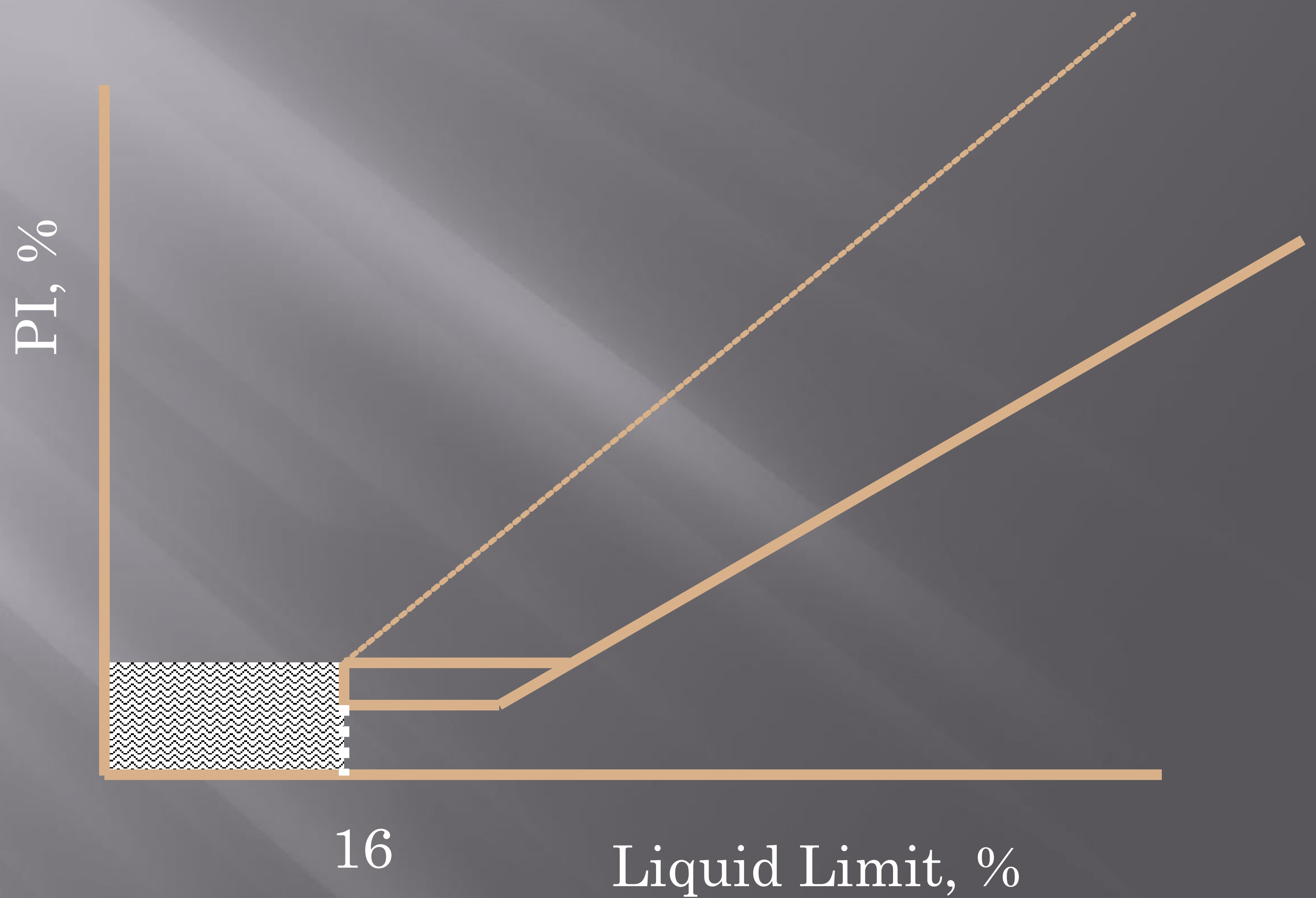
LL Test Procedure

- Perform on 3 to 4 specimens that bracket 25 blows to close groove
- Obtain water content for each test
- Plot water content versus number of blows on semi-log paper

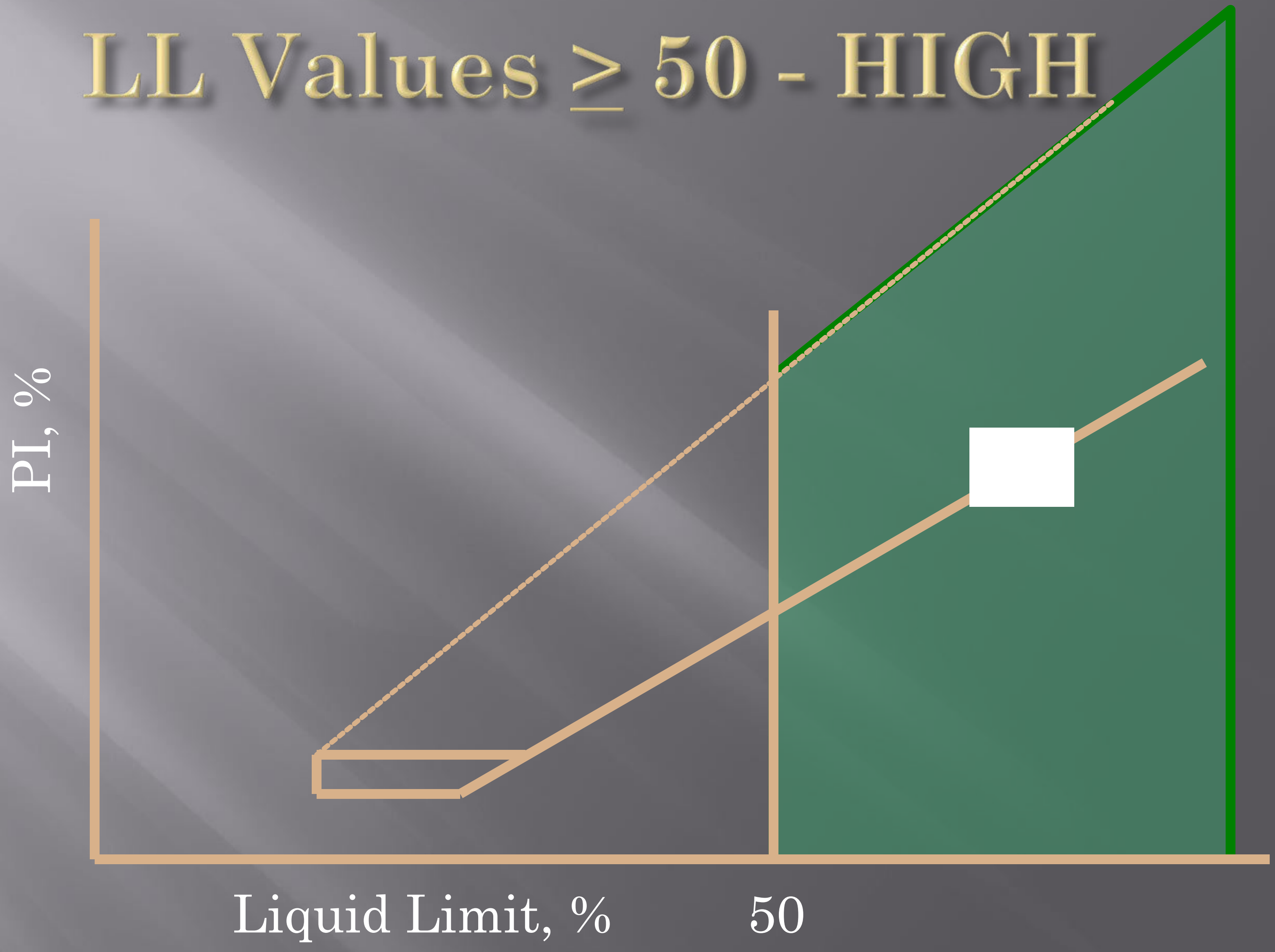
LL Test Results



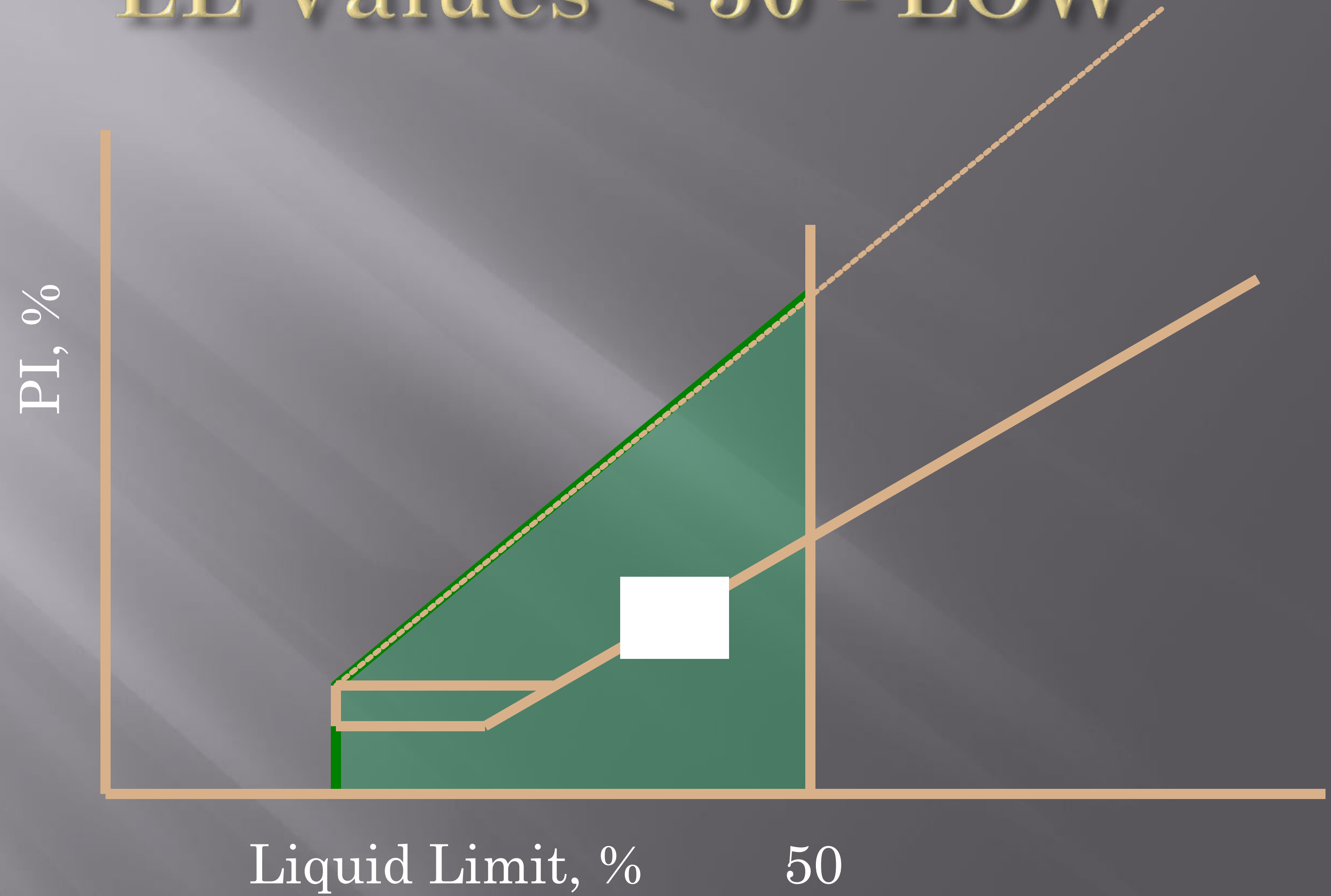
LL Values < 16 % not realistic



LL Values $\geq$ 50 - HIGH

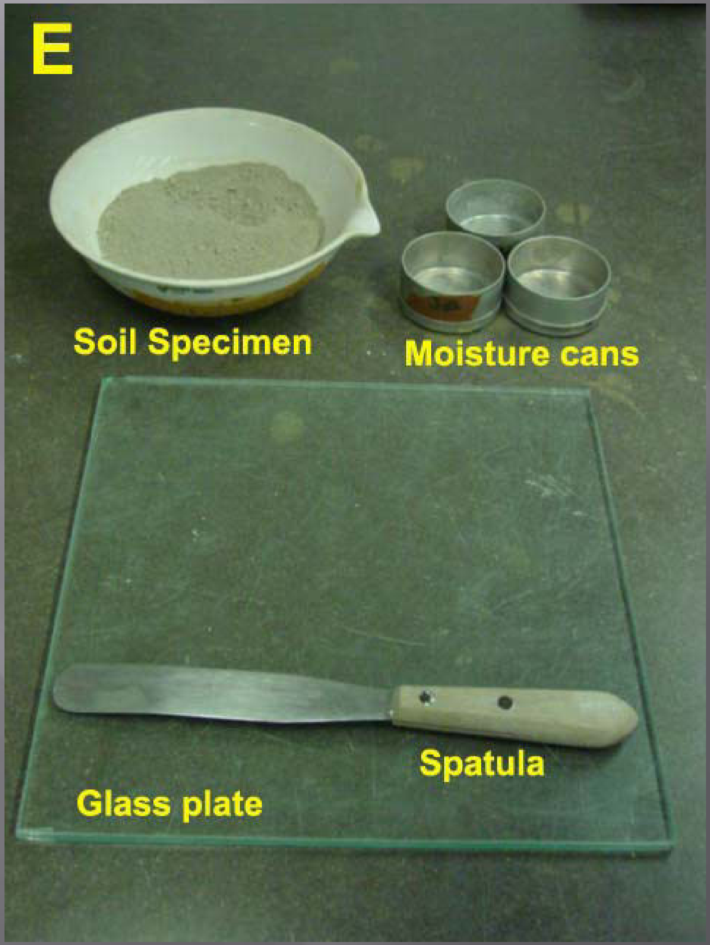


LL Values < 50 - LOW



Plastic Limit

The minimum water content at which a soil will just begin to crumble when it is rolled into a thread of approximately 3 mm in diameter.



Plastic Limit w% procedure

- Using paste from LL test, begin drying
- May add dry soil or spread on plate and air-dry

Plastic Limit w% procedure

- When point is reached where thread is cracking and cannot be re-rolled to 3 mm diameter, collect at least 6 grams and measure water content. Defined plastic limit


F
Ellipsoidal soil mass

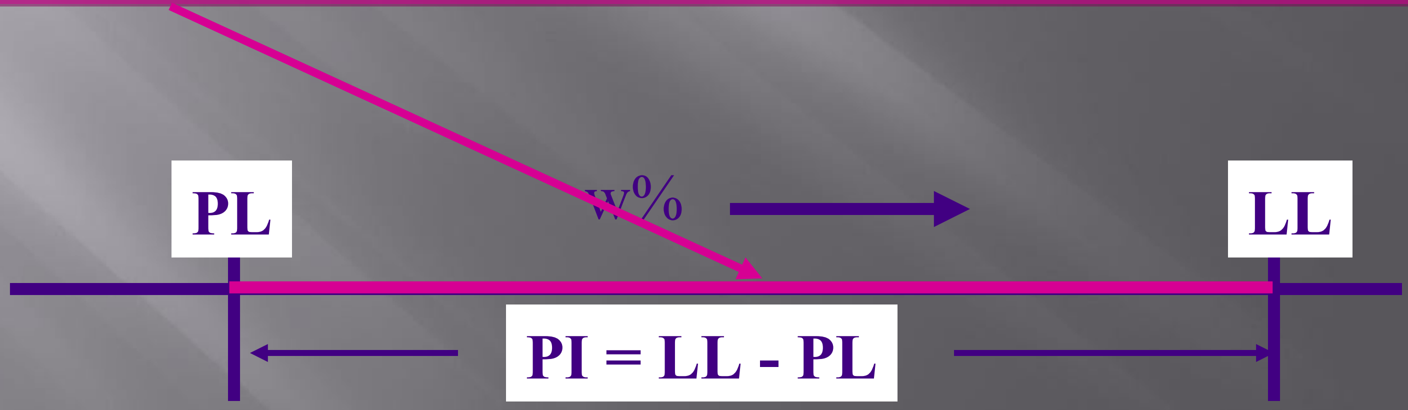

G

1. Calculate the water content of each of the plastic limit moisture cans after they have been in the oven for at least 16 hours.
2. Compute the average of the water contents to determine the plastic limit, PL.

Definition of Plasticity Index

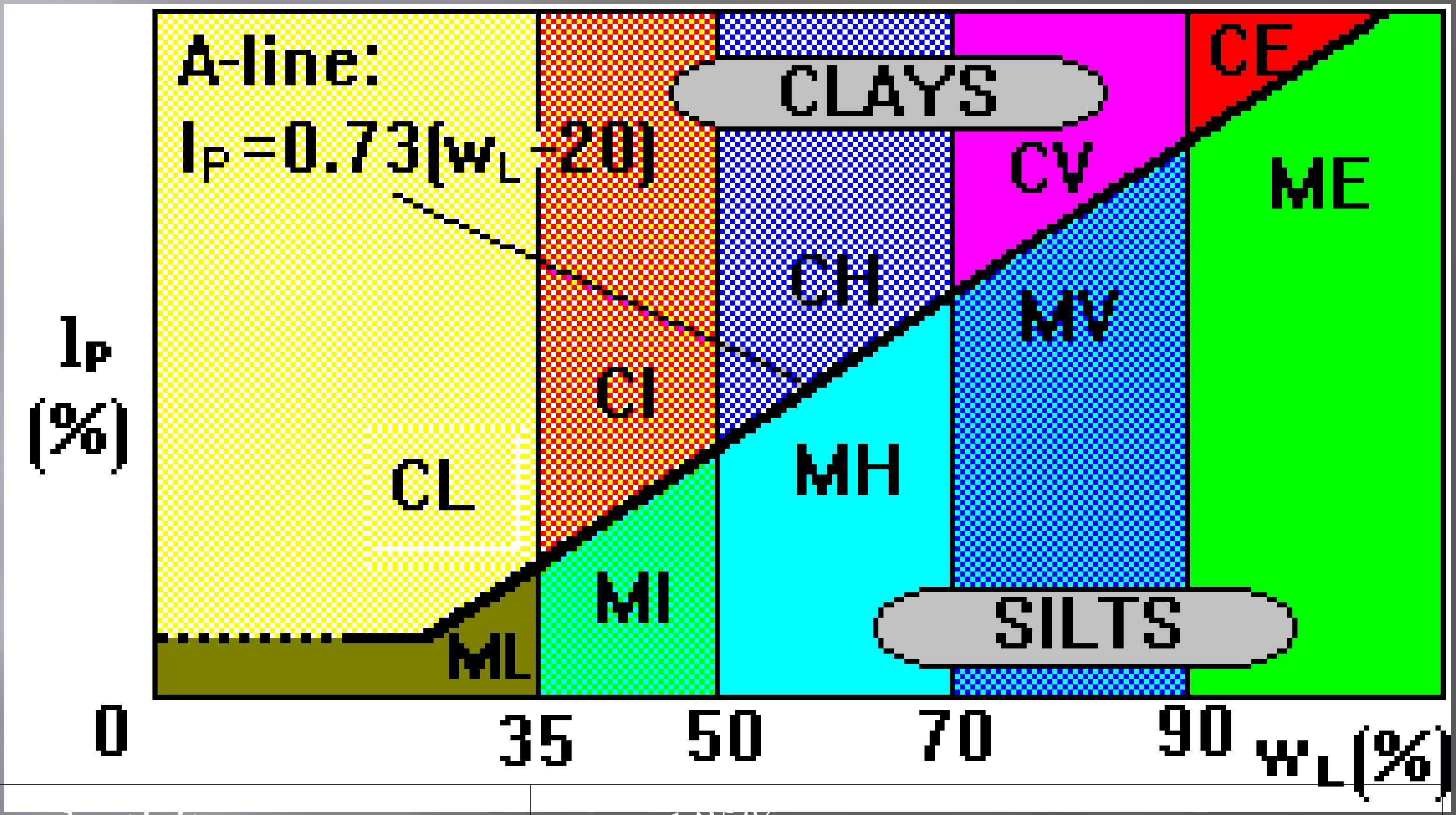
- Plasticity Index is the numerical difference between the Liquid Limit w% and the Plastic Limit w%

Plasticity Index = Liquid Limit – Plastic Limit



plastic (remoldable)

Plasticity Chart



Low plasticity	$w_L = < 35\%$
Intermediate plasticity	$w_L = 35 - 50\%$
High plasticity	$w_L = 50 - 70\%$
Very high plasticity	$w_L = 70 - 90\%$
Extremely high plasticity	$w_L = > 90\%$