Program : **Diploma in Civil Engineering**	
Course Code : **4011**	Course Title: **Geotechnical Engineering**
Semester : **4**	Credits: **4**
Course Category: **Program Core**	
Periods per week: **4 (L:3, T:1, P:0)**	Periods per semester: **60**

Course Objectives:

- To impart knowledge about the index and engineering properties of soil and soil classification
- To impart knowledge about the various methods of determination of soil properties.

Course Prerequisites:

Topic	Course code	Course name	Semester
Basics of mathematics		Engineering Mathematics	1
Basic knowledge about building components and construction techniques		Building Construction and Construction materials	3
Basics of mechanics		Engineering Mechanics	2

Course Outcomes:

COn	Description	Duration (Hours)	Cognitive Level
CO1	Determine the physical and index properties of soil	15	Applying
CO2	Determine the engineering properties such as permeability and shear strength of soil.	13	Applying
CO3	Determine the compressibility of soil.	12	Understanding
CO4	Illustrate the process of field investigation and determine the bearing capacity of soil.	18	Applying
	Series tests	2	

CO – PO Mapping:

Course Outcomes	PO1	PO2	PO3	PO4	PO5	PO6	PO7
CO1	3	3					
CO2	3						
CO3							
CO4	3						

3-Strongly mapped, 2-Moderately mapped, 1-Weakly mapped

Course Outline:

On completion of the course, the student will be able to:

Module Outcomes	Description	Duration (Hours)	Cognitive Level
CO1	**Determine the physical and index properties of soil**		
M1.01	Summarize the physical and index properties of soil.	3	Remembering
M1.02	Solve the Functional relationships.	3	Understanding
M1.03	Discuss the procedures for determination of index properties of soil.	3	Understanding
M1.04	Discuss the consistency limits of soil.	3	Understanding
M1.05	Determine the gradation and classification of soils	3	Applying

Contents:

Introduction to Soil Mechanics: Use of soil as construction material in Civil engineering. Soil formation and transportation of soil - water transported soil, wind transported soil, glacier deposited soil and gravity deposited soil. Field applications of geotechnical engineering.

Physical and Index Properties of Soil:

Soil as a three-phase system: definethe terms - water content, void ratio, porosity, degree of saturation, density index, Unit weight of soil (bulk unit weight, dry unit weight, unit weight of solids, saturated unit weight, submerged unit weight).

Functional relationships: between void ratio and porosity; water content and void ratio; bulk unit weight and void ratio; dry unit weight and water content. Simple problems based on the above functional relationships.

Procedures for determination of: water content by oven drying method (BIS); field density of soil by core cutter and sand replacement method; specific gravity using pycnometer.

Consistency limits of soil: Procedure for determination of liquid limit, plastic limit and shrinkage limit. Define the terms - Plasticity index, consistency index, flow index and liquidity index. Simple problems relating consistency limits and indices. **Gradation of soil:** Define coarse grained and fine-grained soils. Procedure for determination of particle size distribution by sieve analysis. Define effective diameter of soil, well graded soils, uniformly graded soils, Uniformity co-efficient and coefficient of curvature. BIS classification of soil based on particle size.			
CO2	**Determine the engineering properties such as permeability and shear strength of soil.**		
M2.01	Determine the permeability coefficient of soil	3	Understanding
M2.02	Apply Darcy's law to find the co-efficient of permeability	3	Applying
M2.03	Outline the concept of shear strength of soil	3	Understanding
M2.04	Discuss the procedures of direct shear test and vane shear test	4	Understanding
	Series Test – I	1	
Contents: **Permeability of Soil:** Define permeability. State Darcy's law of permeability. List the factors affecting permeability. Procedure for determination of coefficient of permeability by constant head and variable head tests. Simple problems to find permeability of soil. **Shear Strength of Soil:** Define cohesion and internal friction. Define purely cohesive soils and cohesionless soils. Define shear strength of soil. Describe Mohr-Coulomb failure theory - Strength envelope, strength equation for purely cohesive and cohesion less soils. Procedure for determination of shear strength by direct shear test and vane shear test (simple problems on vane shear test only).			
CO3	**Determine the compressibility of soil.**		
M3.01	Explain the procedure for Standard and Modified Proctor Test for the determination of compaction characteristics of soil.	4	Understanding
M3.02	List the factors affecting compaction	1	Remembering
M3.03	Discuss the different field methods of compaction	2	Understanding
M3.04	Outline the concept of consolidation of soil	3	Understanding
M3.05	Compare compaction and consolidation of soil	2	Understanding

Contents:

Compaction of Soil: Define compaction of soil. Procedure for Standard and Modified Proctor Test. Compaction curve - general discussion, differences of curves for sand and clay, Optimum moisture content (OMC), maximum dry density (MDD) and Zero air voids line. List the factors affecting compaction. Field methods of compaction - rolling, ramming and vibration. Suitability of different types of rollers - smooth wheel roller, sheep foot roller, pneumatic tyred roller.

Consolidation of soil: Define consolidation of soil and differentiate between compaction and consolidation. Describe Terzaghi's soil-spring analogy model to explain the process of consolidation and different stages of consolidation (Initial, primary and secondary consolidation).

CO4	**Illustrate the process of field investigation and determine the bearing capacity of soil.**		
M4.01	Enumerate the objectives and the different stages involved in site investigation	1	Understanding
M4.02	Discuss the criteria for deciding depth, location and number of pits or boreholes.	1	Understanding
M4.03	Outline the methods of soil exploration	4	Understanding
M4.04	Define the various terminology connected with bearing capacity of soil.	1	Understanding
M4.05	Discuss the types of bearing capacity failures and Therzaghi's theory of bearing capacity.	2	Applying
M4.06	Identify the field tests for determination of bearing capacity	3	Applying
M4.07	Determine area and depth of foundation	3	Applying
M4.08	Classify types of foundation	3	Understanding
	Series Test – II	1	

Contents:

Site investigation and soil exploration:

List the objectives of site investigation. Discuss the different stages of site investigation. Criteria for deciding the depth, location and number of test pits or bore holes.

Discuss the different methods of soil exploration - Open excavation methods, different types of boring (Auger boring, wash boring, rotary drilling, percussion drillin, core drilling) and geo-physical methods.

Define undisturbed samples.

Bearing Capacity of Soil:

Define terms- bearing capacity, ultimate bearing capacity, safe bearing capacity and allowable bearing pressure.

Discuss the types of bearing capacity failures. Terzaghi's theory of bearing capacity - introduction, assumptions, equation (derivation not required) and simple problems to find area and depth of foundation - Isolated and trip footing only (effect of water table not to be considered). Procedure for determination of bearing capacity of soil - Plate load test (as per IS:1888) and Standard Penetration Test (IS:2131). Different types of foundation - Shallow and Deep - isolated, strip, raft, Pile, well (Types and suitability).

Text / Reference:

T/R	Book Title/Author
T1	Gopal Ranjan & A.S.R Rao, '*Basic and Applied Soil Mechanics'*, New Age International
R1	Punmia, B.C., '*Soil Mechanics and Foundation Engineering*', Laxmi Publication, Delhi.
R2	Arora K.R, '*Soil Mechanics and Foundation Engineering'*, Standard Publisher.
R3	Murthy, V.N.S., '*A Text book of Soil Mechanics and Foundation Engineering'*, CBS Publishers & Distributors Pvt. Ltd., New Delhi.
R4	Ramamurthy, T.N. &Sitharam, T.G., '*Geotechnical Engineering (Soil Mechanics)*', S Chand and Company LTD., New Delhi.
R5	Raj, P. Purushothama, '*Soil Mechanics and Foundation Engineering'*, Pearson India, New Delhi.
R6	Kasamalkar, B. J., '*Geotechnical Engineering'*, Pune Vidyarthi GrihaPrakashan, Pune.

Online Resources:

Sl.No	Website Link
1	https://nptel.ac.in/courses/105/103/105103097/
2	https://nptel.ac.in/courses/105/101/105101084/
3	https://law.resource.org/pub/in/bis/S03
4	https://www.astm.org/Standards/geotechnical-engineering-standards.html

What is Geotechnical Engineering?

Geo

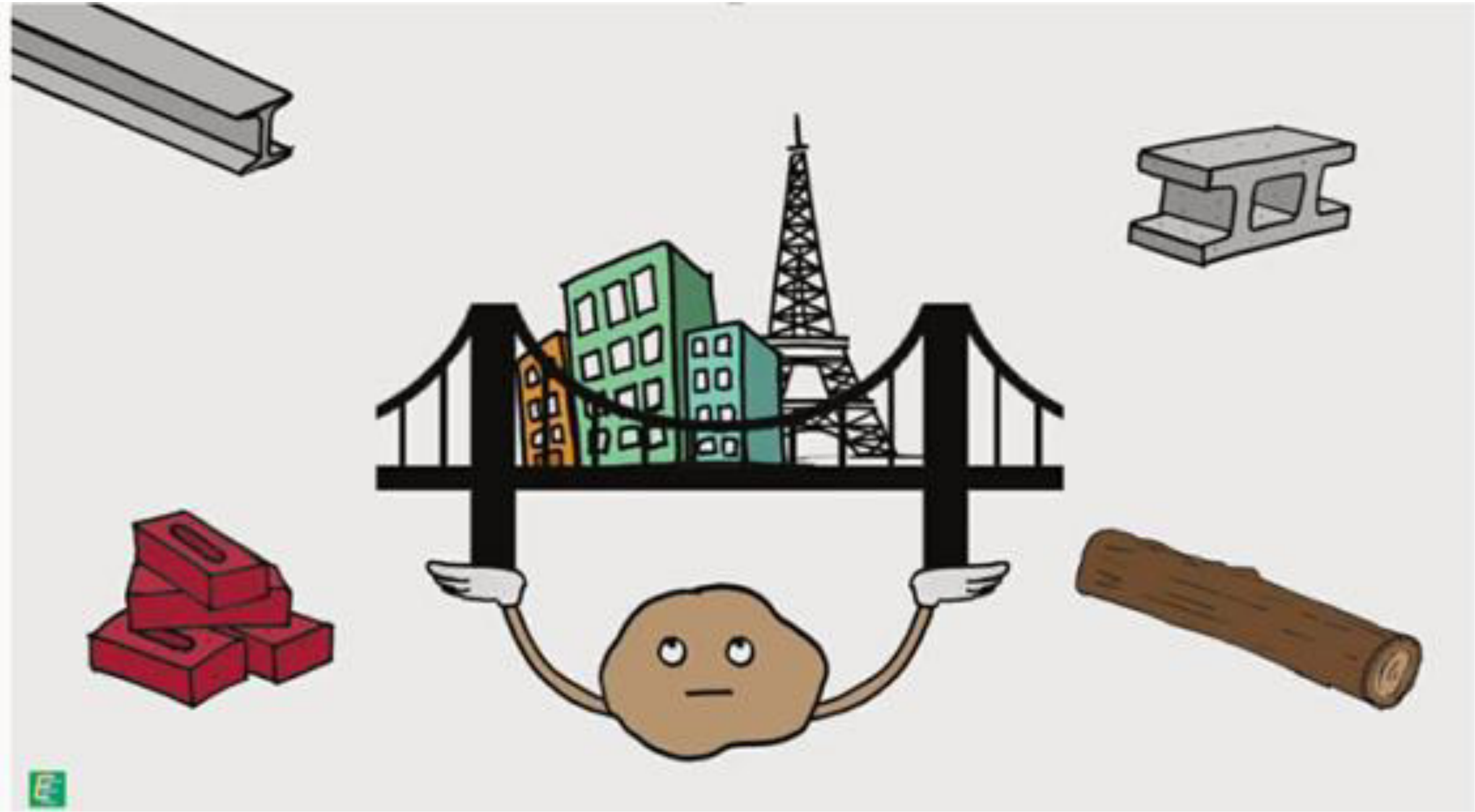
Earth

Technical

Special Knowledge

Why learn Geotechnical Engineering?

Why learn Geotechnical Engineering?

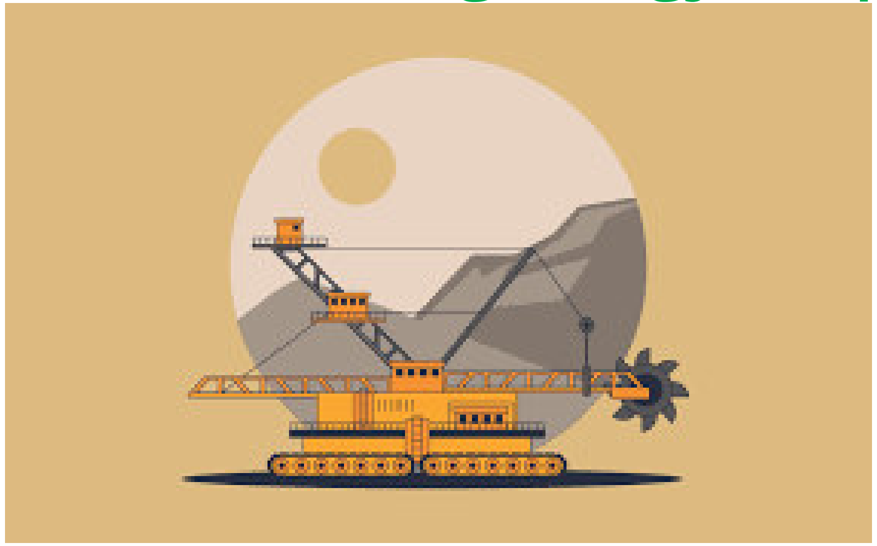


1.1 Definitions

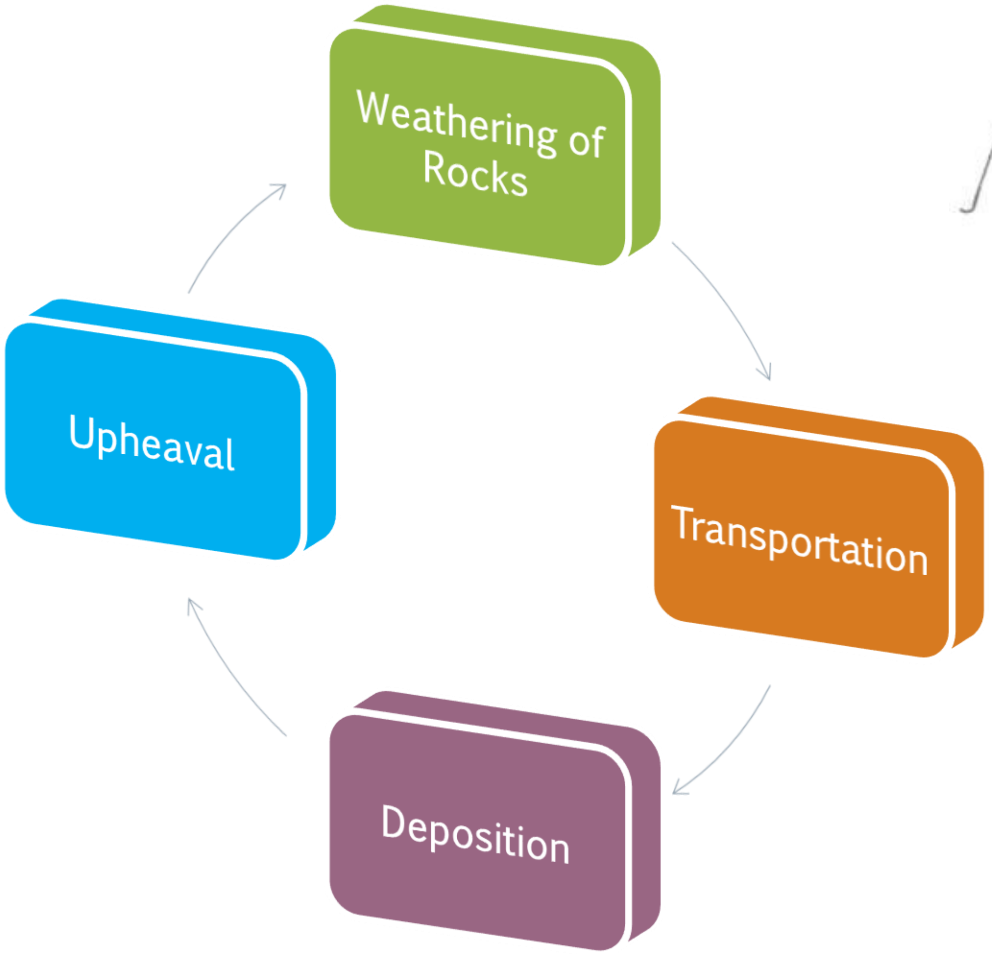
- **Soil – Unconsolidated material**, composed of solid particles, **produced by disintegration of rocks**.
- **Soil Mechanics** - Branch of mechanics which deals with **action of forces in soil** and with the **flow of water in soil**.

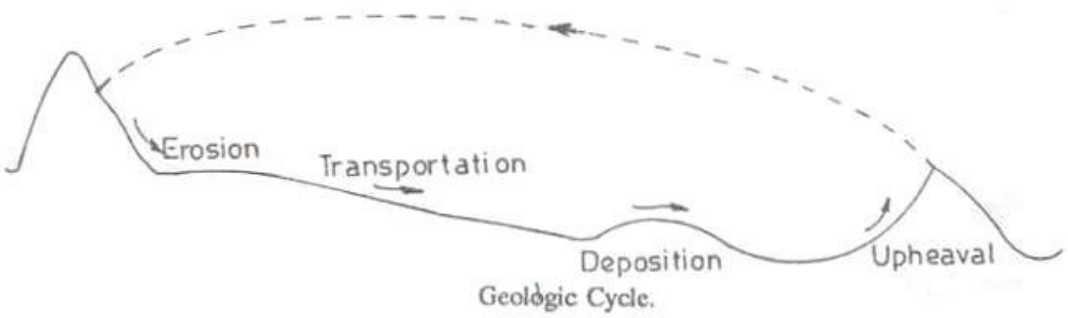
1.1 Definitions

- Soil Engineering – Applied science dealing with the applications of principles of soil mechanics to practical problems.
- Geotechnical Engineering – Applied science dealing with the applications of principles of soil mechanics, rock mechanics and geology to practical problems.



1.1.2 Origin of soil



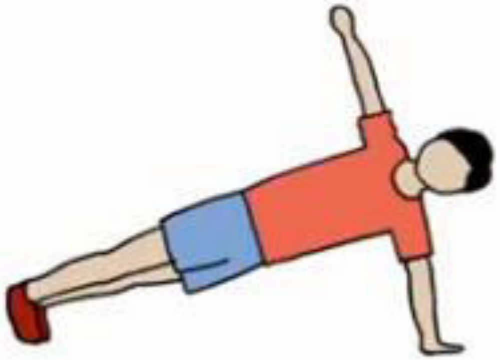


Geological Cycle

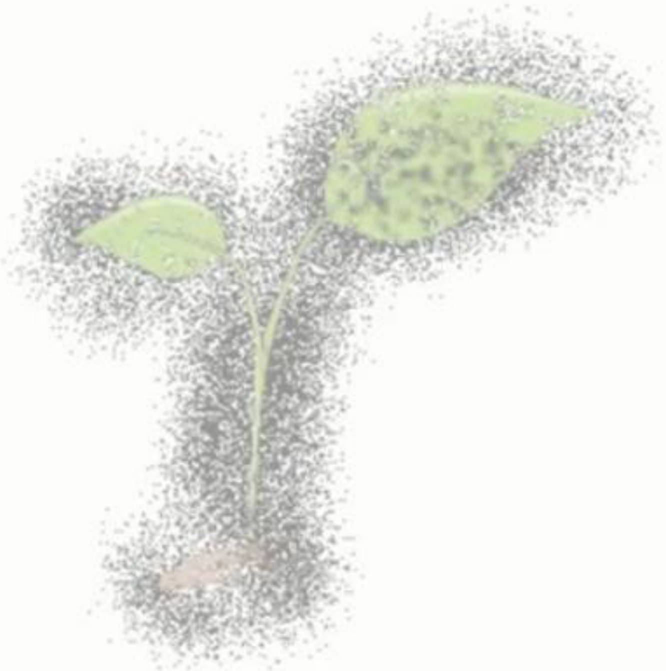
Geological Basis

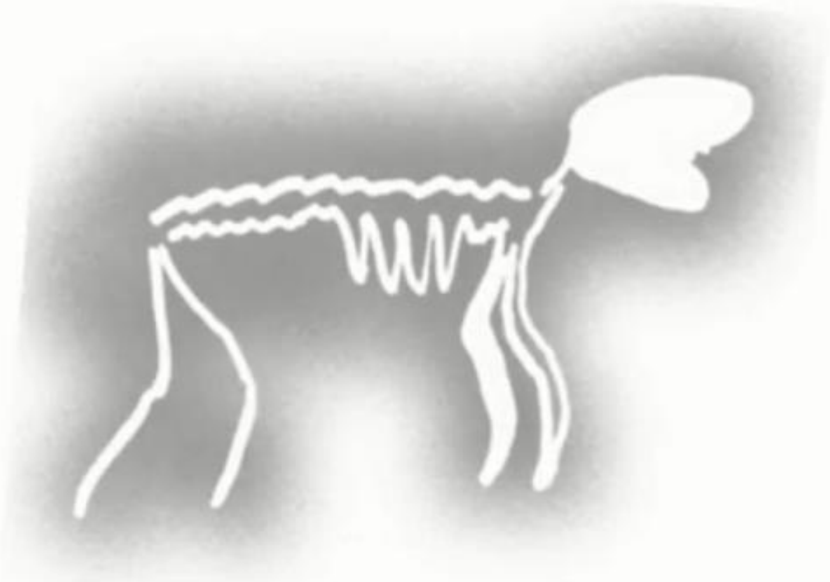
1. Organic Origin

2. Physical and Chemical Weathering of Rocks



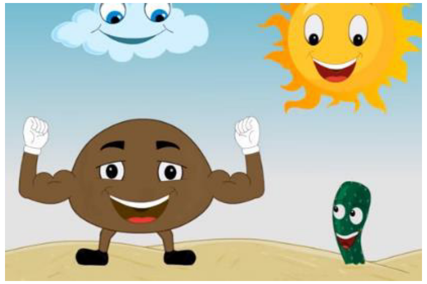
Organic Soils

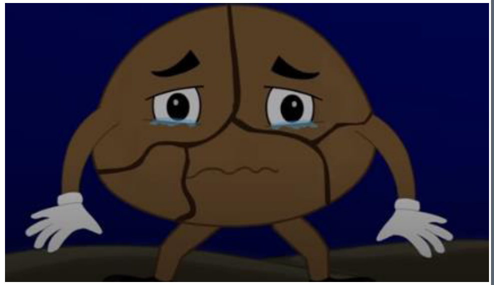




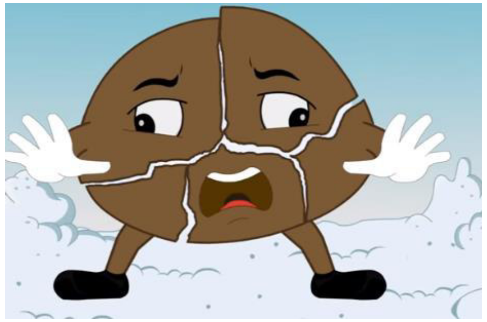
Physical Weathering

- Temperature changes



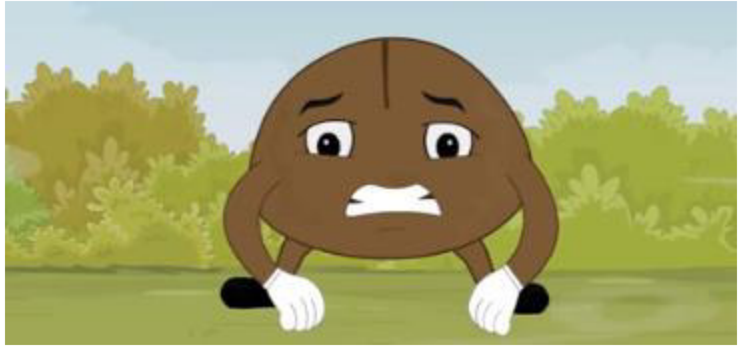


- Wedging action of ice

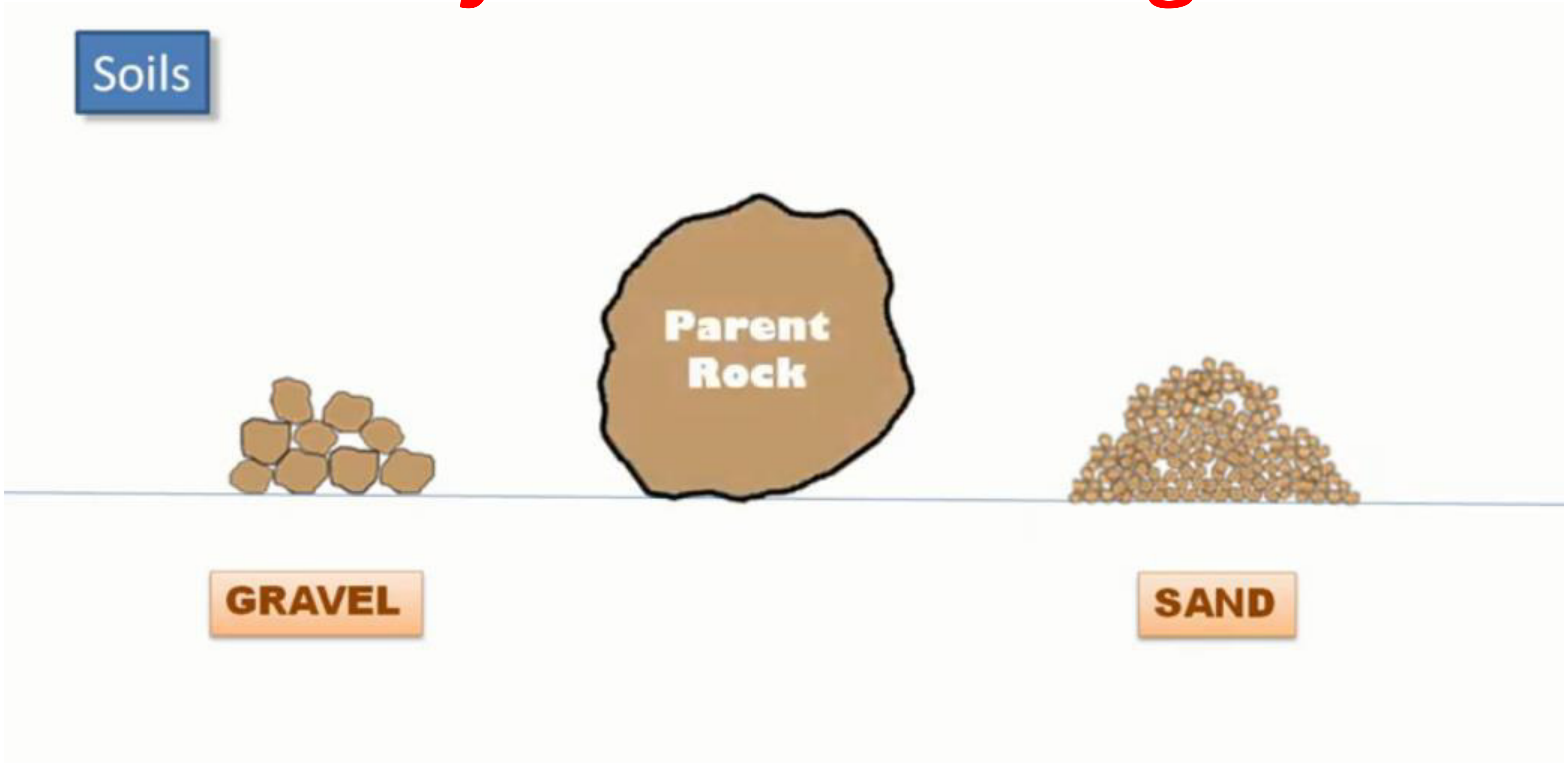


- Spreading of roots of plants

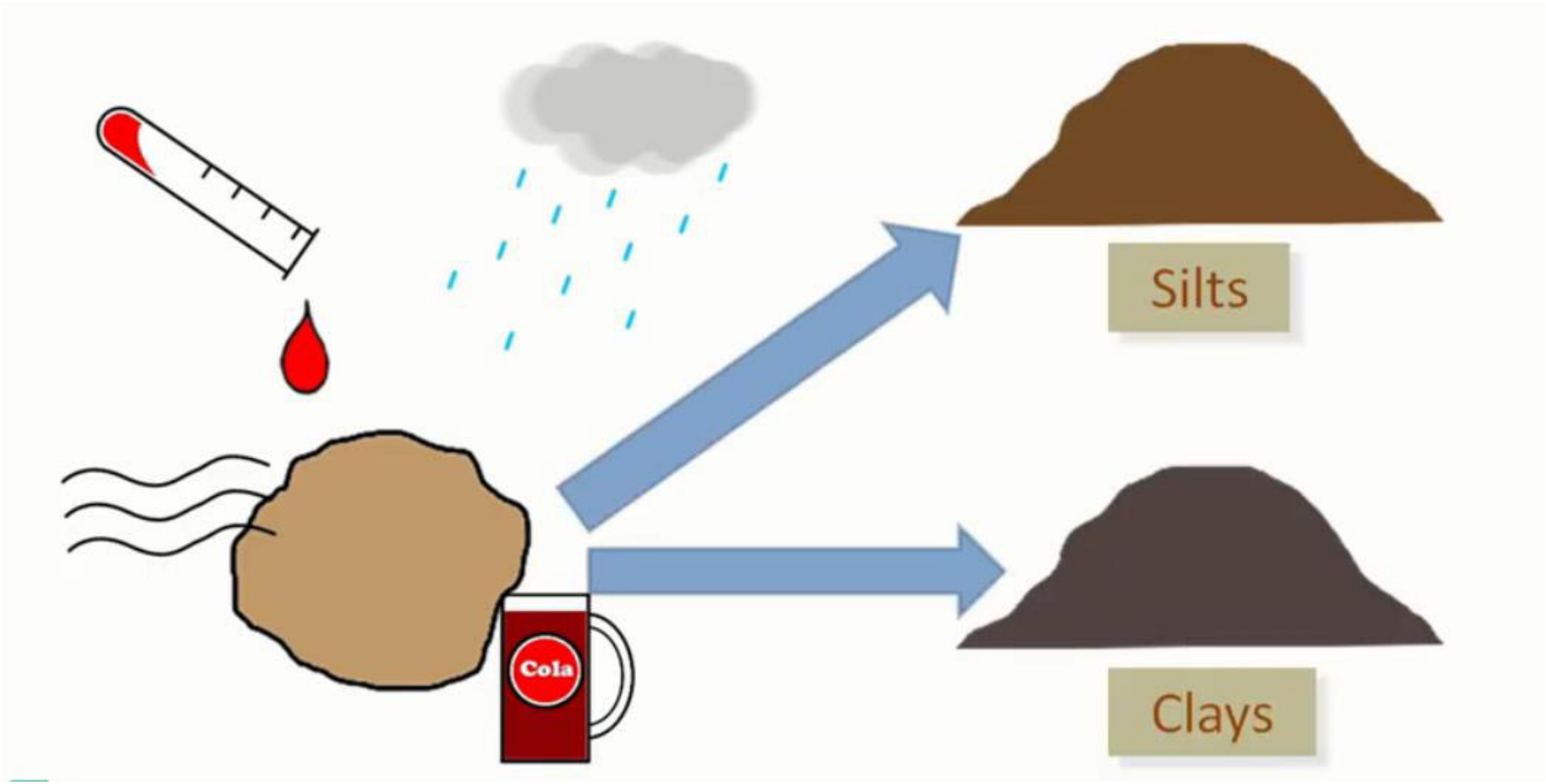
- Abrasion



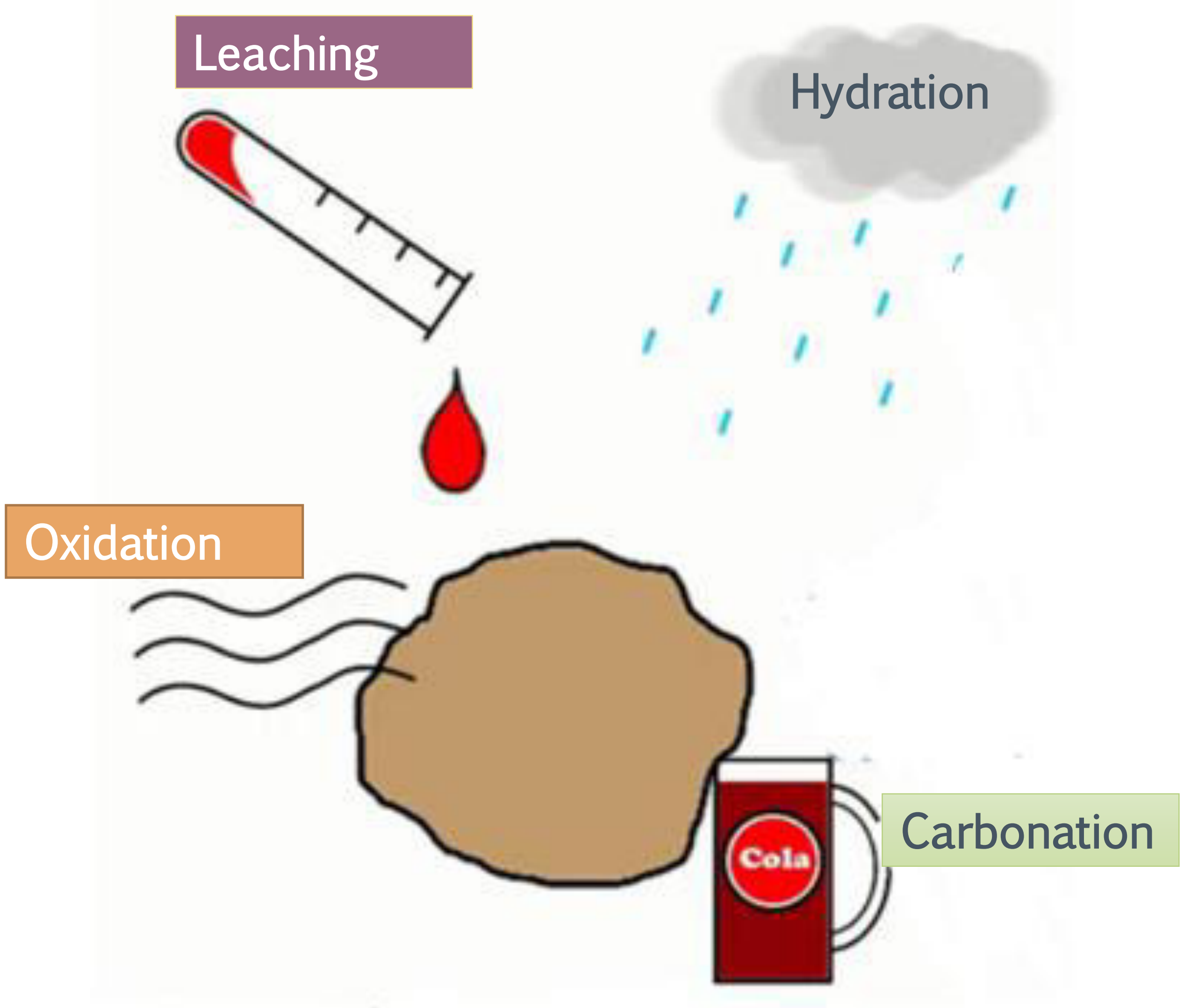
Physical Weathering

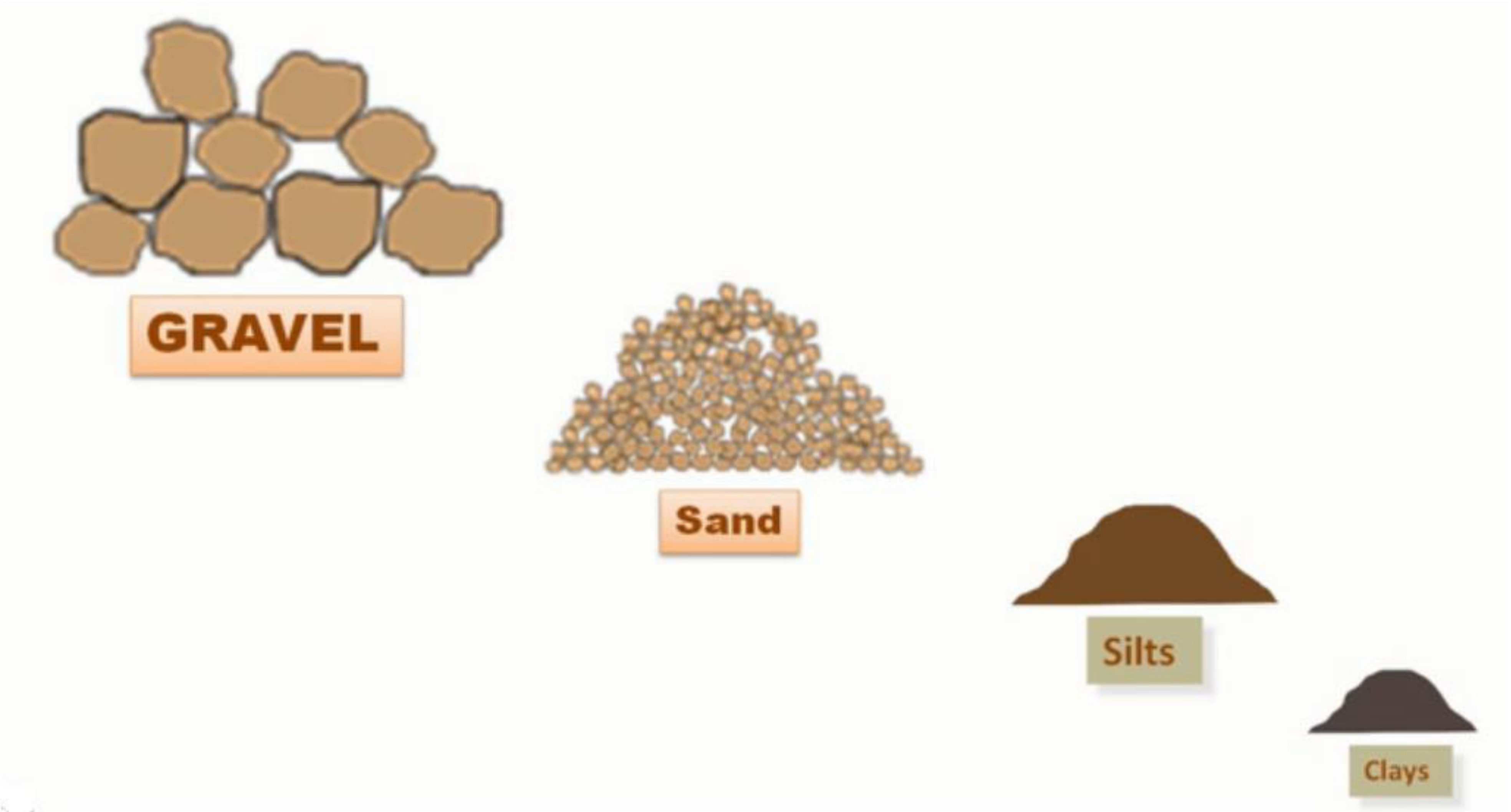


Chemical Weathering



Chemical Weathering




GRAVEL
Sand
Silts
Clays

1.1.3 & 1.1.4 Application of Soil Engineering

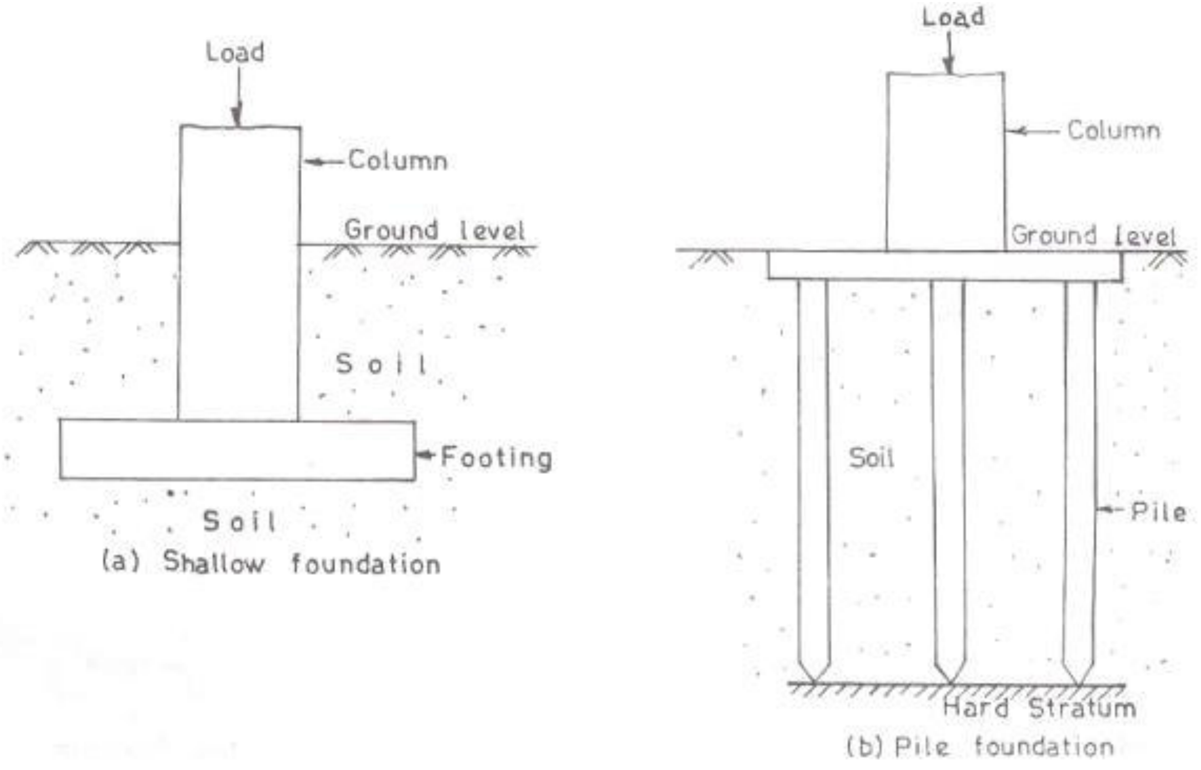
- Foundations
- Retaining Structures
- Pavement design
- Underground structures
- Stability of slopes
- Earth dam

› Foundations : Safe and efficient load transfer to soil.

-shallow foundation

-deep foundation.

Design of foundations involve soil mechanics



Different types of foundations.

- **Retaining structures**: Retain soil when sufficient space is not available for a mass of soil to spread and form a safer slope.
- **Design of retaining structures** involve soil mechanics

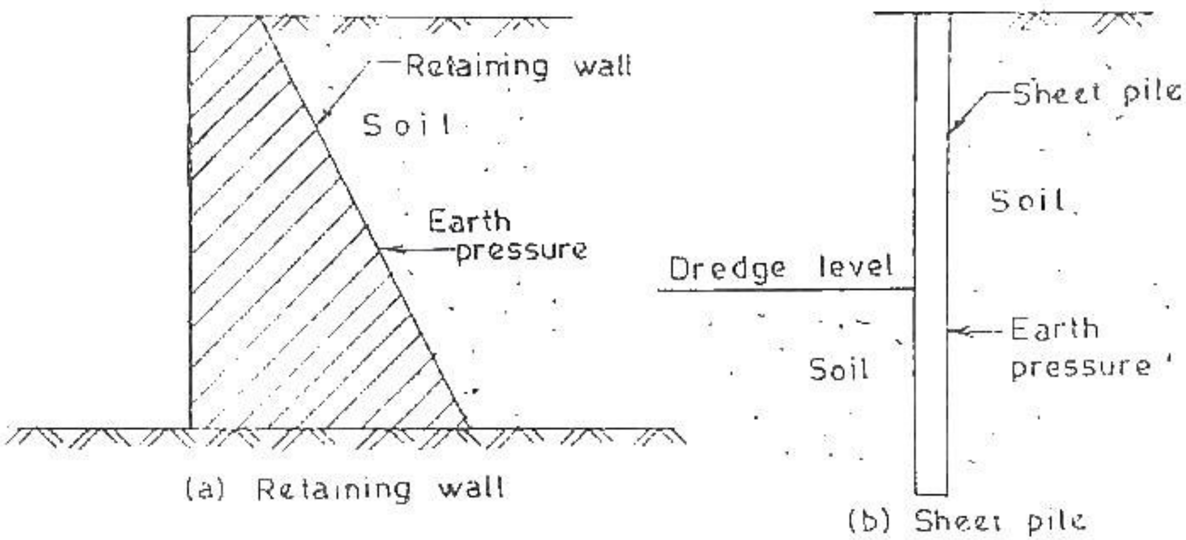
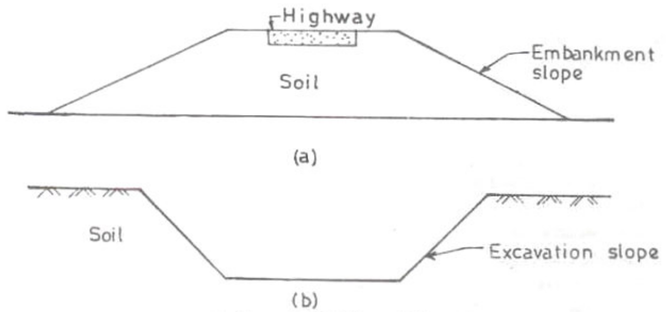


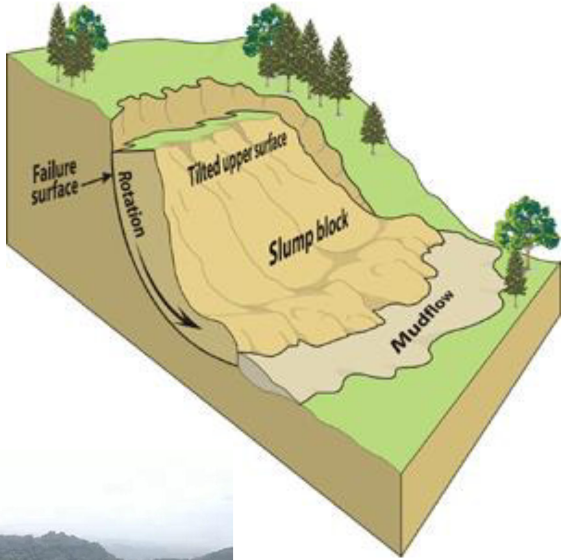
Fig. 1.3. Retaining structures.

› **Stability of slopes** : If soil surface is not horizontal, a component of weight of soil tends to move it downward and causes instability of slope.

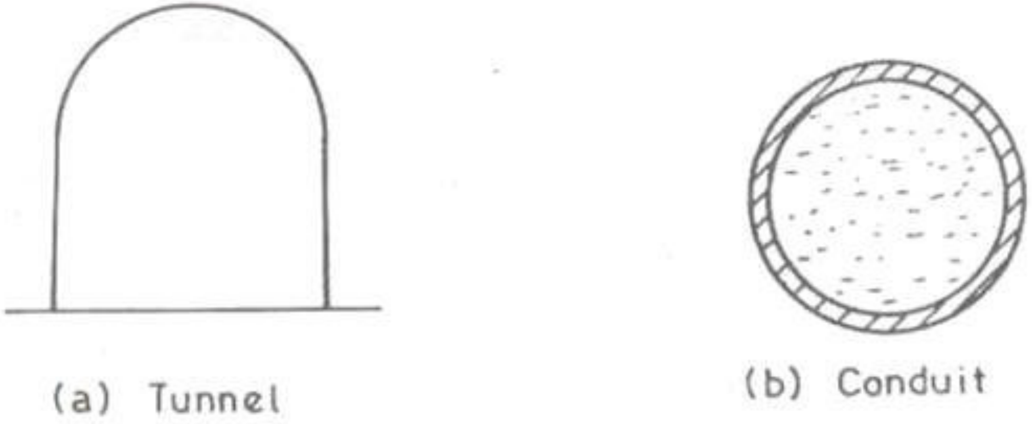
› Soil engineering **provides methods for checking stability of slopes.**



Slopes in (a) filling and (b) cutting.



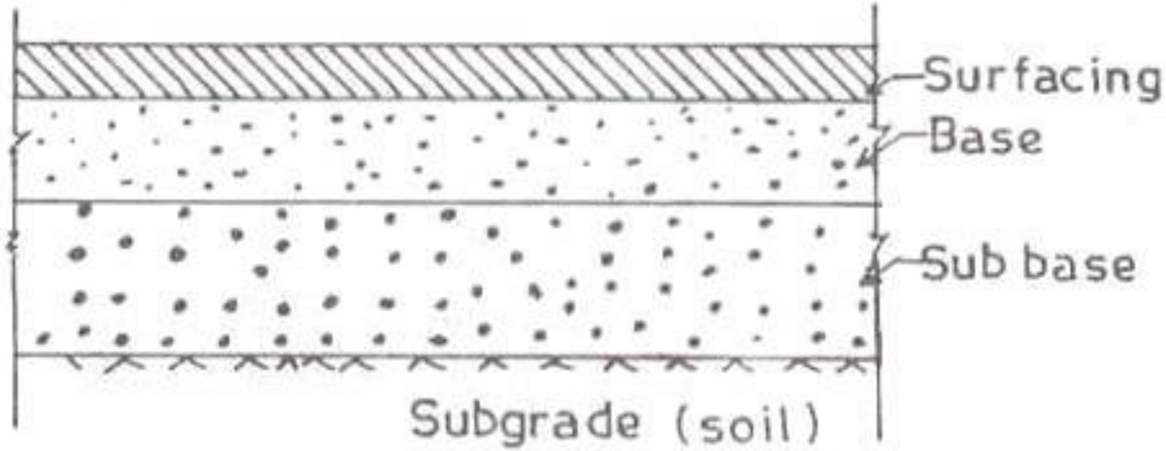
- Underground structures: Design & construction of underground structures such as tunnels, shafts, and conduits requires evaluation of forces exerted by the soil on these structures.



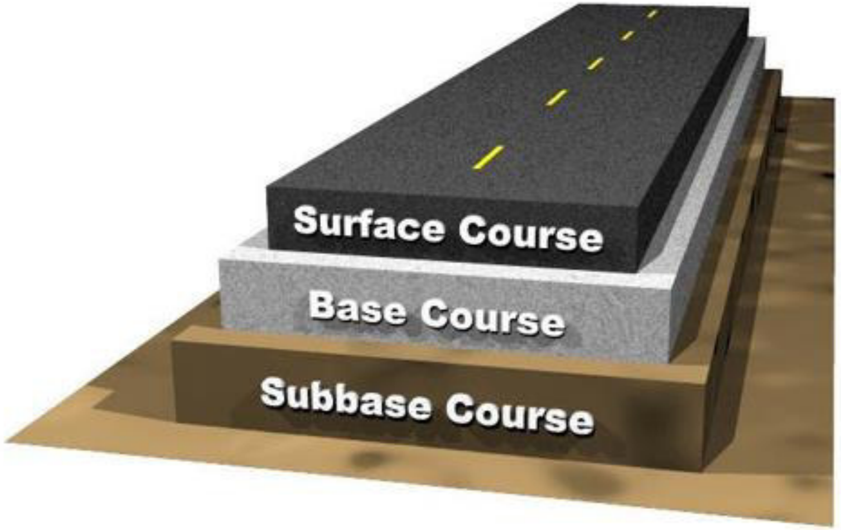
Underground structures.

› Pavement design: Pavement is hard crust placed on soil (subgrade) for the purpose movement of vehicle

Behaviour of subgrade under various conditions of loading and environmental changes is studied in soil engineering

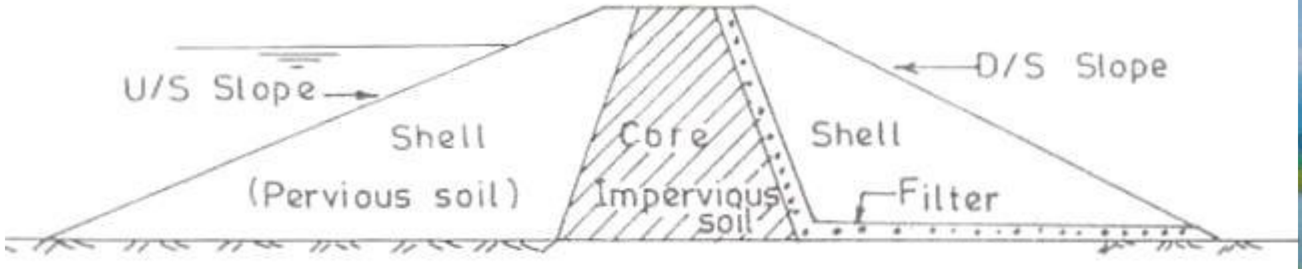


Pavement details.



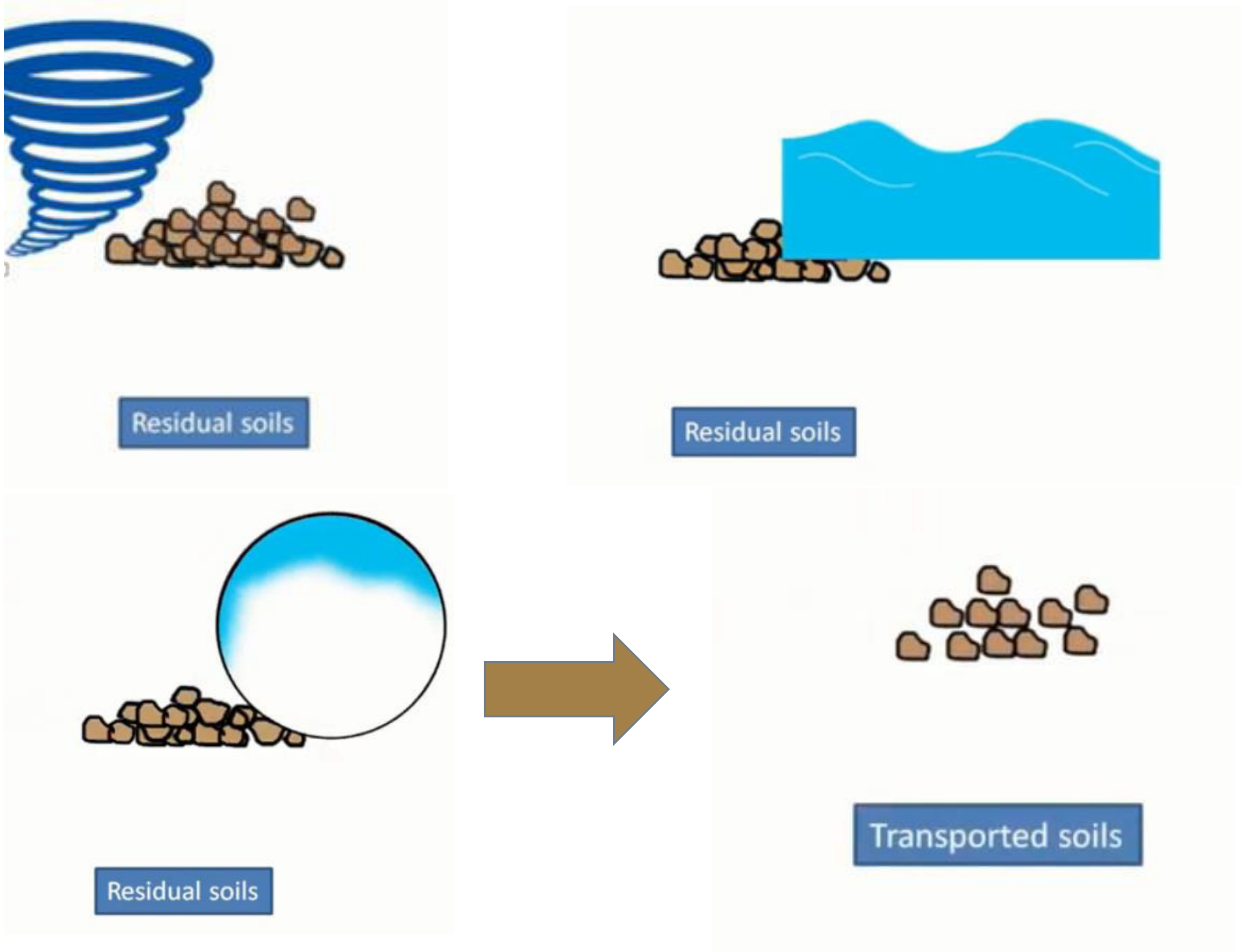
› **Earth dam**: Structures in which soil is used as construction material, built for creating water reservoirs.

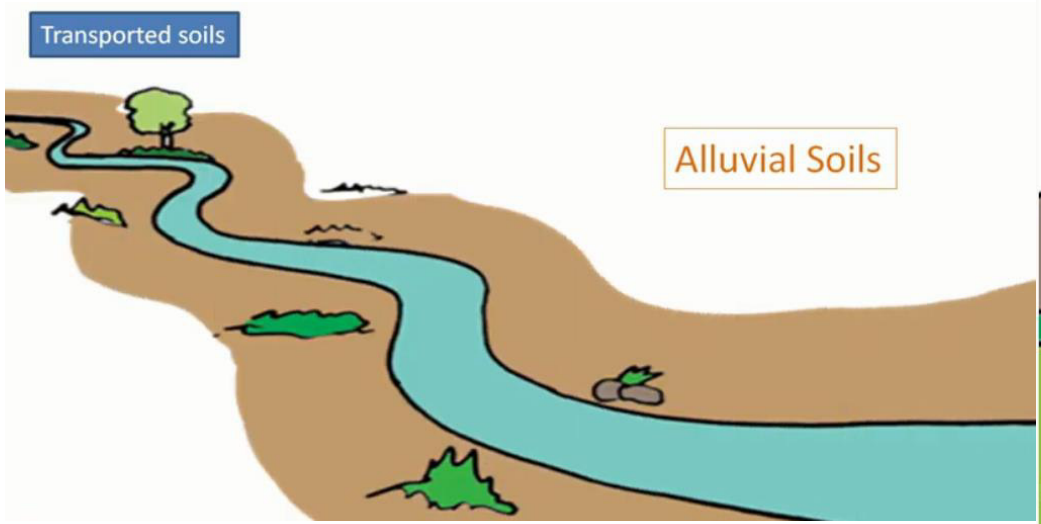
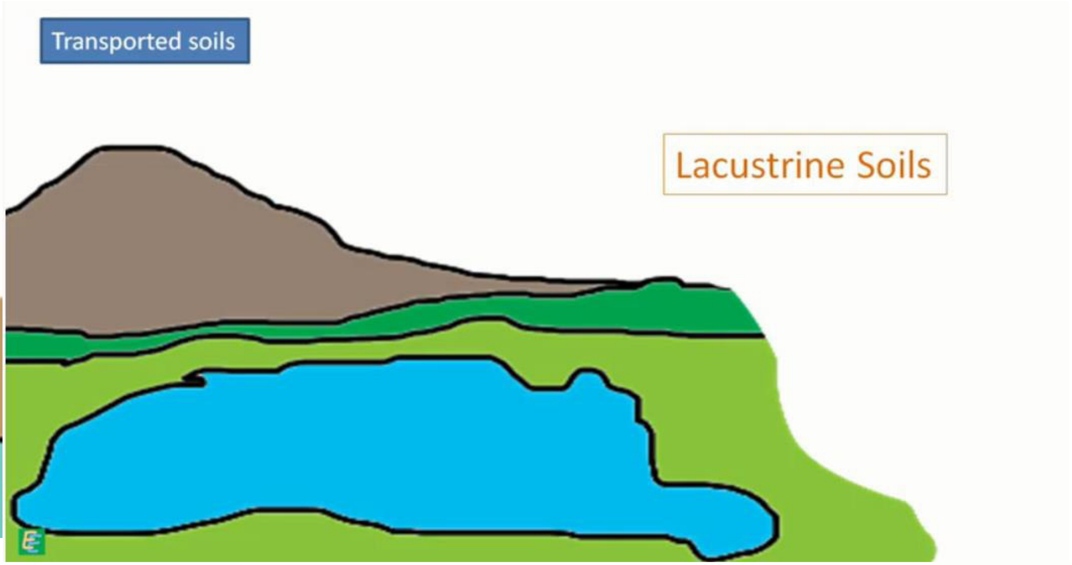
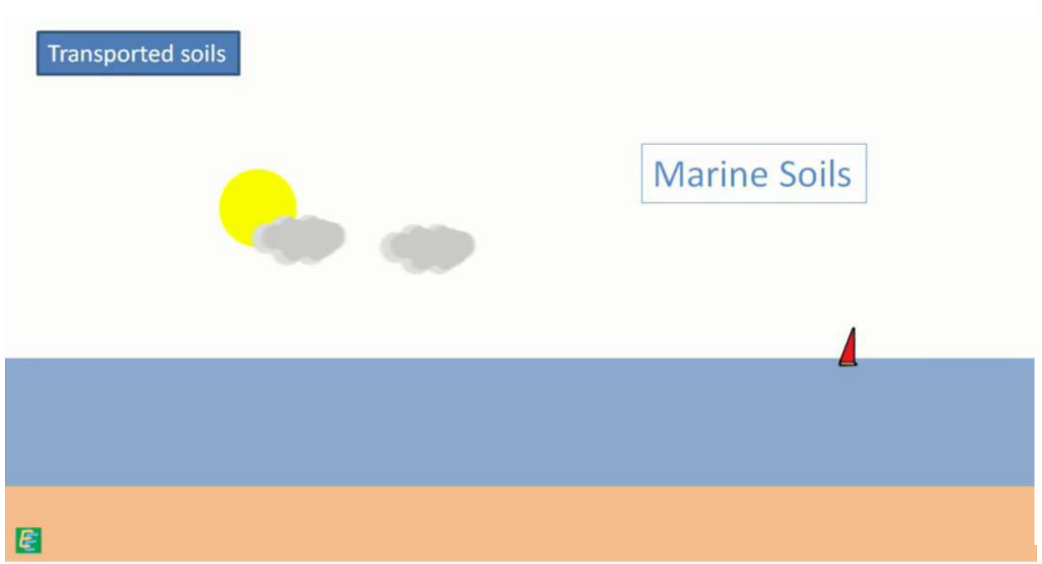
- Knowledge in soil engineering helps in **design of earth dams, reducing the risk of failures.**



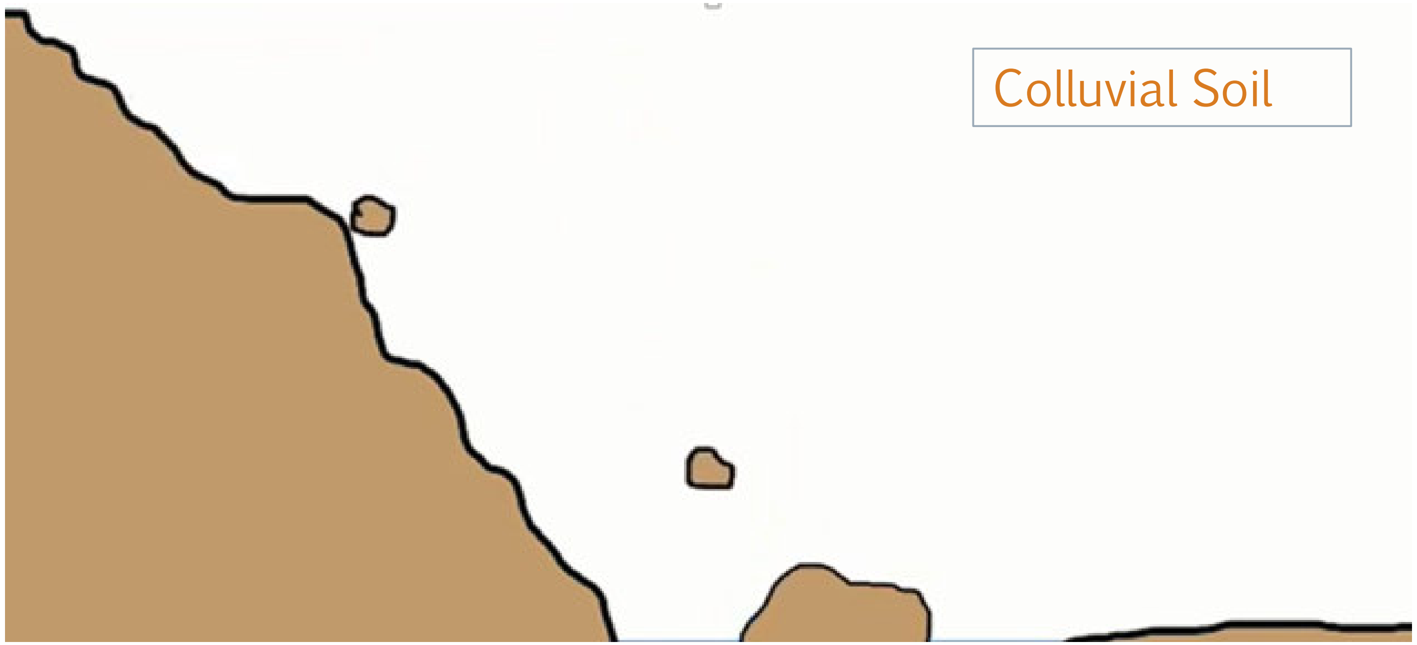
Earth Dam.

1.1.5 Residual & Transported Soil




Transported soils
Alluvial Soils

Transported soils
Lacustrine Soils

Transported soils
Marine Soils

Transported soils
Aeolian Soils
Glacial Deposits


Colluvial Soil


PlONK

1.1.5 Residual & Transported Soil

- Residual or sedentary soil – Soil stays at the formation, just above the parent rock
- Transported soil or sedimentary soil – Soil is deposited at a place far away from place of origin
  - Alluvial Soil - River
  - Lacustrine soil - Lake
  - Marine soil - Sea
  - Aeolian soil – Wind
  - Glacial deposits - Glaciar
  - Colluvial soil - Gravity

SOIL

Soil in soil mechanics is defined as an unconsolidated material, composed of solid particles, produced by disintegration of rocks.

SOIL MECHANICS

Soil mechanics is the application of laws of the laws of mechanics and hydraulics to engineering problems dealing with action of forces on soil and with the flow of water on soil.

SOIL ENGINEERING

Soil engineering is an applied science dealing with the applications of principles of soil mechanics to practical problems.

GEOTECHNICAL ENGINEERING

Broader term which includes soil engineering, rock mechanics and geology

ORIGIN OF SOIL

Soil is formed broadly by two process.

- Weathering of rocks : Disintegration of rocks into small particles.
- Decomposition of organic matter : Organic matter decomposes and forms a part of soil.

Weathering of soil can be by following process.

WEATHERING OF ROCKS	PHYSICAL DISINTEGRATION	Temperature Changes
		Wedging action of ice
		Spreading of roots of plants
		Abrasion
	CHEMICAL DECOMPOSITION	Hydration
		Carbonation
		Oxidation
		Solution
		Hydrolysis

PHYSICAL DISINTEGRATION

- The disintegration of rocks takes place by natural factors.
- Results in the formation of gravel and sand.
- The soil formed have the same properties of parent rock.

1. Temperature Changes
    - Rocks composed of minerals
    - Each mineral expands or contracts differently
    - Stresses causes separation of particles
2. Wedging Action of Ice
    - Water in pores of rock freezes to ice.
    - The formed ice has larger volume than water
    - The stresses due to expansion because of ice formation causes rocks to crack.
3. Spreading of roots of plants
    - Plants grows on cracks in the rocks.
    - The roots growing throw the cracks exerts stress on rocks which causes the rock to disintegrate.
4. Abrasion
    - Abrasion simply means wear or rubbing.
    - In rocks abrasion can be caused by agents like wind, glacier and water which can cause the rock to disintegrate.

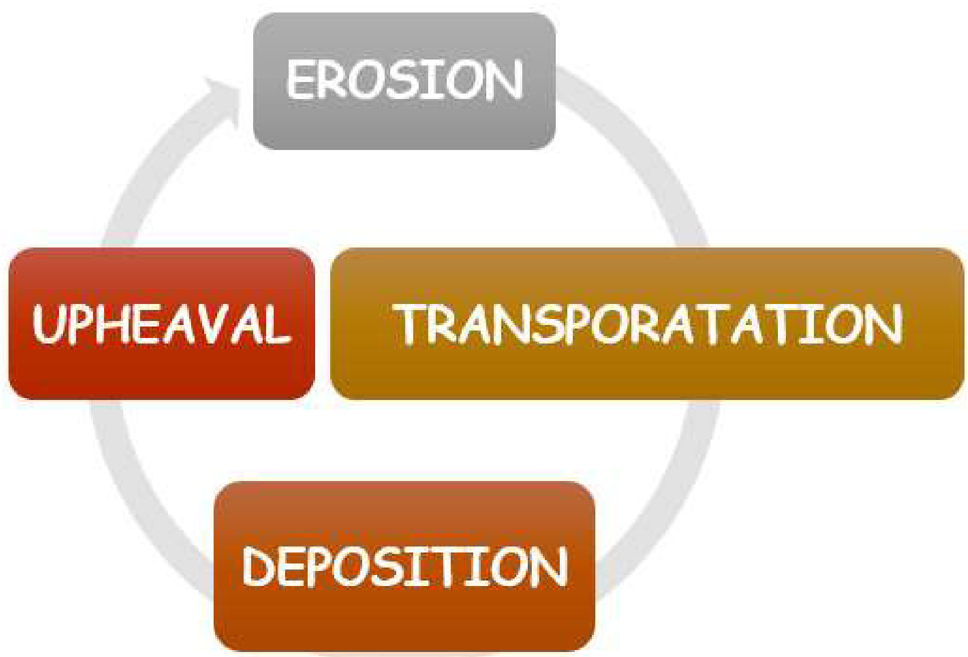
CHEMICAL DISINTEGRATION

- The disintegration of rocks taking place by chemical action is chemical disintegration.
- Here rock minerals transforms to new minerals and hence does not have the same properties of the parent rock.
- Clay is formed by chemical disintegration

1. Hydration
    - Hydration is the reaction between water and the minerals in rocks.
    - The chemical compounds formed as a result of this reaction will causes volume change and hence cause rock disintegration.

2. Carbonation
   - Water in rocks react with carbondioxide forming carbonic acid.
   - Carbonic acid reacting with rock minerals forms new compound and thus disintegration takes place.
3. Oxidation
   - Oxygen ions reacting with rock minerals is oxidation.
   - Oxidation forms new compounds and thus disintegration takes place.
4. Solution
   - Minerals dissolves in water to form solution.
   - Chemical reactions in solution causes disintegration.
5. Hydrolysis
   - Water dissociates to H^+ and OH^- ions
   - H+ is replaced by calcium, potassium etc. in rock minerals.
   - The higher volume compounds formed causes rocks to disintegrate.

<u>GEOLOGIC CYCLE</u>



The cycle shown in the figure that happens in the soil formation on earth is called geological cycle.

- Erosion : The soil disintegrates from the parent rock and get eroded from the rock surface.
- Transportation : The process by which the soil formed at the source is carried away to different locations by agents like gravity, water, wind and glaciers.
- Deposition : The stage in which soil gets deposited at place after getting transported from the parent rock.
- Upheaval : When soil gets accumulated at a place it causes upheaval.

  The cycle again restarts.

CLASSIFICATION OF SOIL

In light of the above process soil is classified into two.

1. RESIDUAL SOIL

   It is the soil that gets deposited near the parent rock without getting transported to another location.

2. TRANSPORTED SOIL

   The soil that get transported away from parent rock is called transported soil.

Following are the different types of transported soil ;

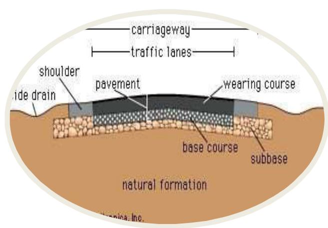
a) Aeolian Soil : The soil transported by wind
b) Glacier Deposits : The soil transported by glaciers.
c) Colluvial Soil : Gravity transported soil
d) Alluvial Soil : Water transported soil
   Alluvial soil deposited in lakes is called lacustrine deposits.
   Alluvial soil deposited in sea or ocean is called Marine deposits.

APPLICATION OF SOIL MECHANICS

1. FOUNDATIONS
   - Foundations are the structural element that transmits structural load to soil.
   - Hence to design foundation the capacity of soil to be known.

2. RETAINING STRUCTURES
    - These are vertical structures constructed to support soil.
    - To design these the pressure exerted by the soil to be known.

3. STABILITY OF SLOPES
    - At slopes soil can slide off due to instability
    - Soil properties to be known for making it stable.
4. TUNNELS
    - Tunnel are structures constructed through soil.
    - To design these force exerted by soil around tunnel has to be determined.
5. PAVEMENT DESIGN
    - Road pavements rest on soil.
    - Study of soil characteristics is required to design the pavement.



6. EARTH DAMS
    - Water reservoirs made with soil.
    - Soil properties to be studied to know whether the dam can hold water pressure.

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THREE PHASE SYSTEM OF SOIL

- Soil mass is composed of different soil grains.
- These grains are irregular in shape which makes soil porous.
- That is between individual grains there will be empty spaces in soil mass.
- These empty spaces in between soil grains are called voids.
- Voids are usually filled with air and water.
- Hence if we take a soil sample it has soil grains/soil solids and air and water in voids. As there are three constituents, soil is known as three phase system.
- But these three phases of soil are intermixed and is complex to analyse.
- So for analysis the three phases are represented in a diagram by placing one phase above other and represented by their mass and volume. Such a digram is known as three phase diagram.

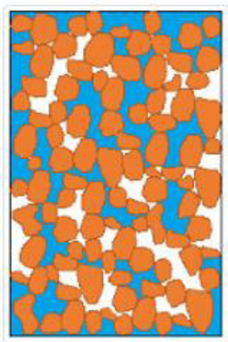


Figure 1: Soil Mass

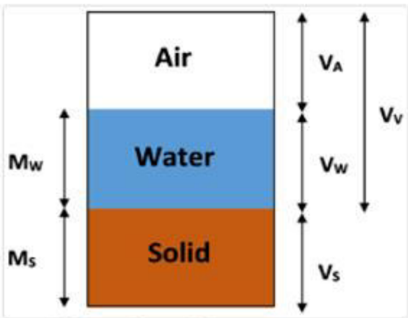


Figure 2: Three Phase Diagram

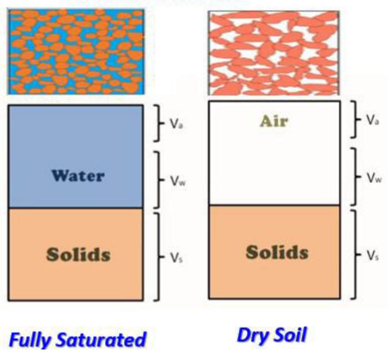
The soil mass containing soilds, air and water is called partially saturated soil.

A soil mass having no water in the voids is known as dry soil.(Only solids and air in voids)

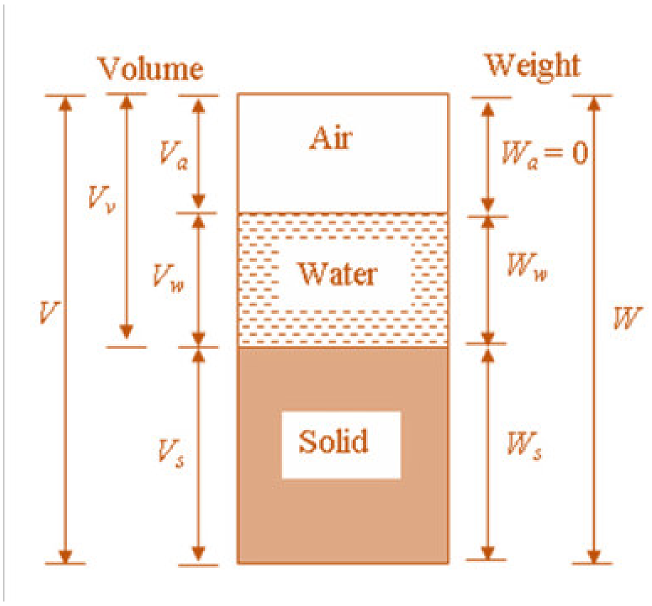
A soil mass having its voids filled with water is called fully saturated soil or simply saturated soil (only water and soilds. No air)

So saturated soil and dry soil forms two phase systems.

2 PHASE DIAGRAMS



BASIC DEFINITIONS



V_s	:	Volume of solids
V_w	:	Volume of water
V_a	:	Volume of air
V_v	:	Volume of voids = $V_a + V_w$
V	:	Volume of soil = $V_v + V_s$
W_w	:	Weight of water
W_s	:	Weight of solids
W	:	Weight of soil = $W_s + W_w$
W_d	:	Weight of dry soil = W_s

1. VOID RATIO (e)

- It is the ratio of ***volume of voids*** in the soil to ***volume of solids*** in the soil.
- Mathematically,

$$\boxed{e = \frac{V_v}{V_s}}$$

- Can have any value larger than zero.
- **No soil with out voids, V_v can not be zero so e > 0.**

2. POROSITY (n)

- It is the ratio of *volume of voids* in the soil to *total volume* of the soil expressed as percentage.
- Mathematically,

$$\boxed{n = \frac{V_v}{V} * 100}$$

- Can have any value between 0 and 100 (**0 < n < 100**)

Among void ratio and porosity void ratio is usually preferred by geotechnical engineer as it has lesser number of variables. Both numerator denominator for porosity is variable where as in void ratio equation the volume of solids is always constant for a soil sample.

3. DEGREE OF SATURATION (S)

- It is the ratio of ***volume of water*** *in the voids to* ***total volume of the voids*** *expressed as percentage.*
- Mathematically,

$$\boxed{S = \frac{V_w}{V_v} * 100}$$

- **$0 \leq S \leq 100$**

4. AIR CONTENT (a_c)

- It is the ratio of ***volume of air*** in the voids to ***total volume of the voids*** expressed as percentage.
- Mathematically,

$$\boxed{a_c = \frac{V_a}{V_v}}$$

- **$S + a_c = 1$** *: Relation between degree of saturation and air content*

Now, for a saturated soil, S = 1 (100%) and **$a_c = 0$**

For a dry soil, S = 0 and **$a_c = 1$**

5. PERCENTAGE AIR VOIDS (n_a)

- It is the ratio of ***volume of air in the voids to total volume of the soil*** expressed as percentage.
- Mathematically,

$$\boxed{n_a = \frac{V_a}{V} * 100}$$

- **$n\, a_c = n_a$** *: Relation between air content, porosity and percentage of air voids*

6. WATER CONTENT (w)

- It is the ratio of ***weight of water in the soil to weight of solids in the soil*** expressed as a percentage.
- Mathematically,

$$\boxed{w = \frac{w_w}{w_s} * 100}$$

- Lower limit = 0 % for dry soil.
- There is no upper limit.

7. BULK UNIT WEIGHT (γ)

- It is the ratio of ***weight of soil sample to the total volume of soil sample.***
- It is the unit weight for sample with its natural moisture content.
- Mathematically,

$$\boxed{\gamma = \frac{W}{V}}$$

8. DRY UNIT WEIGHT (γ_d)

- It is the ratio of ***weight of solids to the volume of sample.***
- It is the unit weight for Unit weight of fully dry soil.
- Mathematically,

$$\boxed{\gamma_d = \frac{W_s}{V}}$$

9. SATURATED UNIT WEIGHT (γ_{sat})

- It is the ratio of ***weight of saturated soil to the volume of sample.***
- It is the unit weight for fully saturated soil
- Mathematically,

$$\boxed{\gamma_{sat} = \frac{W_{sat}}{V}}$$

10. SUBMERGED UNIT WEIGHT (γ' or γ_b)

- It is the ratio of ***weight of submerged soil to the volume of sample.***
- It is the unit weight of fully submerged soil.
- Mathematically,

$$\boxed{\gamma' = \frac{W_{sub}}{V}}$$

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

11. UNIT WEIGHT OF SOILDS (γ_s)

- It is the ratio weight of ***solids*** to the ***volume of solids.***
- It is the unit weight of solids in soil sample alone
- Mathematically,

$$\boxed{\gamma s = \frac{W_s}{V_s}}$$

12. UNIT WEIGHT OF SOILDS (γ_s)

- Ratio of ***unit weight of a substance*** to the ***unit weight of a standard substance.***
- Usually for solids water is considered as the standard substance.

a) SPECIFIC GRAVITY OF SOLIDS / ABSOLUTE SPECIFIC GRAVITY (G or G_s)

- It is the ratio of ***unit weight of solids to the unit weight of water.***
- Mathematically,

$$\boxed{G = \frac{\gamma_s}{\gamma_w}}$$

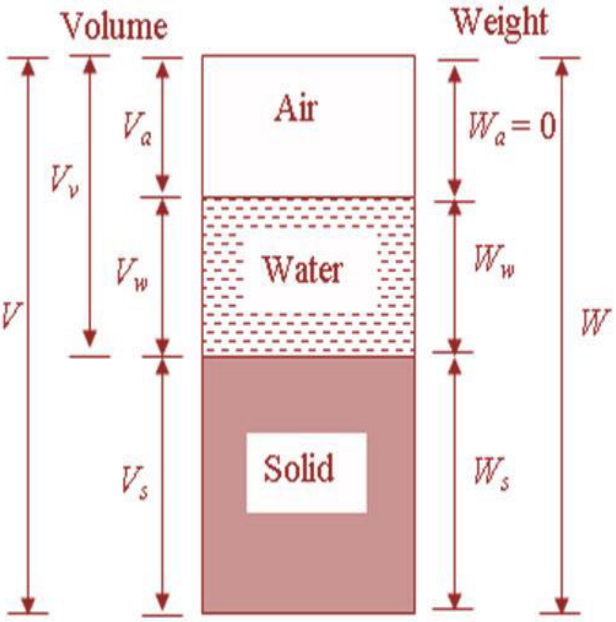
b) BULK SPECIFIC GRAVITY/ MASS SPECIFIC GRAVITY/ TRUE SPECIFIC GRAVITY (G_m)

- It is the ratio of ***bulk unit weight to the unit weight of water.***
- Mathematically,

$$\boxed{G_m = \frac{\gamma}{\gamma_w}}$$

DERIVATION OF FUNCTIONAL RELATIONSHIPS

1. Relation between Void ratio (e) and Porosity (n)



We know,

Void ratio, $e = \frac{Volume\ of\ voids}{Volume\ of\ solids} = \frac{V_v}{V_s}$ ….(1)

But from phase diagram we have,

$$V_s = V - V_v \quad \text{…………….(2)}$$

Substituting (2) in (1) we get,

$$e = \frac{V_v}{V - V_v}$$

Taking reciprocal,

$$\frac{1}{e} = \frac{V - V_v}{V_v}$$

$$\frac{1}{e} = \frac{V - V_v}{V_v}$$

$$\frac{1}{e} = \frac{V}{V_v} - \frac{V_v}{V_v} \qquad \frac{\text{Volume}}{\text{Volume of voids}} = \frac{1}{\text{POROSITY}} = \frac{1}{n}$$

Substituting,

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

Taking Reciprocal,

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

Similarly we can prove,

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

2. **Relation between Void ratio (e), water content (w),**

Degree of saturation (S) and Specific gravity (G)

We know,

Water content, $w = \frac{Weight\ of\ water}{Weight\ of\ solids} = \frac{w_w}{w_s}$

Can be written as, $w = \frac{V_w \gamma_w}{V_s \gamma_s}$ .... (1)

Specific gravity, $G = \frac{\gamma_s}{\gamma_w}$

From this, $\gamma_s = G\gamma_w$ ....(2)

Degree of saturation, $S = \frac{V_w}{V_v}$

From this, $V_w = S V_v$ ....(3)

Substituting (3) and (2) in (1), $w = \frac{SV_v * \gamma_w}{V_s * G\gamma_w}$

$$w = \frac{SV_v * \gamma_w}{V_s * G\gamma_w}$$

$$w = \frac{S}{G}\frac{V_v}{V_s}\frac{\gamma_w}{\gamma_w}$$

$\frac{\text{Volume of voids}}{\text{Volume of solids}}$ = VOID RATIO(e)

Substituting,

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

Re arranging,

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

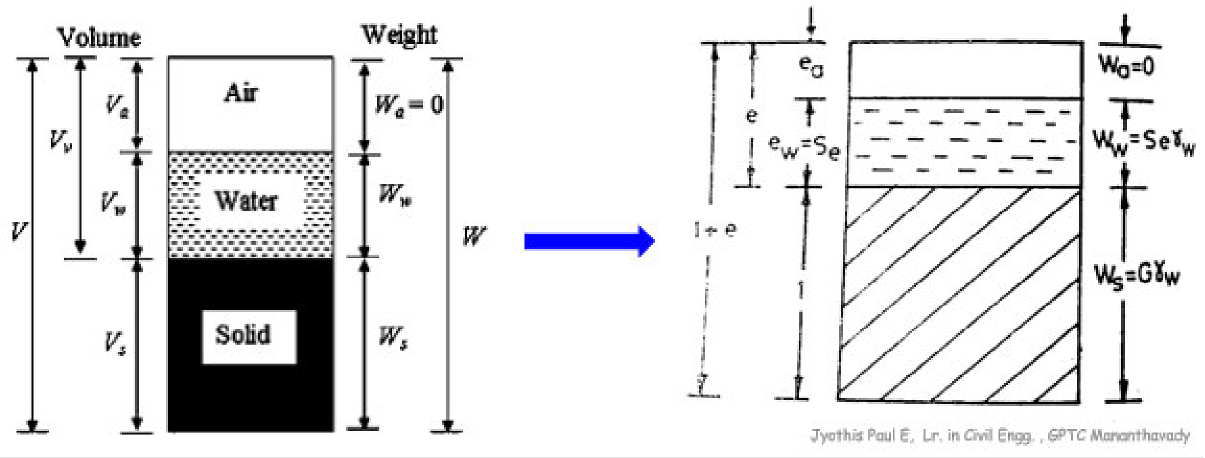
3. Relation between Void ratio (e), Specific gravity (G),
Degree of saturation (S) Unit weight (γ) and γ_w

- First we are going to re construct 3 phase diagram.
- Assume volume of solids is **unity.**

That is , $V_s = 1$

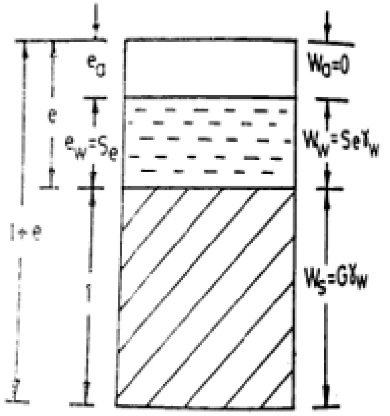
Now void ratio, $e = V_v / V_s = V_v$

Total volume, $V = V_v + V_s = 1+e$



Now unit weight, $\gamma = \frac{W}{V} = \frac{W_s + W_w}{V}$ .... (1)

Volume of sample, $\mathbf{V = 1+e}$ .... (2)



(b)

The weight of water, $W_w = V_w * \gamma_w$ ... (3)

Degree of saturation, $S = \frac{V_w}{V_s} = \frac{V_w}{e}$

We get, $\mathbf{V_w = e\,S}$

Substituting V_w in 3, $W_w = e\,S\,\gamma_w$ ....(4)

The weight of solids $W_s = \overset{1}{\cancel{V_s}} * \gamma_s = \gamma_s$ ...... (5)

Specific gravity, $G = \frac{\gamma_s}{\gamma_w} \longrightarrow \gamma_s = G\,\gamma_w$

Substituting γ_s in 5, $W_s = G\,\gamma_w$ ......(6)

$$\gamma = \frac{W_s + W_w}{V} \quad .... (1)$$

$\mathbf{V = 1+e}$ .... (2)

$\mathbf{W_w = e\,S\,\gamma_w}$ ....(4)

$\mathbf{W_s = G\,\gamma_w}$ ....(6)

Substituting (2),(4) and (6) in (1),

$$\gamma = \frac{G\,\gamma_w + e\,S\,\gamma_w}{1+e}$$

Re arranging,

$$\boxed{\gamma = \frac{\gamma_w\,(G + e\,S)}{1+e}}$$

DRY SOIL

$S = 0$, $\gamma = \gamma_d$

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

SATURATED SOIL

$S = 1$, $\gamma = \gamma_{sat}$

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

4. Relation between Dry unit weight (γ_d) , unit weight (γ), and Water content (w)

We have earlier derived,

Bulk unit weight, $\gamma = \frac{\gamma_w (G+e\,S)}{1+e}$ .... (1)

Void ratio, $e = \frac{wG}{S}$ .... (2)

$eS = wG$ .... (3)

Substituting (2) and (3) in (1),

$$\gamma = \frac{\gamma_w (G+wG)}{1+\frac{wG}{S}}$$

Rearranging, $1+\frac{wG}{S} = \frac{G\,\gamma_w (1+w)}{\gamma}$ .... (4)

We have earlier proved,

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

Substituting for e from (2),

$$\gamma_d = \frac{\gamma_w\, G}{1+{wG}/{S}}$$

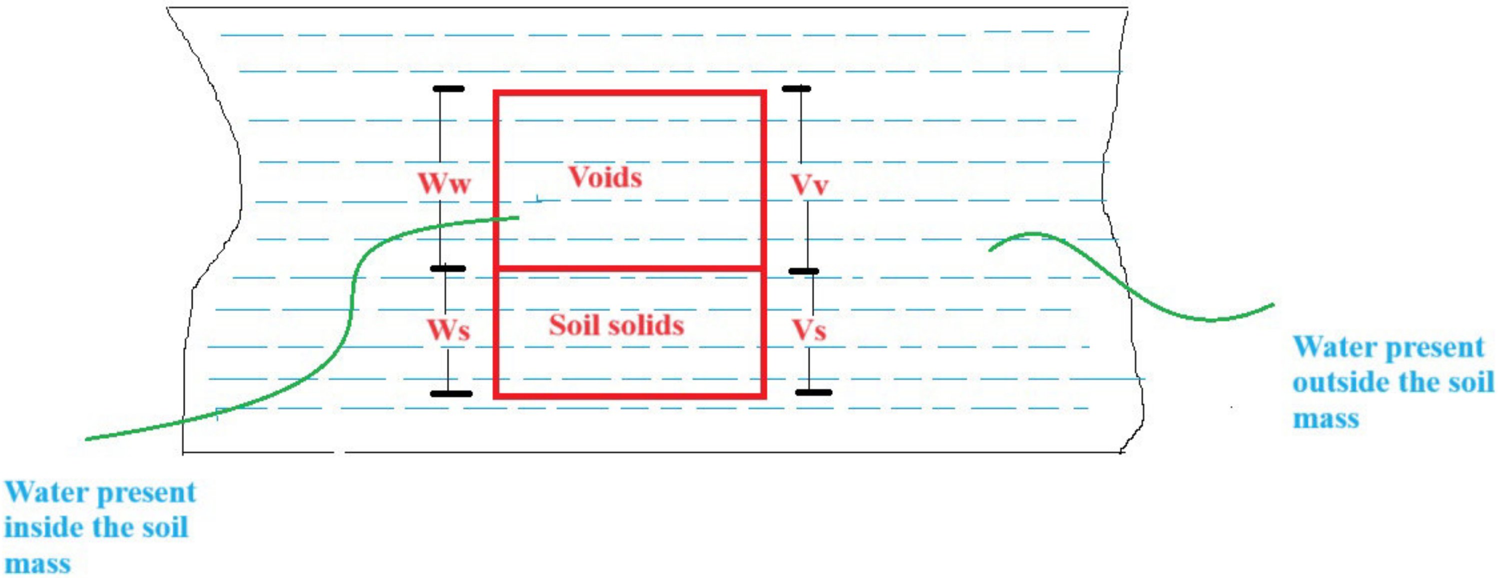
Rearranging,

$1+{wG}/{S} = \frac{\gamma_w\, G}{\gamma_d}$ .... (5)

Substituting (4) in (5) ,

$$\frac{\cancel{G\,\gamma_w}(1+w)}{\gamma} = \frac{\cancel{\gamma_w\, G}}{\gamma_d}$$

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



$$Submerged\ unit\ weight = \frac{Weight\ of\ soil\ mass\ inside\ water}{TOtal\ volume}$$

$$\gamma_{sub} = \frac{(W_s + W_w) - V\gamma_w}{V}$$

Where, $V\gamma_w = Weight\ of\ water\ displaced\ by\ soil\ mass$

Rewriting,

$$\gamma_{sub} = \frac{(W_s + W_w)}{V} - \gamma_w$$

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

In submerged condition, we have to consider buoyant effect of water on soil mass

ASSIGNMENT 1 (SAMPLE ANSWER)

1. DERIVE

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

SOLUTION

Relation between Voids ratio and porosity

porosity, $n = \frac{V_v}{V}$ —(1)

$V = V_v + V_s$ —(2)

sub (2) in (1)

$$n = \frac{V_v}{V_v + V_s}$$

$$1/n = \frac{V_v + V_s}{V_v}$$

$$1/n = \frac{V_v}{V_v} + \frac{V_s}{V_v} \quad \text{—(3)}$$

we know $\frac{V_v}{V_s} = e$

$\therefore \frac{V_s}{V_v} = 1/e$ —(4)

sub (4) in (3)

$$1/n = 1 + 1/e$$

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

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

PROBLEMS

1. The weight of a chunk of moist soil is **0.196 kN** and its volume is **0.011 m³**. After drying in the oven the weight reduces to **0.162 kN**. Determine *i) Water content, ii) Unit weight of moist soil, iii) the dry unit weight, iv) void ratio, v) porosity, and vi) degree of saturation*. Take G=**2.7** and unit weight of water is **= 10 kN/m³**

SOLUTION

Weight of soil sample, W = 0.196 kN
Volume of soil sample, V = 0.011 m³
Weight of dry soil , W_s = 0.162 kN

i) Water content

Water content, $w = \frac{W_w}{W_s} * 100 \quad = \frac{0.034}{0.162} * 100 = \mathbf{21\%}$

(Weight of water, $W_w = W - W_s = 0.196 - 0.162 = 0.034$ kN)

ii) Unit wt. of moist soil/Bulk unit wt.

Bulk unit wt, $\gamma = \frac{W}{V}$

$= \frac{0.196}{0.011} \quad = \mathbf{17.82\ kN/m^3}$

iii) Dry unit weight

Dry unit wt, $\gamma_d = \frac{W_s}{V}$

$= \frac{0.162}{0.011} \quad = \mathbf{14.72\ kN/m^3}$

iv) Void Ratio

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

Void ratio , $e = \frac{G\gamma_w}{\gamma_d} - 1$

$= \frac{2.7 * 10}{14.72} - 1 \quad = 0.83$

v) Porosity

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

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

$= \frac{0.83}{0.83+1} = 0.45 \quad (45\%)$

v) Degree of Saturation

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

Degree of saturation, $S = \frac{wG}{e} \quad = \frac{0.21*2.7}{0.83}$

$= 0.68 \quad (68\%)$

2. The **mass** of a chunk of moist soil is **20 kg** and its volume is **0.011 m^3**. After drying in the oven the **mass** reduces to **16.5 kg**. Determine *i) Water content, ii) Density of moist soil, iii) the dry density, iv) void ratio, v) porosity, and vi) degree of saturation*.

Take G = **2.7**

SOLUTION

Mass of soil sample, M = 20 kg
Vol. of soil sample, V = 0.011 m^3
Mass of dry soil , M_s = 16.5 kg
Density of water , ρ_w = 1000 kg/m^3

i) Water content

Water content, $w = \frac{M_W}{M_S} * 100 \quad = \frac{3.5}{16.5} * 100$ **= 21.21%**

(Weight of water, $M_w = M - M_s = 20\text{-}16.5 = 3.5$ kg)

ii) Density of moist soil/Bulk density

Bulk density, $\rho = \frac{M}{V}$

$= \frac{20}{0.011}$ = 1818.18 kg/m^3

iii) Dry Density

Dry density, $\rho_d = \frac{M_s}{V}$

$= \frac{16.5}{0.011}$ = 1500 kg/m^3

iv) Void Ratio

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

Void ratio, $e = \frac{G\rho_w}{\rho_d} - 1$

$= \frac{2.7 * 1000}{1500} - 1$ = 0.8

v) Porosity

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

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

$= \frac{0.8}{0.8+1}$ = 0.45 **(45%)**

v) Degree of Saturation

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

Degree of saturation, $S = \frac{wG}{e} \quad = \frac{0.21 * 2.7}{0.8}$

= 0.71 **(71%)**

3. The total unit weight of soil sample is **16 kN/m³**. The water content of soil is **17%.** Calculate *i) Dry unit weight, ii) Void ratio, iii) Porosity and iv) Degree of saturation.*

   Take G=**2.67** and unit weight of water is **= 10 kN/m³**

SOLUTION

Unit Weight of soil sample, $\gamma = 16$ kN/m³

Water content of soil sample, $w = 17$ %

Specific Gravity, $G = 2.67$

i) Dry unit weight

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

Dry unit weight, $\gamma_d = \frac{\gamma}{(1+w)} = \frac{16}{1+0.17}$ **= 13.67 kN/m³**

ii) Void Ratio

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

Void ratio , $e = \frac{G\gamma_w}{\gamma_d} - 1$

$= \frac{2.67 * 10}{13.67} - 1$ **= 0.95**

iii) Porosity

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

$= \frac{0.95}{0.95+1} = 0.487$ **(48.7%)**

iv) Degree of Saturation

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

Degree of saturation, $S = \frac{wG}{e} = \frac{0.17 * 2.67}{0.95}$

$= 0.48$ **(48%)**

4. A soil sample has unit weight **20.11 kN/m³** and water content **15%.** Calculate *water content* if the soil partially dries to a unit weight of **19.42 kN/m³** and the **void ratio remains unchanged**.

   SOLUTION

   From the given data,

   Void ratio is constant.

   For a given soil sample dry density is also constant. We can solve based on these

CASE 1 : BEFORE PARTIAL DRYING

$\gamma_1 = 20.11$ kN/m^3

$w_1 = 15$ %

$$\gamma_{d1} = \frac{\gamma_1}{(1 + w_1)} = \frac{20.11}{1+0.15}$$

$$= 17.48 \text{ kN/m}^3$$

CASE 2 : AFTER DRYING PARTIALLY

$\gamma_2 = 19.42$ kN/m^3

$\gamma_{d1} = 17.48$ kN/m^3

$$\gamma_{d1} = \frac{\gamma_2}{(1 + w_2)}$$

$$w_2 = \frac{\gamma_2}{\gamma_{d1}} - 1$$

$$= \frac{19.42}{17.48} - 1 = 0.11$$ **(11%)**

ASSIGNMENT 2 (SAMPLE ANSWER FROM STUDENTS)

(R is the last two digits of register number)

1. A sample of moist clay has a volume of 14.88 cc. Total mass is 28.81 g and dry mass is 24.83-(R/100) Determine *i) Water content, ii) Dry density, iii) Void ratio, iv) Degree of saturation?* Take G=**2.7** .

1) Volume $= 14.88\ cm^3$ R = 10

total mass, $m = 28.81\ g$

dry mass of solid soil, $m_s = 24.83 - R/100$

$= 24.83 - 10/100$

$= 24.73\ g$ G = 2.7

$m_w = 28.81 - 24.73 = 4.08\ g$

i) water content $= \frac{m_w}{m_s} \times 100$

$= \frac{4.08}{24.73} \times 100$

$= 16.49\%$

ii) dry density, $\rho_d = \frac{m_s}{V}$

$= \frac{24.73}{14.88}$

$= 1.66\ g/cm^3$

iii) $\rho_d = \frac{\rho_w G}{1+e}$ $\rho_w = 1000\ kg/m^3 = 1\ g/cc$

$\therefore$ Voids ratio, $e = \frac{\rho_w G}{\rho_d} - 1$

$= \frac{1 \times 2.7}{1.66} - 1$

$= .626$

$w = \frac{m_w}{m_s} = \frac{4.08}{24.73} = .16$

iv) degree of saturation, $s = \frac{wG}{e} \times 100$

$= \frac{.16 \times 2.7}{.626} \times 100$

$= .69 \times 100$

$= 69\%$

2. The **weight** of a chunk of moist soil is **0.2 kN** and its volume is **0.012 m³**. After drying in the oven the **weight** reduces to **0.16-(R/1000) kN**. Determine degree of saturation , void ratio and porosity.

Take G = 2.67 and unit weight of water is 9.81 kN/m^3

<u>SOLUTION</u>

ii) weight, $w = .2$ kN

volume $= 0.012$ m^3

$R = 10$

$w_s = 0.16 - R/1000$

$= 0.16 - 10/1000$

$= 0.15$ kN

$G = 2.67$

$\gamma_w = 9.81$ kN/m^3

$w_w = .2 - .15 = .05$ kN

dry weight $\gamma_d = w_s/V$

$= 0.15/0.012$

$= 12.5$ kN/m^3

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

$$e = \frac{\gamma_w G}{\gamma_d} - 1$$

$$w = \frac{W_w}{W_s} = \frac{.05}{.15} = .33$$

ii) voids ratio, $e = \frac{\gamma_w G}{\gamma_d} - 1$

$$= \frac{9.81 \times 2.67}{12.5} - 1$$

$$= 1.09$$

i) degree of saturation

$$S = \frac{wG}{e} \times 100$$

$$= \frac{.33 \times 2.67}{1.09} \times 100$$

$$= 80.8\%$$

iii) porosity, $n = e/1+e$

$$= \frac{1.09}{1+1.09}$$

$$= \frac{1.09}{2.09} = 0.52$$

$$= 52\%$$

LABORATORY PROCEDURES FOR THE EXPERIMENTS DISCUSSED

(For theoretical explanation refer to the slides)

1. MEASUREMENT OF WATER CONTENT BY OVENDRYING METHOD

Apparatus : Air tight container, Weighing balance, Hot air oven, Desiccator.

Procedure

1. Clean the container with lid dry it and weigh it (W1).
2. Take a specimen of the sample in the container and weigh with lid (W2).
3. Keep the container in the oven with lid removed. Dry the specimen to constant weight maintaining the temperature between 105^0C to 110^0 C for a period varying with the type of soil but usually 16 to 24 hours.
4. Record the final constant weight (W3) of the container with dried soil sample. Peat and other organic soils are to be dried at lower temperature (say60^0 C) possibly for a longer period.

Certain soils contain gypsum which on heating loses its water if crystallization. If it is suspected that gypsum is present in the soil sample used for moisture content determination it shall be dried at not more than 80^0 C and possibly for a longer time.

Now, Water content , w = $\mathbf{[(W_2-W_3)/(W_3-W_1)]x100}$

2. MEASUREMENT OF SPECIFIC GRAVITY BY SPECIFIC GRAVITY BOTTLE

APPARATUS :

1. Specific gravity bottle
2. Balance to weigh the materials (accuracy 10gm).
3. Wash bottle with distilled water.
4. Alcohol and ether.

PROCEDURE

1. Clean and dry the specific gravity bottle
   a. Wash the specific gravity bottle with water and allow it to drain.

b. Wash it with alcohol and drain it to remove water.

c. Wash it with ether, to remove alcohol and drain ether.

2. Weigh the specific gravity bottle (W1)
3. Take about 200 gm of oven-dried soil sample which is cooled in a desiccator. Transfer it to the specific gravity bottle. Find the weight of the specific gravity bottle and soil (W2).
4. Put 10ml of distilled water in the specific gravity bottle to allow the soil to soak completely. Leave it for about 2 hours.
5. Again fill the specific gravity bottle completely with distilled water put the stopper and keep the specific gravity bottle under constant temperature water baths (Tx^0).
6. Take the specific gravity bottle outside and wipe it clean and dry it. Now determine the weight of the specific gravity bottle and the contents (W3).
7. Now empty the specific gravity bottle and thoroughly clean it. Fill the specific gravity bottle with only distilled water and weigh it. Let it be W4 at temperature (Tx^0 C).
8. Repeat the same process for 2 to 3 times, to take the average reading of it.

Now, specific gravity is determined by

$$\textit{Specific gravity of soil} = \frac{\text{Density of water at 27 C}}{\text{Weight of water of equal volume}}$$

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

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

3. <u>MEASUREMENT OF FIELD DENSITY BY CORE CUTTER METHOD</u>

<u>APPARATUS</u>

a) Special:
   i. Cylindrical core cutter
   ii. Steel rammer
   iii. Steel dolly

b) General:

i. Balance of capacity 5 Kg and sensitivity 1 gm.

ii. Balance of capacity 200gms and sensitivity 0.01 gms.

iii. Scale

iv. Spade or pickaxe or crowbar

v. Trimming Knife

vi. Oven

vii. Water content containers

viii. Desiccator.

PROCEDURE

i. Measure the height and internal diameter of the core cutter. The volume of cutter is (V)
ii. Weight the clean core cutter. (W1)
iii. Clean and level the ground where the density is to be determined.
iv. Press the cylindrical cutter into the soil to its full depth with the help of steel rammer.
v. Remove the soil around the cutter by spade.
vi. Lift up the cutter.
vii. Trim the top and bottom surfaces of the sample carefully.
viii. Clean the outside surface of the cutter.
ix. Weight the core cutter with the soil. (W2)
x. Remove the soil core from the cutter and take the representative sample in the water content containers to determine the moisture content by any of the methods. Let 'w' be the water content obtained.

Now , field density,

$$\boxed{\text{Field density, } \rho = (W2 - W1)/V}$$

And,

$$\boxed{\text{Dry density, } \rho_d = \frac{\rho}{1+w}}$$

4. MEASUREMENT OF FIELD DENSITY BY SAND REPLACEMENT METHOD

APPARATUS REQUIRED

1. Sand pouring cylinder of 3 litre/16.5 litre capacity mounted above a pouring come and separated by a shutter cover plate.
2. Tools for excavating holes; suitable tools such as scraper tool to make a level surface.
3. Cylindrical calibrating container with an internal diameter of 100 mm/200 mm and an internal depth of 150 mm/250 mm fitted with a flange 50 mm/75 mm wide and about 5 mm surrounding the open end.
4. Balance to weigh unto an accuracy of 1g.
5. Metal containers to collect excavated soil.
6. Metal tray with 300 mm/450 mm square and 40 mm/50 mm deep with a 100 mm/200 mm diameter hole in the centre.
7. Glass plate about 450 mm/600 mm square and 10mm thick.
8. Clean, uniformly graded natural sand passing through 1.00 mm I.S. sieve and retained on the 600micron I.S. sieve. It shall be free from organic matter and shall have been oven dried and exposed to atmospheric humidity.
9. Suitable non-corrodible airtight containers.
10. Thermostatically controlled oven with interior on non-corroding material to maintain the temperature between 105^0C to 110^0C
11. A dessicator with any desiccating agent other than sulphuric acid.

PROCEDURE

Calibration of the Cylinder

1. Fill the sand pouring cylinder with clean sand so that the level of the sand in the cylinder is within about 10 mm from the top. Find out the initial weight of the cylinder plus sand (W_1) and this weight should be maintained constant throughout the test for which the calibration

is used.

2. Allow the sand of volume equal to that of the calibrating container to run out of the cylinder by opening the shutter, close the shutter and place the cylinder on the glass sand takes place in the cylinder close the shutter and remove the cylinder carefully. Weigh the sand collected on the glass plate. Its weight (W_2) gives the weight of sand filling the cone portion of the sand pouring cylinder. Repeat this step at least three times and take the mean weight (W_2) Put the sand back into the sand pouring cylinder to have the same initial constant weight (W_1)

Determination of Bulk Density of Soil

3. Determine the volume (V) of the container be filling it with water to the brim. Check this volume by calculating from the measured internal dimensions of the container.

4. Place the sand poring cylinder centrally on the top of the calibrating container making sure that constant weight (W_1) is maintained. Open the shutter and permit the sand to run into the container. When no further movement of sand is seen close the shutter, remove the pouring cylinder and find its weight (W_3).

Determination of Dry Density of Soil in Place

5. Approximately 60 sq.cm of area of soil to be tested should be trimmed down to a level surface, approximately of the size of the container. Keep the metal tray on the level surface and excavate a circular hole of volume equal to that of the calibrating container. Collect all the excavated soil in the tray and find out the weight of the excavated soil (W_4). Remove the tray, and place the sand pouring cylinder filled to constant weight so that the base of the cylinder covers the hole concentrically. Open the shutter and permit the sand to run into the hole. Close the shutter when no further movement of the sand is seen. Remove the cylinder and determine its weight (W_5).

6. Keep a representative sample of the excavated sample of the soil for water content determination.

$$\boxed{\text{Density of sand}, \rho_s = \frac{\text{Mass of sand in container}}{\text{Volume of Container}} = \frac{W1 - W3 - W2}{V}}$$

$$\text{Volume of hole}, V_h = \frac{W_1 - W_5 - W_2}{\rho_s}$$

$$\boxed{\textbf{Field density}, \rho = \frac{W_4}{V_.}}$$

$$\boxed{\textbf{Dry density}, \rho_d = \frac{\rho}{1+w}}$$

DETERMINATION OF WATER CONTENT

OVEN DRYING METHOD

$$\textbf{Water content, } w = \frac{M_w}{M_s} * 100$$

M_s : Mass of solids/ Dry weight

M_w : Mass of water

Just find the moist mass and dry mass !!!

Air tight containers

Weighing balance

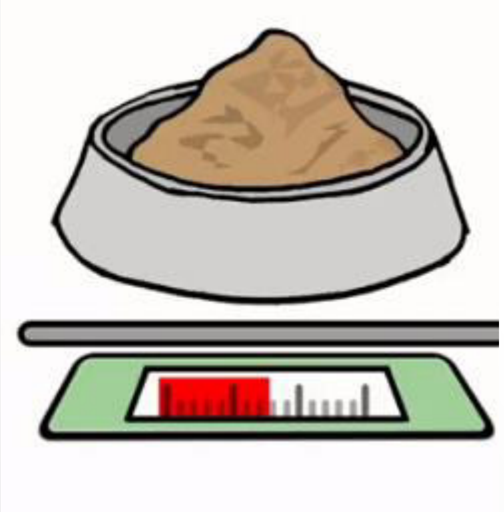
Hot air oven

Desiccator

STEP 1

Take empty mass of container, M_1

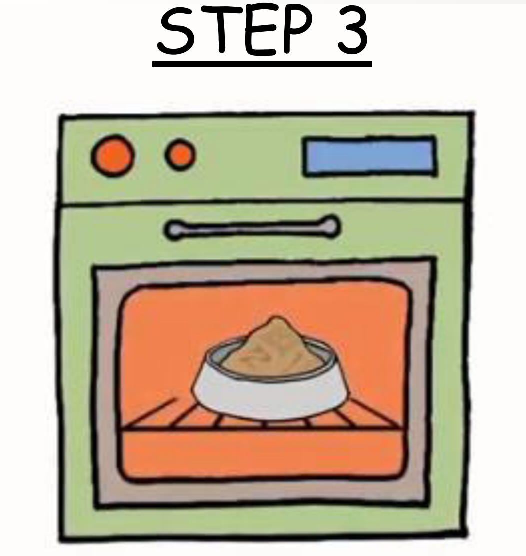
STEP 2



Take moist soil in the container and take mass, M_2

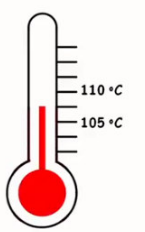
- *Quantity of soil taken depends on gradation.*

STEP 3



Keep the sample in hot air oven

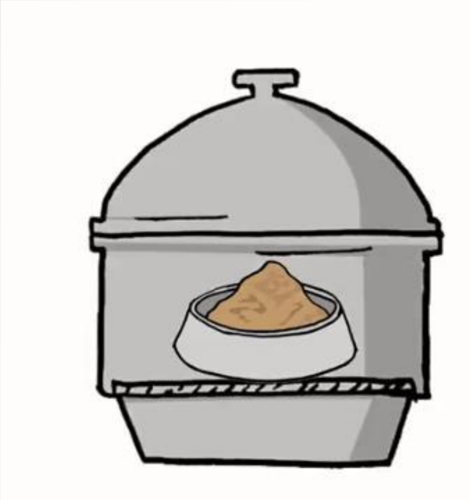
For **24 hours**



@ 105 - 110 °**C**

- Water in normal soil evaporates and soil dries @ this conditions

STEP 3



Cool down to room temperature using Desiccator

STEP 4

Take the mass of dry soil, M_3

M_1 : Mass of container
M_2 : Mass of container+ Moist soil
M_3 : Mass of container+ Dry soil

$M_s = M_3 - M_1$

$M_w = M_2 - M_3$

Water content is

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

Repeat for atleast 3 samples

DETERMINATION OF SPECIFIC GRAVITY

PYCONOMETER & SPECIFIC GRAVITY BOTTLE METHODS

$$\text{Specific Gravity, } G = \frac{\rho_s}{\rho_w}$$

ρ_s : Density of solids = $\frac{M_s}{V_s}$

ρ_w : Density of water = $\frac{M_w}{V_w}$

- So , $G = \frac{M_s/\cancel{V_s}}{M_w/\cancel{V_w}}$
- Hence specific gravity can also be written as

$$G = \frac{\text{Mass of specific volume of solids}}{\text{Mass of equivalent volume of water}}$$

→ Principle for the test !!!

SPECIFIC GRAVITY BOTTLE

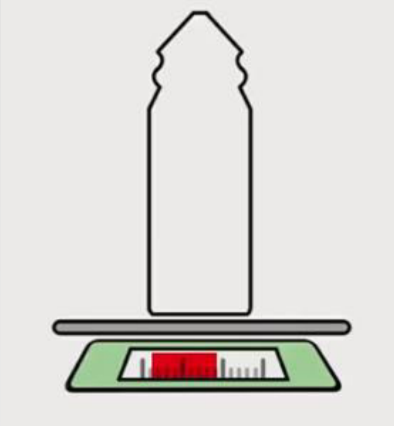
- Generally used for **fine grained soil**
- 5- 10 g of oven dry sample is used for test

PYCNOMETER

- Generally used for **medium and coarse grained soil**
- 200- 300g of oven dry sample is required

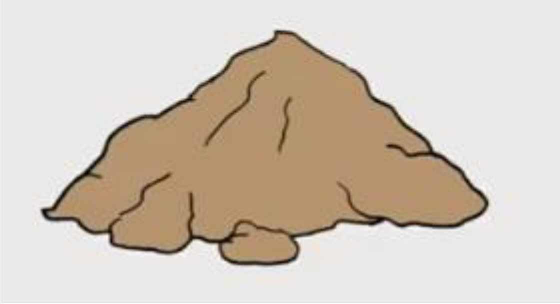
Procedure is same in both methods.

STEP 1



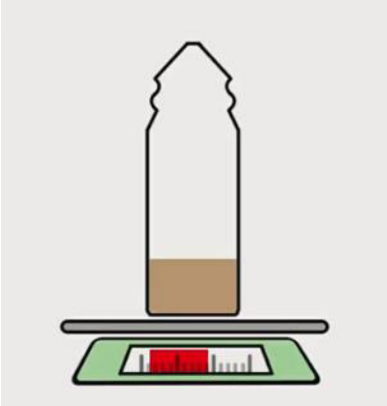
Take empty mass of pycnometer, M_1

STEP 2



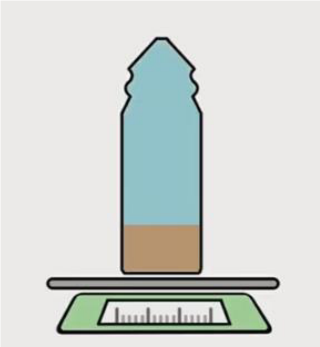
Take required amount of oven dried soil sample

STEP 3



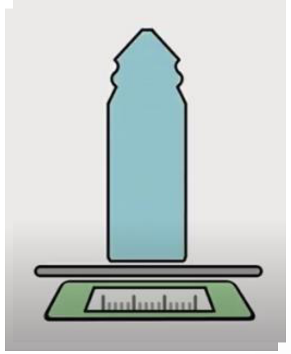
Fill the soil in pycnometer and take the mass, M_2

STEP 4



Fill pycnometer with water and take mass, M_3

STEP 5



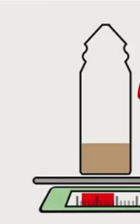
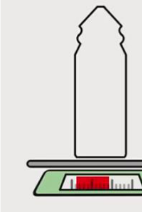
Empty and clean pycnometer and fill it with water , mass is M_4

We have,

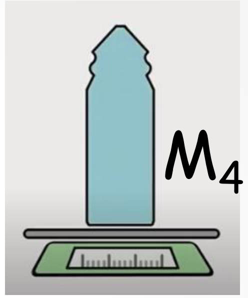
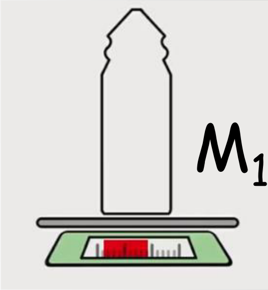
M_1 : Mass of pycnometer
M_2 : Mass of pycnometer + dry soil
M_3 : Mass of pycnometer + dry soil + water
M_4 : Mass of pycnometer + water

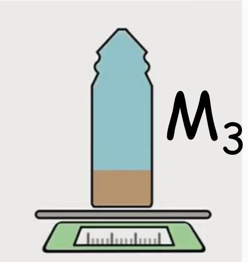
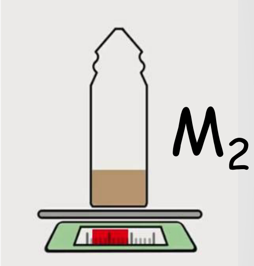
We need

$$G = \frac{\text{Mass of specific volume of solids } (Ms)}{\text{Mass of equivalent volume of water } (Mw)}$$

M_s =  M_2 -  M_1

Next ,we need mass of ***water that occupies the volume of soil*** *(M_w)*

1. Mass of water that completely fills pycnometer =  M_4 -  M_1

2. Mass of water excluding soil in pycnometer =  M_3 -  M_2

$$M_w = (1) - (2) = (M_4 - M_1) - (M_3 - M_2)$$

$$M_w = (M_2 - M_1) - (M_3 - M_4)$$

$$\boxed{G = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}}$$

Image Courtesy : Elementary Engineering

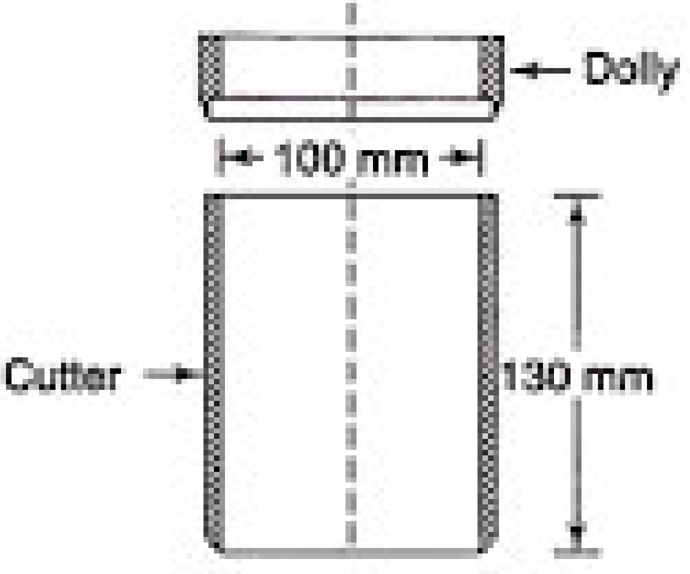
Jyothis Paul E, Lr. in Civil Engg. , GPTC Mananthavady

DETERMINATION OF FIELD DENSITY

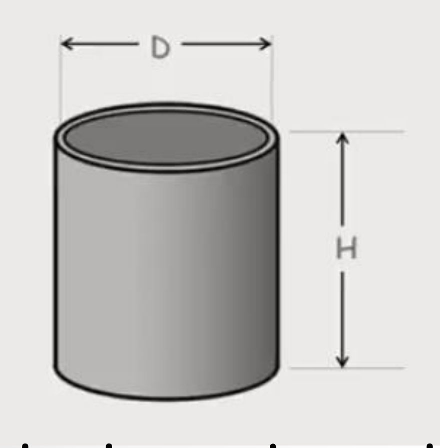
CORE CUTTER METHOD

$$\text{Field density, } \rho = \frac{M}{V}$$

M : Mass of in situ soil
V: Volume occupied by soil

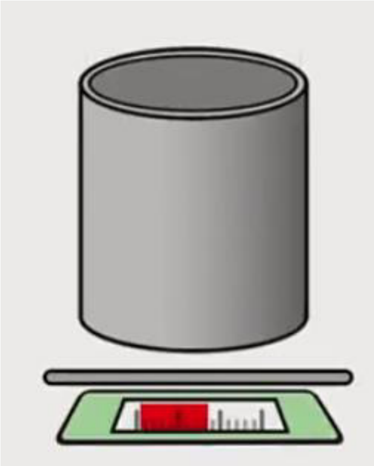


STEP 1



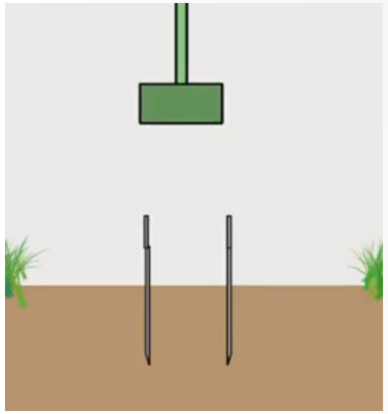
Calculate the volume of cutter, **V**

STEP 2



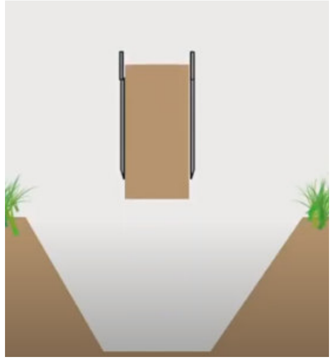
Take the mass of cutter, **M_1**

STEP 3



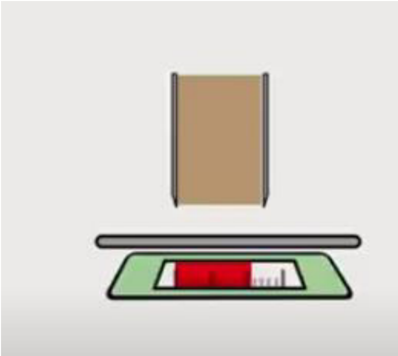
Clean & level the surface and using rammer insert cutter to soil

STEP 4



Take out the sample, remove dolly and trim edges

STEP 5



Take the mass of cutter with collected soil , **M_2**

Image Courtesy : Elementary Engineering

Jyothis Paul E, Lr. in Civil Engg. , GPTC Mananthavady

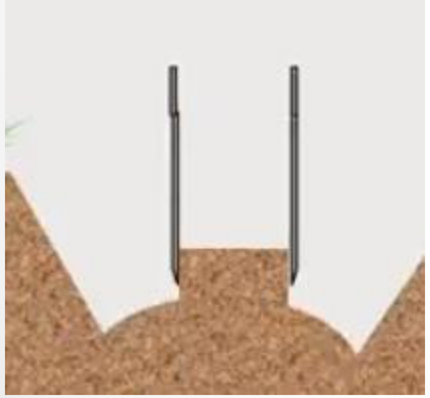
M_1 : Mass of cutter
M_2 : Mass of cutter + soil
V : Volume of container
Mass of soil $M = M_2 - M_1$

$$\textbf{Field density, } \rho = \frac{M_2 - M_1}{V}$$

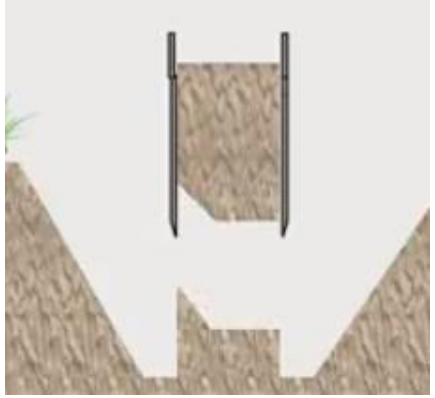
- Take a quantity of sample tested and **determine its water content**

We can find,

$$\textbf{Dry density, } \rho_d = \frac{\rho}{1+w}$$



Granular Soil



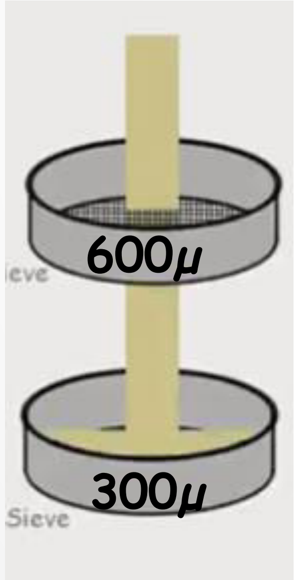
Hard Soil

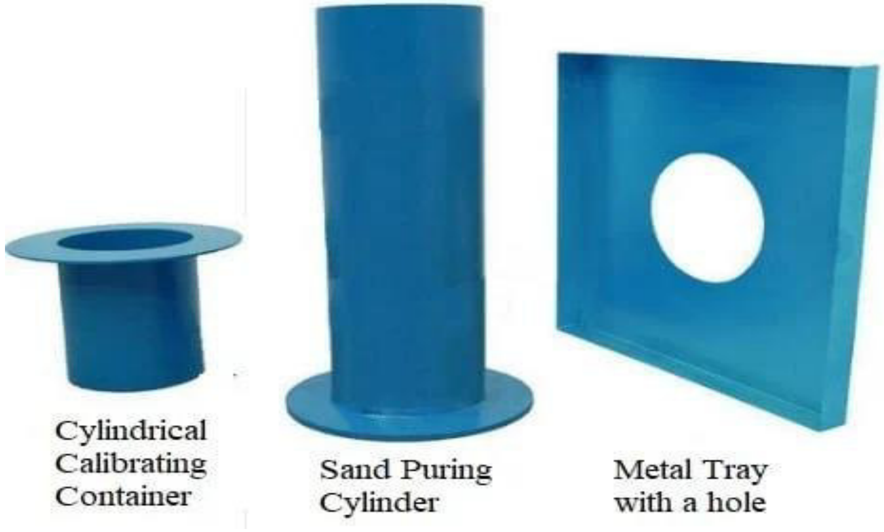
Core cutter method is of no use !!!

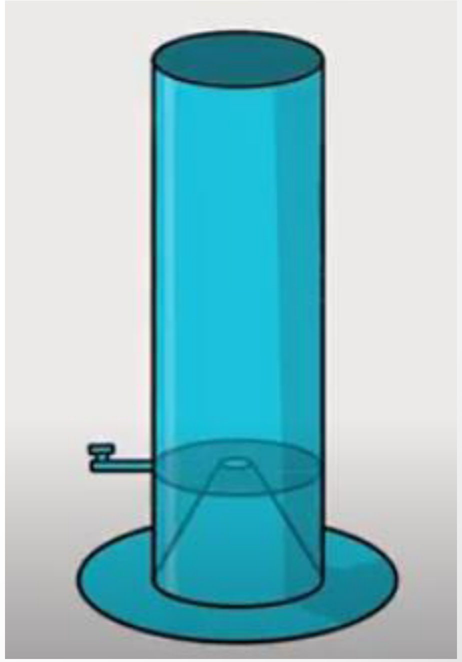
DETERMINATION OF FIELD DENSITY

SAND REPLACEMENT METHOD

- Used on soils in which core cutter method is not possible.
- Density of sample is **indirect**ly calculated **using sand** as a medium.



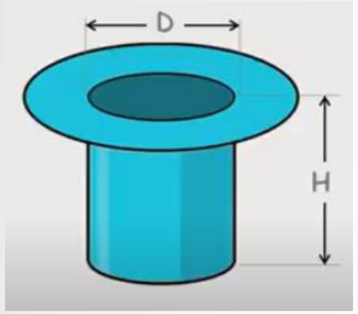




1.CALIBRATION OF APPARATUS

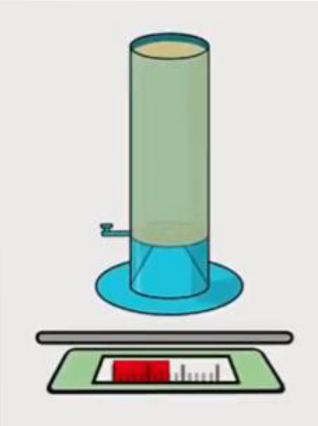
To Find Density of Sand

STEP 1



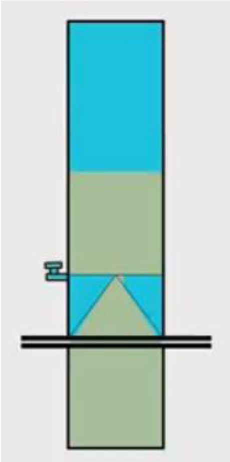
Calculate volume of calibrating container, V_c

STEP 2



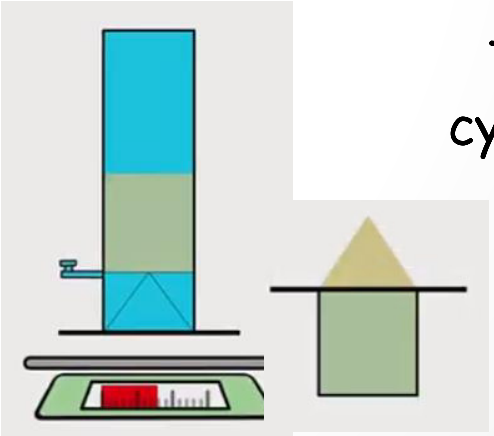
Take mass of sand pouring cylinder , M_1

STEP 3



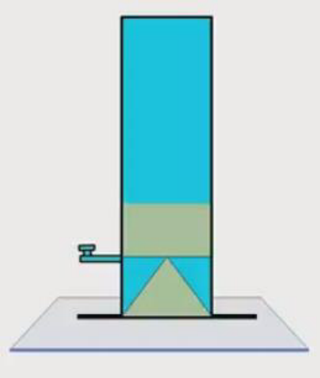
Pour sand into the calibrating container

STEP 4



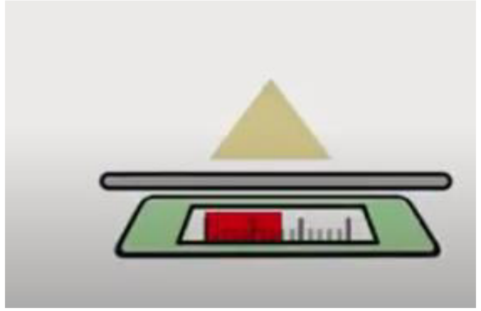
Take the mass of cylinder after filling container, M_2

STEP 5



Pour sand to glass plate

STEP 6



Take the mass of sand from glass plate, **M_3**

V_c : Volume of calibrating container

M_1 : Mass of cylinder + Fully filled sand

M_2 : Mass of cylinder + Sand after filling calibrating container

M_3 : Mass of sand forming cone only (Mass taken on glass plate)

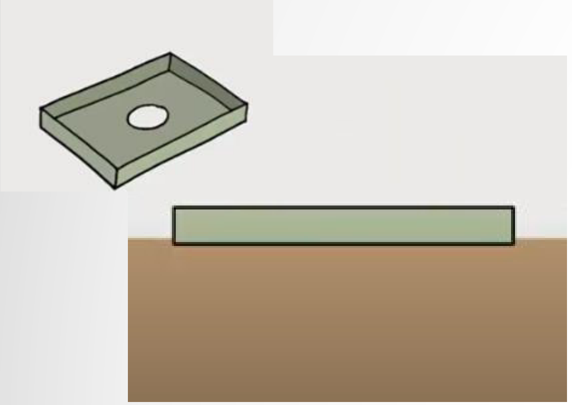
Mass of sand collected in the container $= M_1 - M_2 - M_3$

$$\text{Density of sand},\ \rho_s = \frac{\text{Mass of sand in container}}{\text{Volume of Container}} = \frac{M_1 - M_2 - M_3}{V_c}$$

2.CALCULATING VOLUME OF HOLES

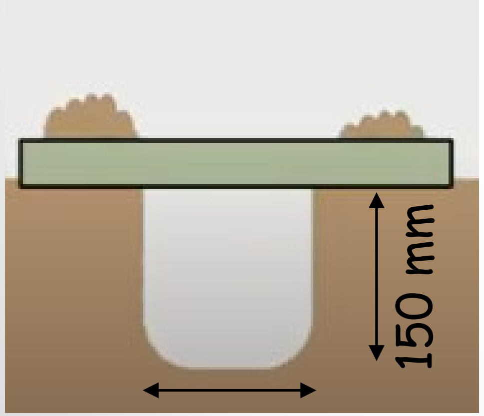
Finding Density of Soil

STEP 1



At site clean and level the soil surface and place the metal tray with hole.

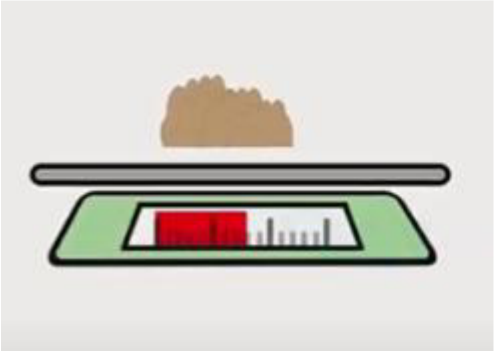
STEP 2



100 mm

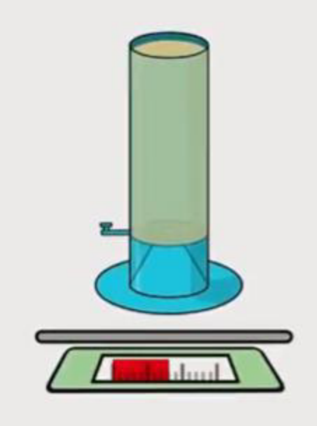
- Dig a hole in soil taking the hole in the tray as pattern.
- Carefully collect the excavated soil in the tray

STEP 3



Take the mass of excavated soil, M_4

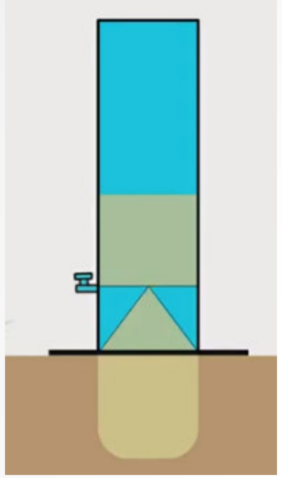
STEP 4



Fill sand again and take mass of sand pouring cylinder , M_5

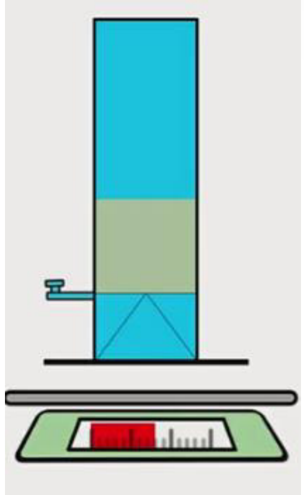
Image Courtesy : Elementary Engineering

STEP 5



Place cylinder on soil and fill the hole with sand

STEP 6



Take the weight of cylinder with sand after filling the hole, M_6

M_4 : Mass of soil excavated from hole

ρ_s : Density of sand

M_5 : Mass of cylinder + Fully filled sand

M_6 : Mass of cylinder + Sand after filling hole

M_3 : Mass of sand forming cone only

Mass of sand in the hole = $M_5 - M_6 - M_3$

Volume of hole, $V_h = \frac{M_5 - M_6 - M_3}{\rho_s}$

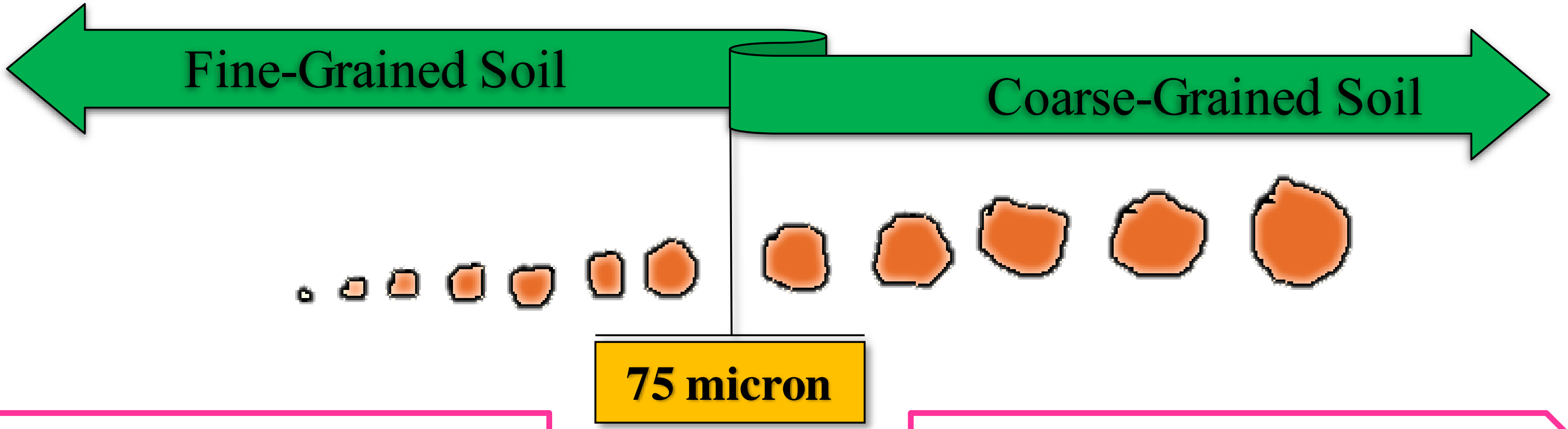
$$\textbf{Field density, } \rho = \frac{M_4}{V_h}$$

- Water content of excavated sample can be found

$$\textbf{Dry density, } \rho_d = \frac{\rho}{1+w}$$

Particle Size Analysis

Particle size analysis is the method of separation of any soil sample into different fractions based on their particles sizes.

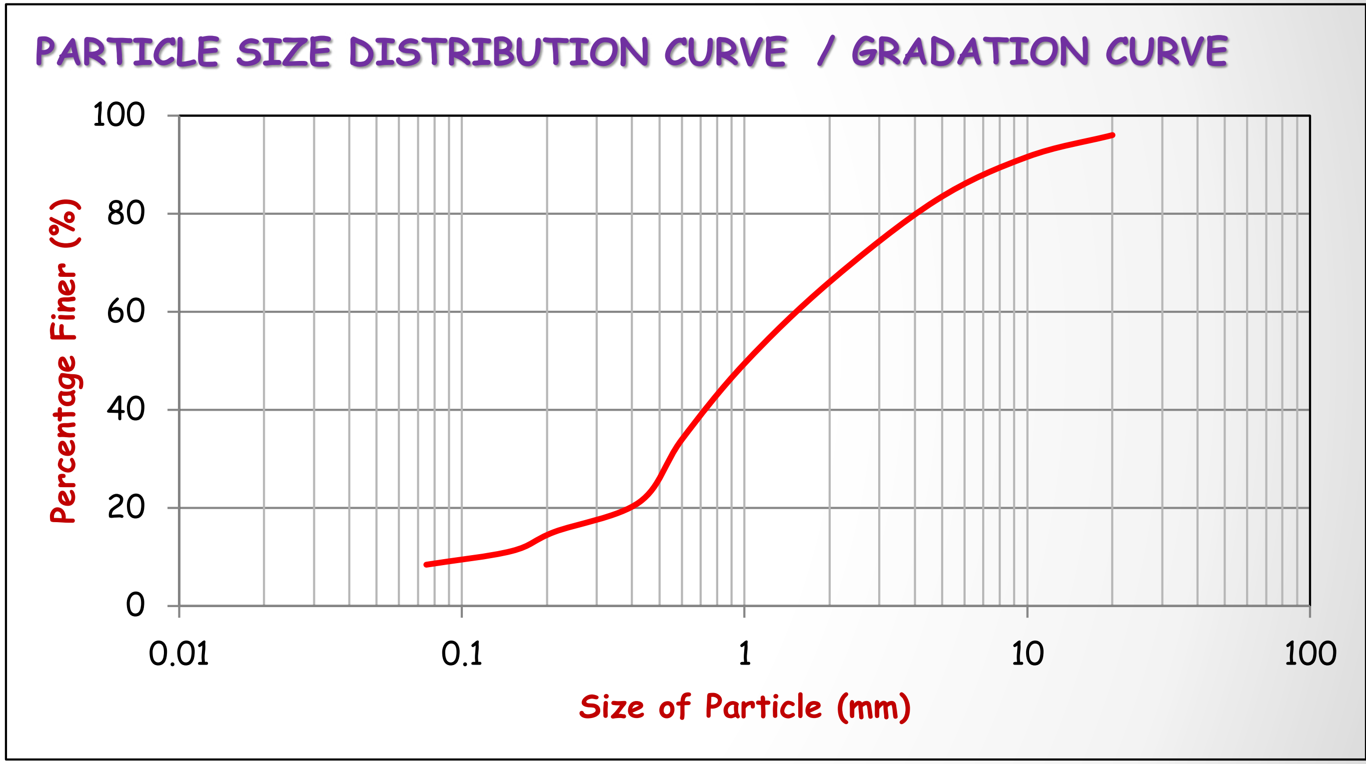


The **Sedimentation Analysis** is done for Fine-Grained Soil.

The **Sieve Analysis** is done for Coarse-Grained Soils

PARTICLE SIZE DISTRIBUTION CURVE

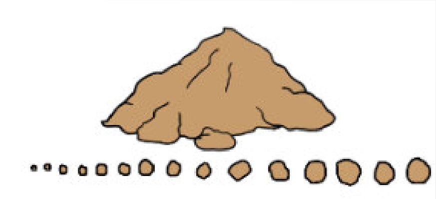
SIEVE SIZE	MASS OF SOIL RETAINED	PERCENTAGE RETAINED	CUMULATIVE PERCENTAGE RETAINED	PERCENTAGE FINER
80 mm	m_1	$P_1 = \frac{m_1}{M}*100$	$C_1 = P_1$	$N_1 = 100 - C_1$
40 mm	m_2	$P_2 = \frac{m_2}{M}*100$	$C_2 = P_1+P_2$	$N_2 = 100 - C_2$
20 mm	m_3	$P_3 = \frac{m_3}{M}*100$	$C_3 = P_1+P_2+P_3$	$N_3 = 100 - C_3$
10 mm	m_4	$P_4 = \frac{m_4}{M}*100$	$C_4 = P_1+P_2+P_3+P_4$	$N_4 = 100 - C_4$
4.75 mm	m_5	$P_5 = \frac{m_5}{M}*100$	$C_6 =$	$N_5 = 100 - C_5$
2 mm	m_6	$P_6 = \frac{m_6}{M}*100$	$C_7 =$	$N_6 = 100 - C_6$
1 mm	m_7	$P_7 = \frac{m_8}{M}*100$	$C_8 =$	$N_7 = 100 - C_7$
600 μ	m_8	$P_8 = \frac{m_8}{M}*100$	$C_9 =$	$N_8 = 100 - C_8$
425 μ	m_9	$P_9 = \frac{m_9}{M}*100$	$C_{10} =$	$N_9 = 100 - C_9$
300 μ	m_{10}	$P_{10} = \frac{m_{10}}{M}*100$	$C_{11} =$	$N_{10} = 100 - C_{10}$
212 μ	m_{11}	$P_{11} = \frac{m_{11}}{M}*100$	$C_{12} =$	$N_{11} = 100 - C_{11}$
150 μ	m_{12}	$P_{12} = \frac{m_{12}}{M}*100$	$C_{13} =$	$N_{12} = 100 - C_{12}$
75 μ	m_{13}	$P_{13} = \frac{m_{13}}{M}*100$	$C_{14} =$	$N_{13} = 100 - C_{13}$
PAN	m_{14}	$P_{14} = \frac{m_{14}}{M}*100$	$C_{15} = P_1+P_2+P_3+P_4+$....................$+P_{15}$	

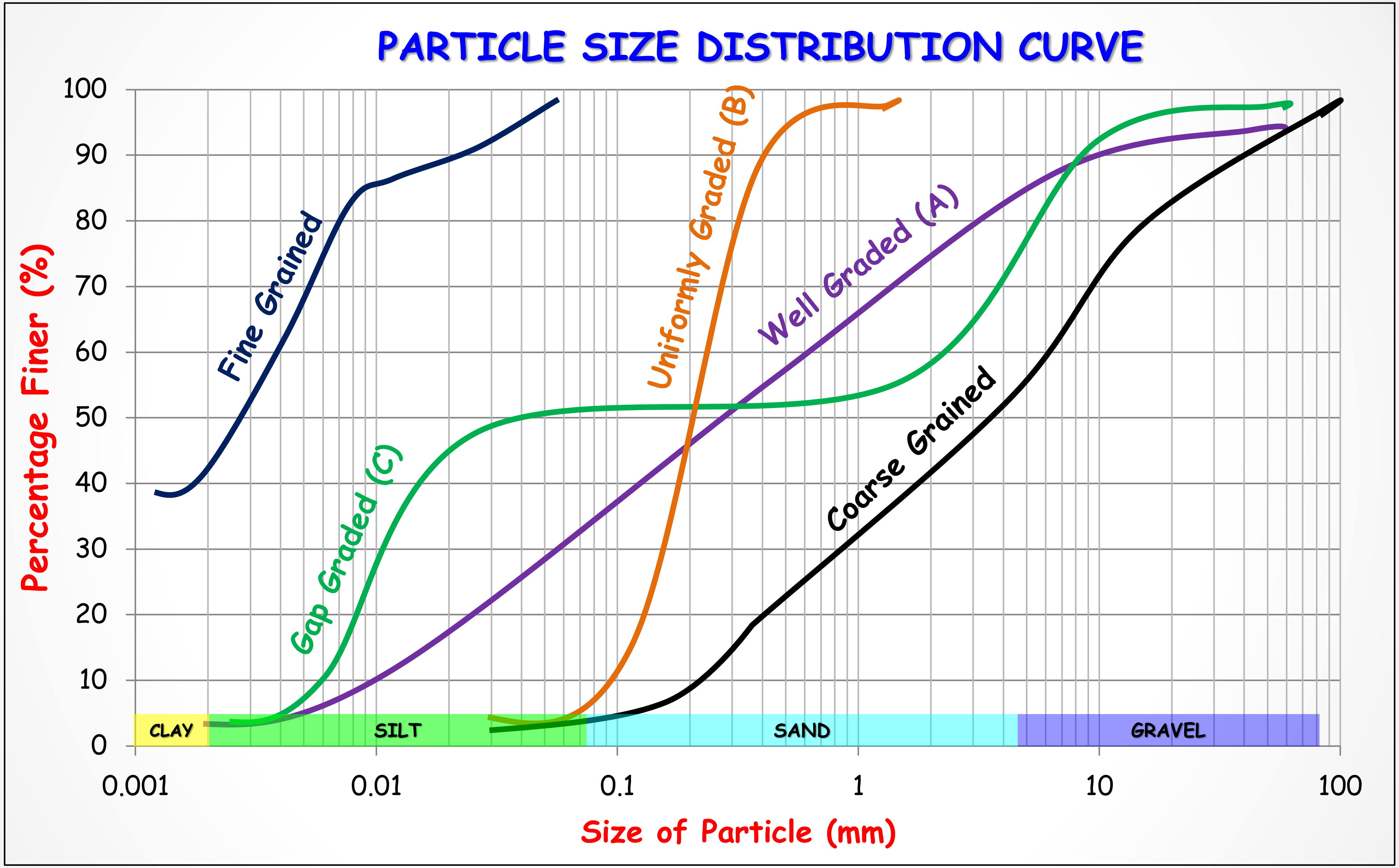


Represents

GRADING OF SOIL

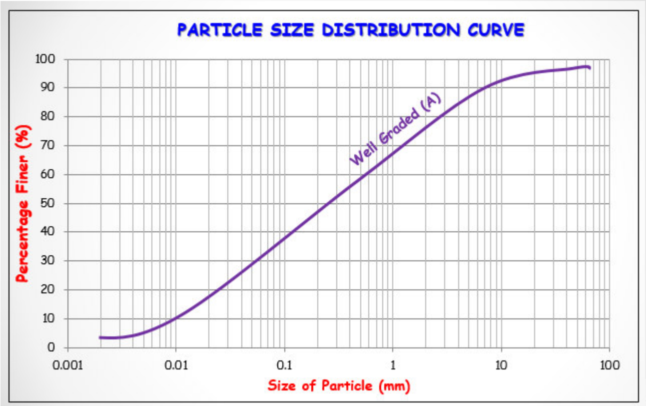
Distribution of particles of different sizes in soil mass




PARTICLE SIZE DISTRIBUTION CURVE
Percentage Finer (%)
Size of Particle (mm)
100
90
80
70
60
50
40
30
20
10
0
0.001
0.01
0.1
1
10
100
Fine Grained
Gap Graded (C)
Uniformly Graded (B)
Well Graded (A)
Coarse Grained
CLAY
SILT
SAND
GRAVEL

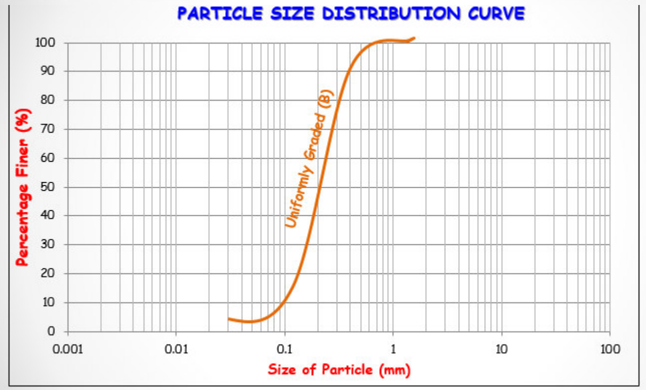
1. WELL GRADED SOIL

- Soil sample with flat S curve (A in the plot).
- Contains particles of **all sizes in good proportion.**
- As particles of all sizes is present, lesser voids, more strength.



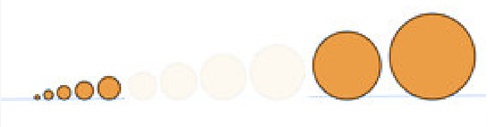
2. UNIFORMLY GRADED SOIL

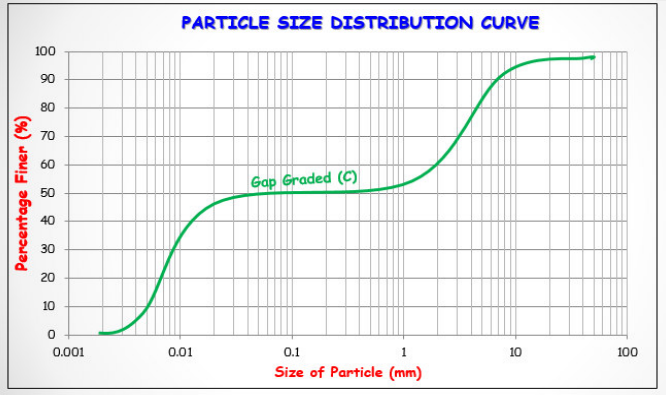
- Soil sample with a steep curve (B in the plot).
- Contains particles of **same size.**
- Soil is **poorly graded** – more voids

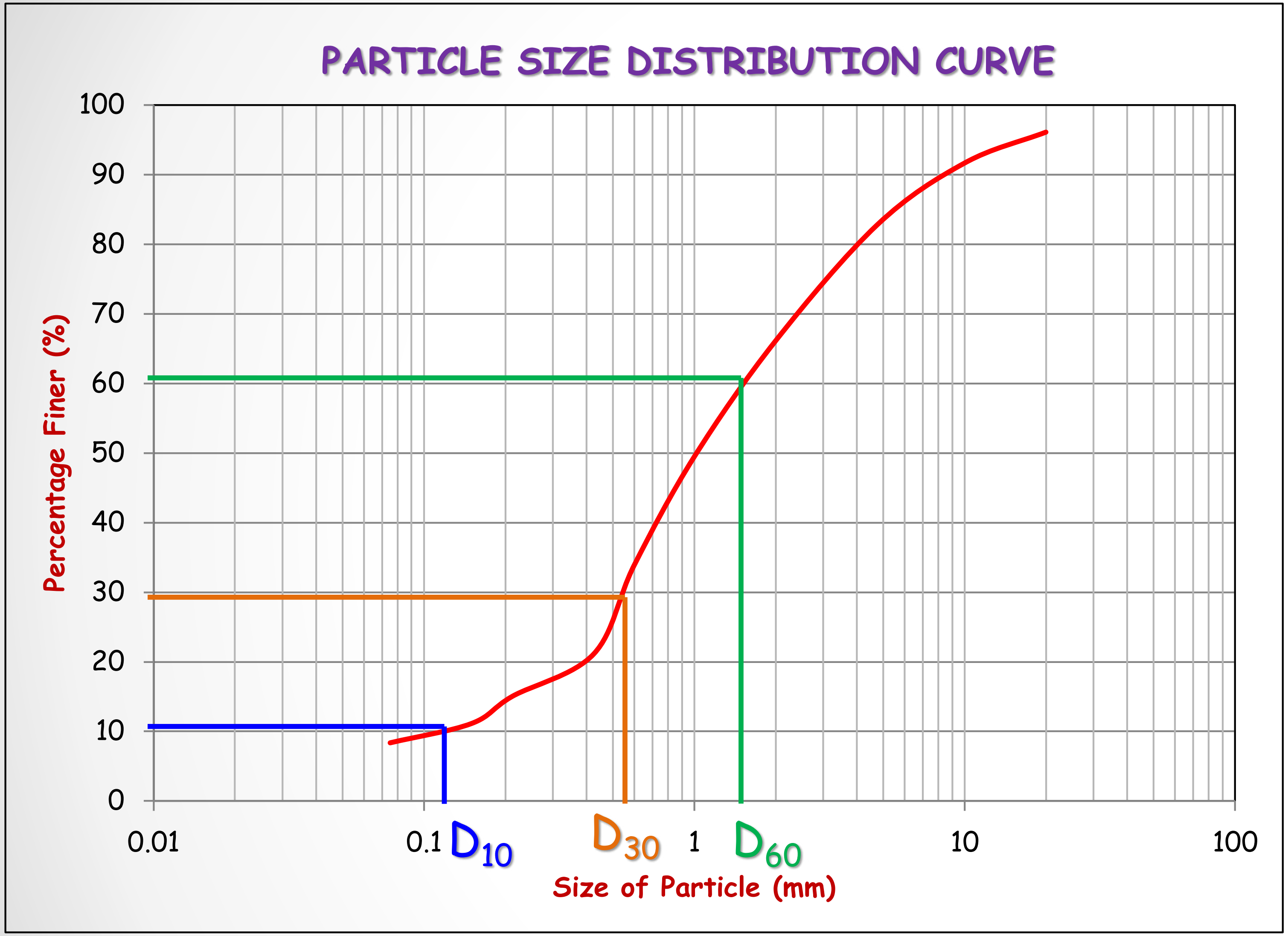


3. GAP GRADED OR SKIP GRADED SOIL

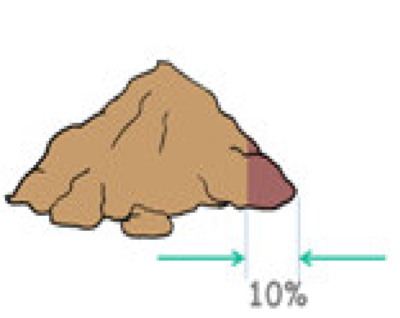
- Soil sample with a hump in the curve (C in the plot).
- Some of the **intermediate particles are missing.**
- Soil is **poorly graded** – more voids





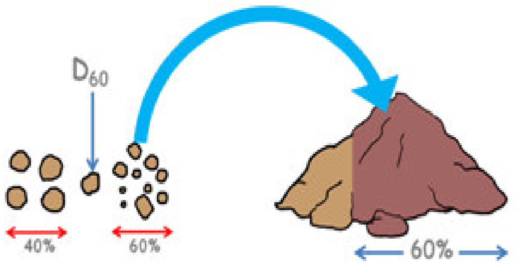


D_{10}



Only **10 % of the particles** in the entire soil mass is **lesser than this size.** **EFFECTIVE SIZE**

D_{60}



60 % of the particles lesser than this size.

D_{30}

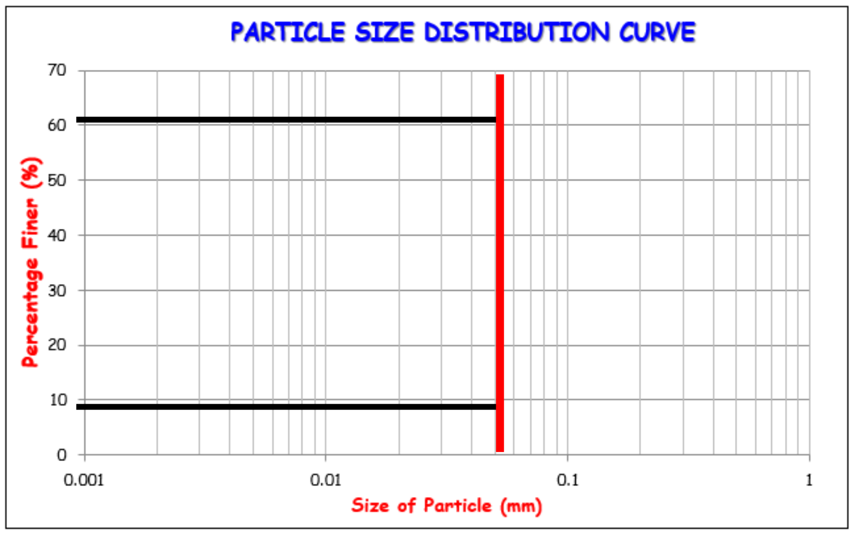
30 % of the particles lesser than this size.

COEFFICIENT OF UNIFORMITY

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

Represents uniformity of particles present in soil mass

Suppose, $C_u = 1 \longrightarrow D_{60} = D_{10}$

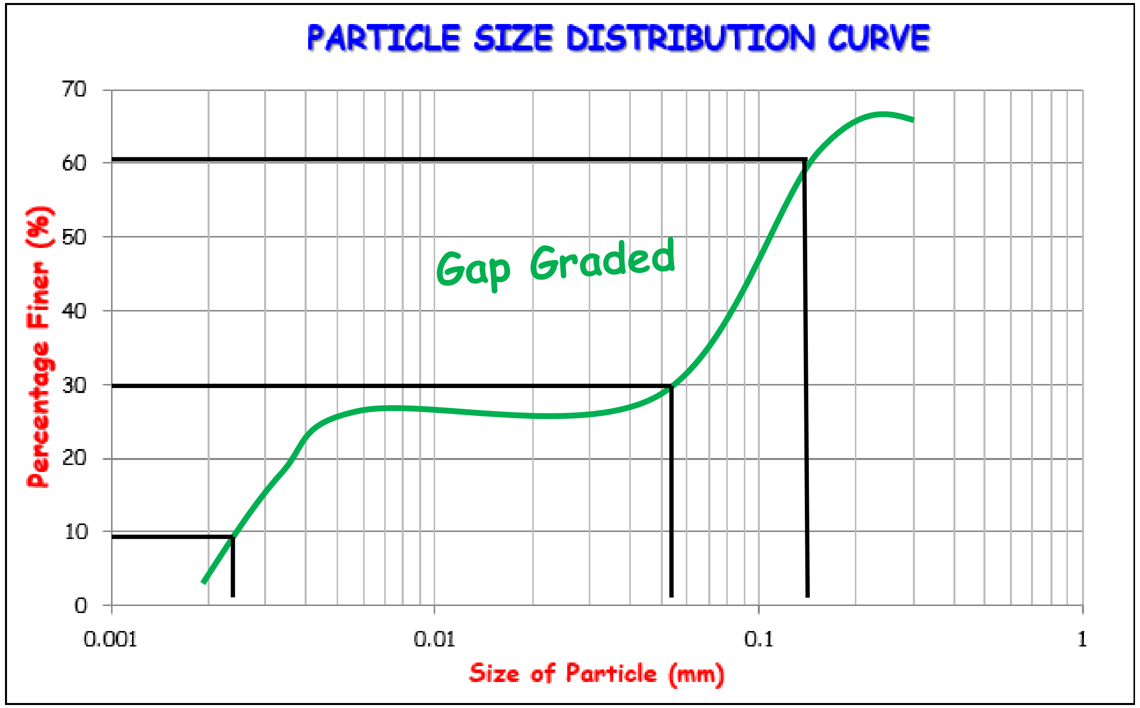


	$C_u < 2$	UNIFORM SOIL
GRAVELS	$C_u > 4$	WELL GRADED GRAVEL
SANDS	$C_u > 6$	WELL GRADED SAND

COEFFICIENT OF CURVATURE

$$C_c = \frac{D^2{}_{30}}{D_{60} * D_{10}}$$

Represents shape of the gradation curve



For gap graded soil Cc is required establish the shape of curve !!!!

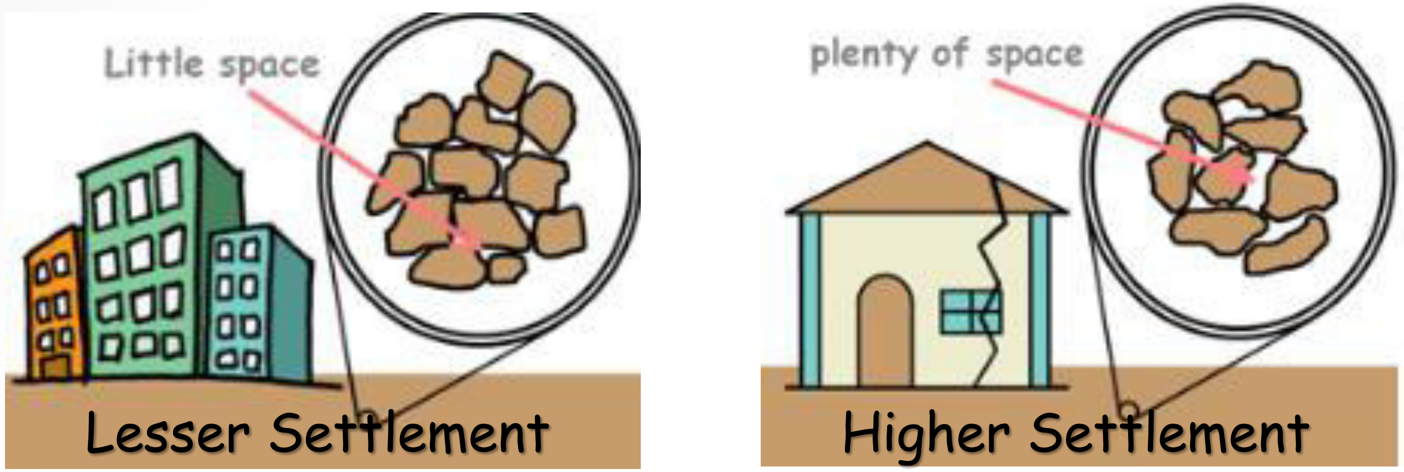
C_c between 1&3 → **WELL GRADED SOIL**

USES OF PARTICLE SIZE DISTRIBUTION CURVE

1. For classification and identification of soil	
Well graded	Poorly graded

2. Gives approximate idea about Engineering Properties		
Permeability	Compressibility	Shear Strength

RELATIVE DENSITY



Denseness of soil to be known before design to keep settlement within limits

MEASURE OF DENSENESS → RELATIVE DENSITY / DENSITY INDEX

$$D_r / I_D = \frac{e_{max} - e}{e_{max} - e_{min}} * 100$$

e : Void ratio of soil in field conditions
e_{max} : Void ratio of soil in its loosest state
e_{min} : Void ratio of soil in its densest state

Relative Density (%)	Classification
< 15	Very Loose
15 - 35	Loose
35 - 65	Medium dense
65 - 85	Dense
> 85	Very Dense

CONSISTENCY LIMITS

Consistency

Resistance to deformation

Consistency Of Fine Grained Soil

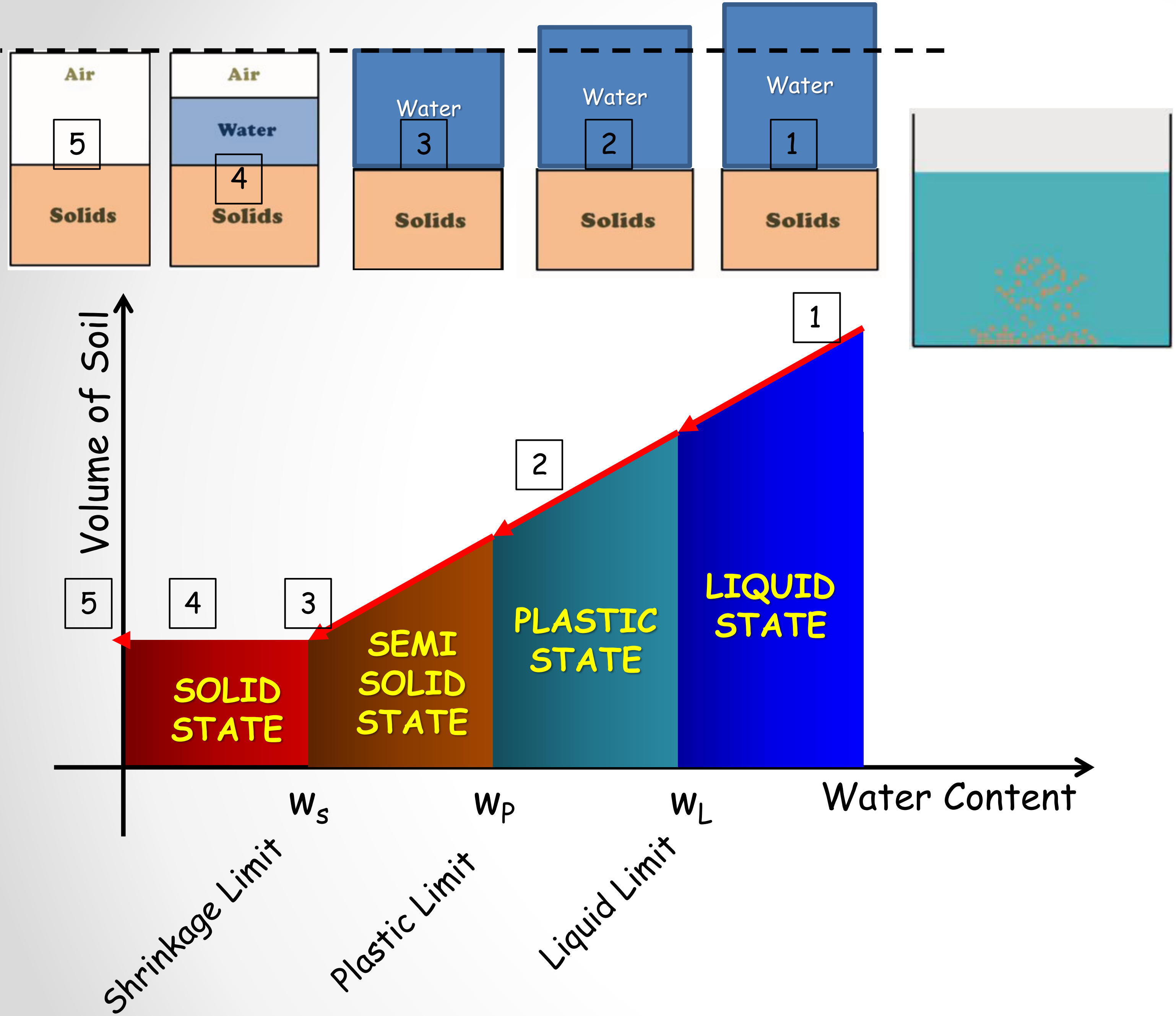
Water Content of Soil

Albert Atterberg

CONSISTENCY STATES

- LIQUID STATE
- PLASTIC STATE
- SEMI SOLID STATE
- SOLID STATE

Boundaries of these states are Consistency Limits/ Atterberg Limits



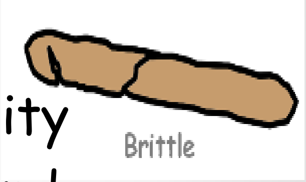
LIQUID STATE

- No shear strength
- No resistance to flow

PLASTIC STATE

- Develops shear strength
- Can be moulded to different shapes without rupture

SEMI SOLID STATE



- Soil looses plasticity
- Becomes brittle and crumbles when moulded.

SOLID STATE

- Soil starts to dry
- Air fills voids & can not be compressed further
- No longer fully saturated

ATTERBERG/CONSISTENCY LIMITS

CONSISTENCY LIMITS

LIQUID LIMIT (LL or w_L)

Water content at which soil changes from liquid state to plastic state

PLASTIC LIMIT (PL or w_P)

Water content below which soil stops behaving as a plastic material

(Boundary b/n plastic and semisolid states)

SHRINKAGE LIMIT (SL or w_S)

Maximum water content below which reduction in water content will not cause decrease in volume of soil mass.

(Boundary b/n semisolid and solid states)

DETERMINATION OF LIQUID LIMIT

1. CASAGRANDE'S METHOD

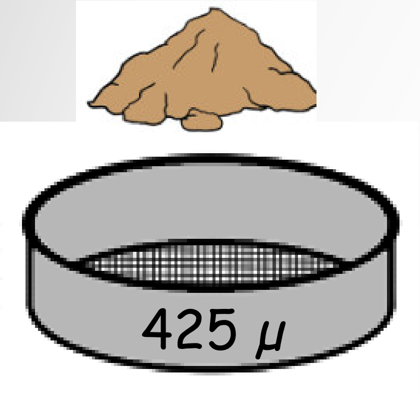
Based on shear strength

CASAGRANDE'S APPARATUS

SPATULA

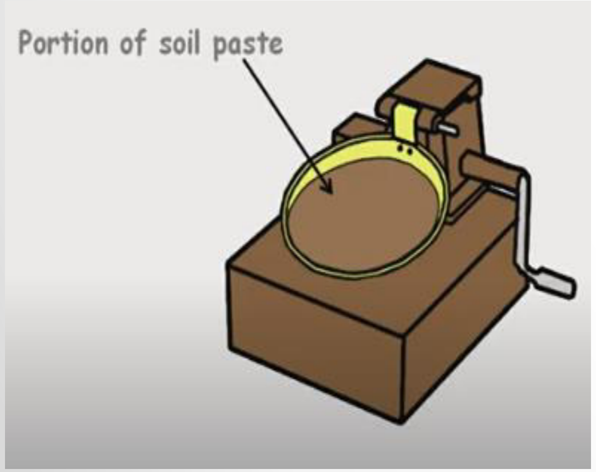
GROOVING TOOLS

STEP 1



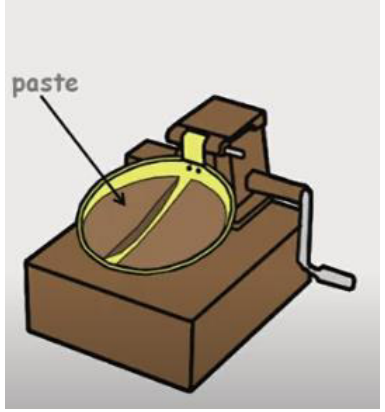
- Take **125 grams** of air dried soil sample passing through **425 µ sieve.**
- Mix it with distilled water to form a uniform paste

STEP 2



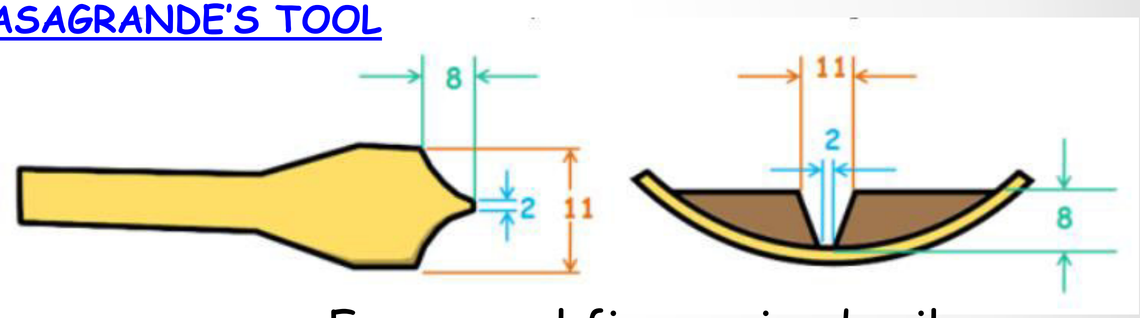
- Portion of soil sample is kept on the brass cup.

STEP 3



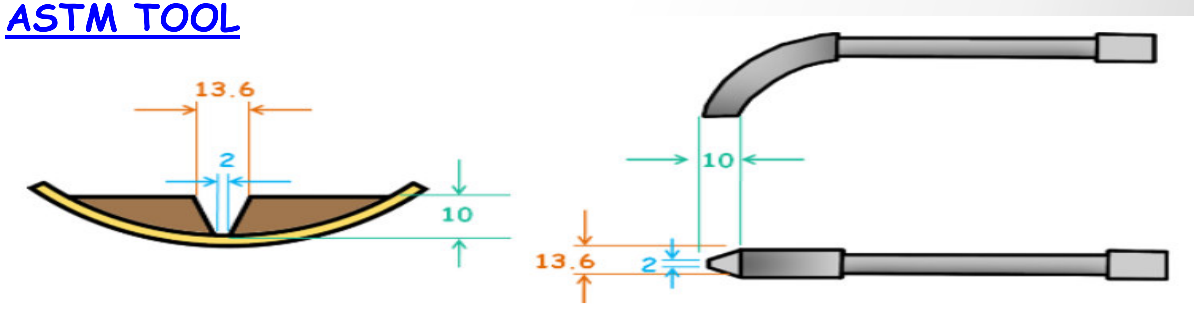
- A sharp groove is cut symmetrically through the sample using a **standard grooving tool.**

CASAGRANDE'S TOOL



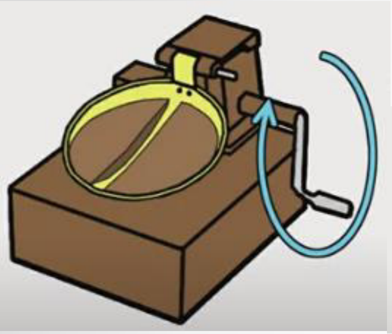
For normal fine grained soils

ASTM TOOL



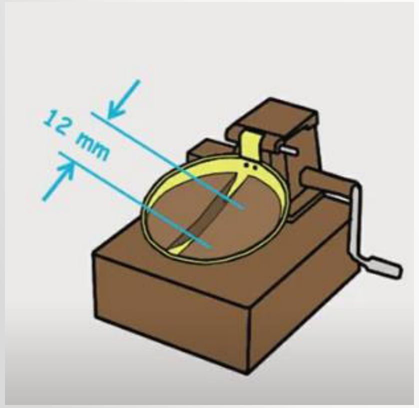
For sandy, fine grained soils

STEP 4



- The handle is rotated at the rate of **2 rev/s**
- The groove starts to close.

STEP 5



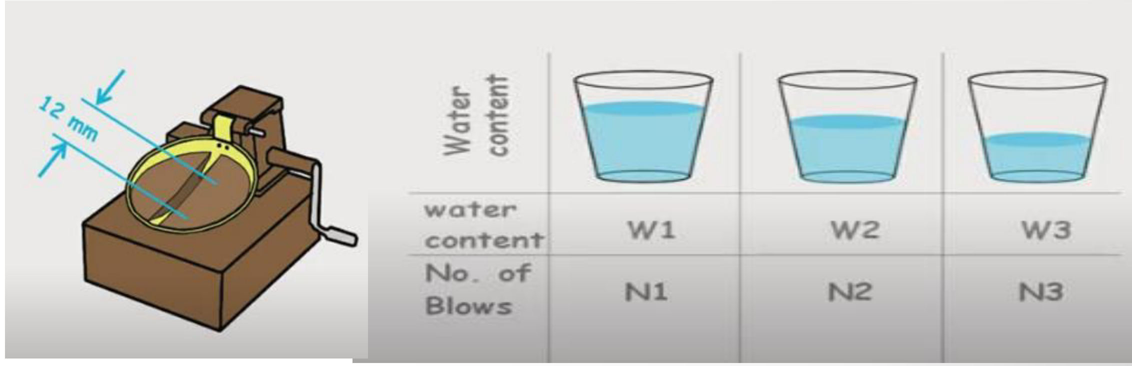
- Continued till the groove closes by a length of 12mm.
- Groove should be closed only by **flow of soil,** not by slippage.

STEP 6

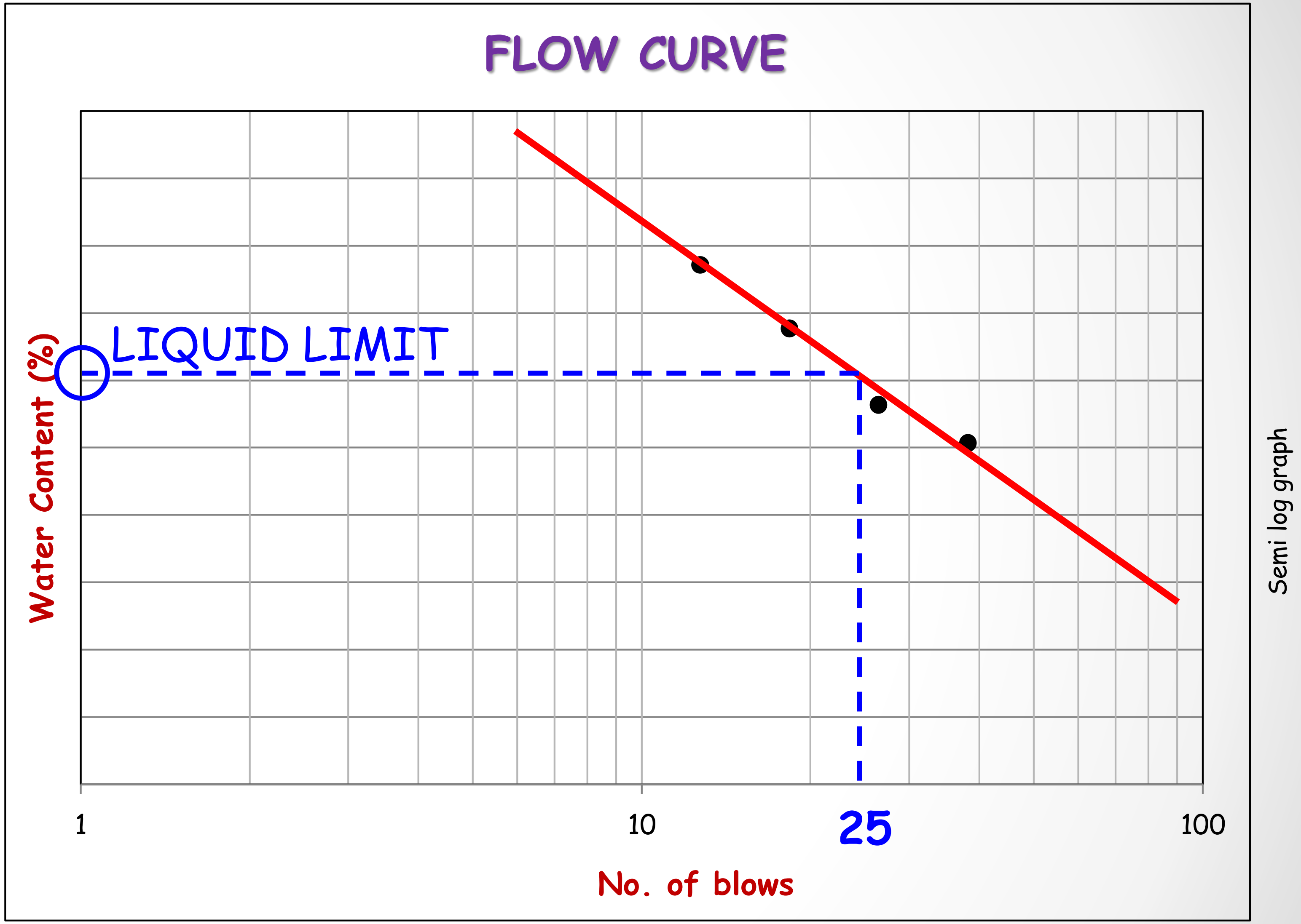
- A portion of sample is taken for water content determination.
- Water content **(w_1)** and number of blows at which grove closes by 12 mm **(N_1)** are recorded.

STEP 7

- Test is repeated for different water contents to get number of blows in the range 10 - 40



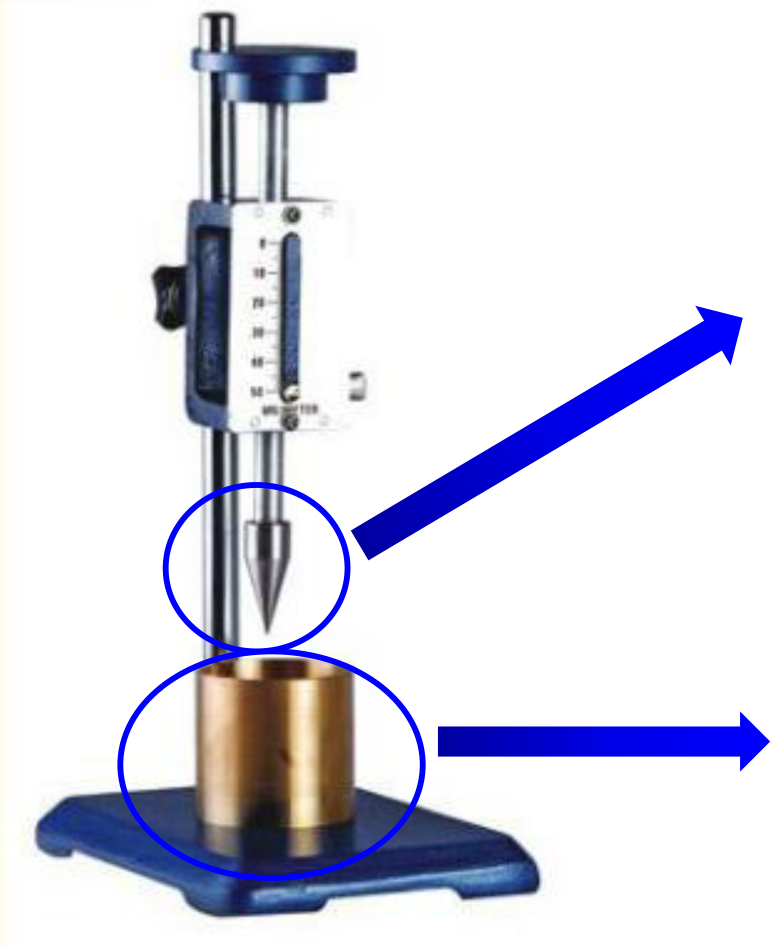
Sl.No.	Water Content	No. of Blows
1	w1	N1
2	w2	N2
3	w3	N3
4	w4	N4

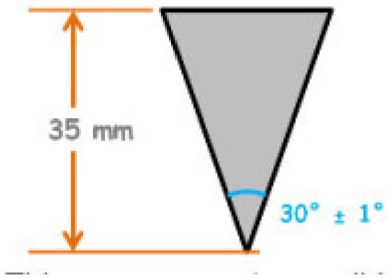


Water content corresponding to **25 number of blows** is **LIQUID LIMIT**

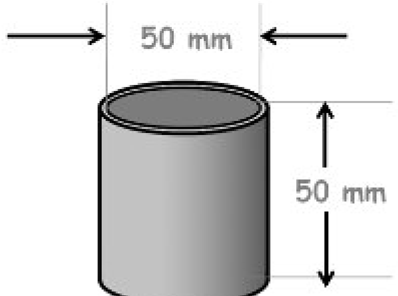
DETERMINATION OF LIQUID LIMIT

2. CONE PENETRATION METHOD

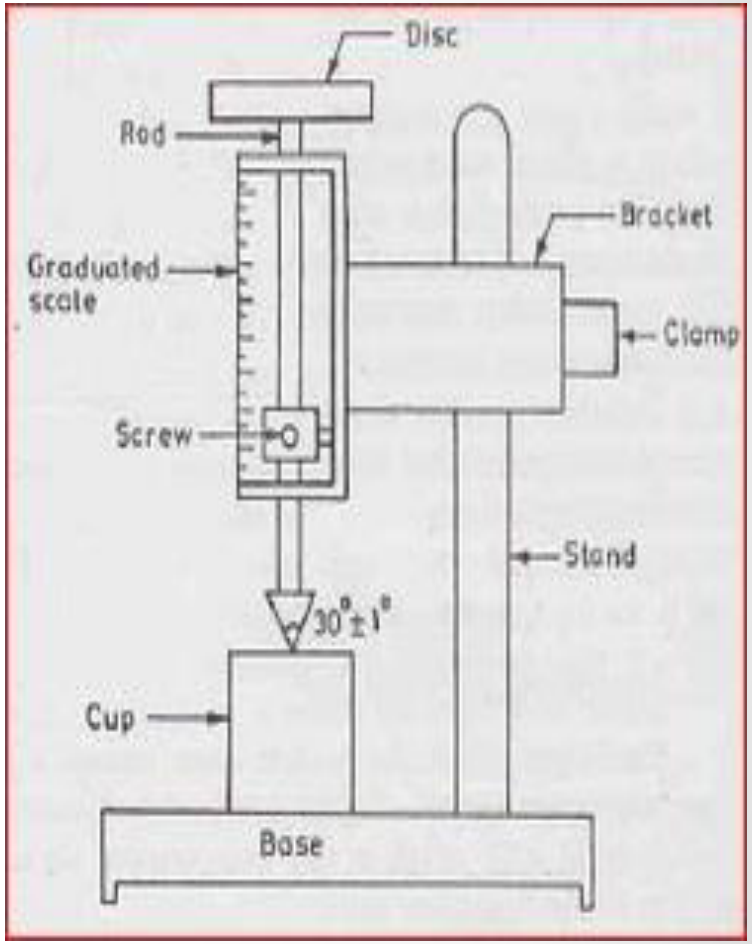




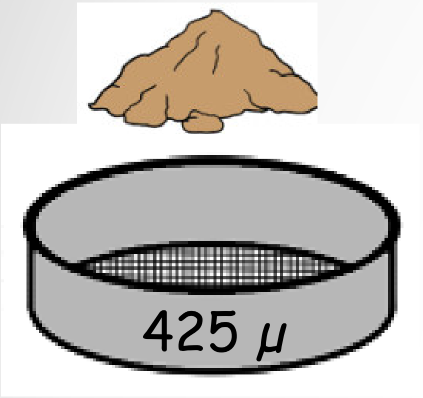
CONE



BRASS CUP

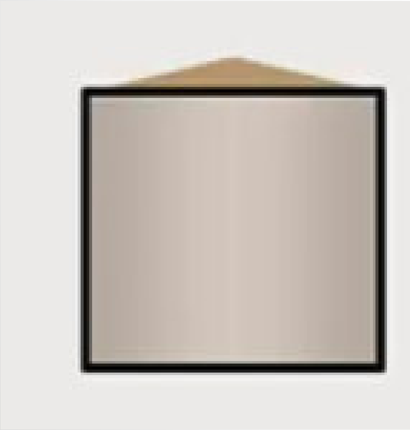


STEP 1



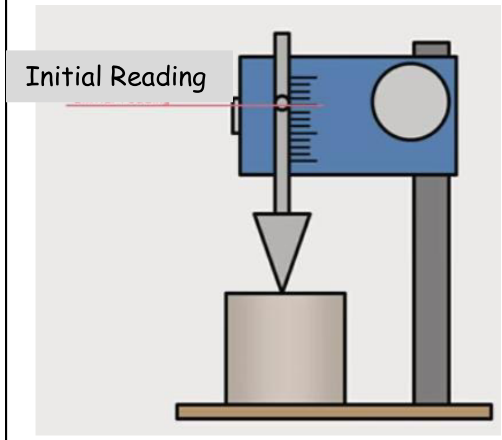
- Take **125 grams** of air dried soil sample passing through **425 μ sieve.**
- Mix it with distilled water to form a uniform paste

STEP 2



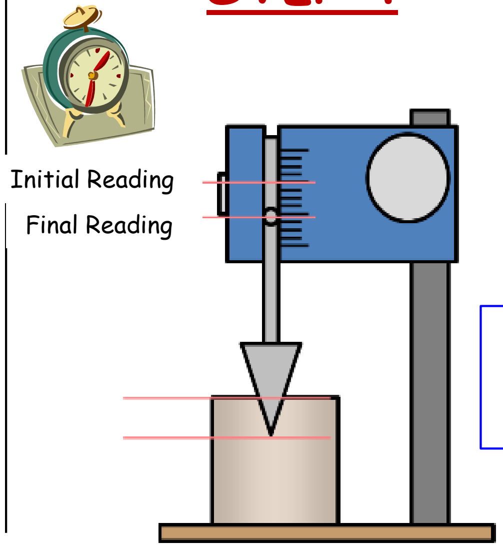
- Portion of soil sample is kept on the brass cup.
- Make sure no air is entrapped.

STEP 3



- Surface is levelled and placed under the cone.
- The cone is placed just above the soil, and reading noted is **initial reading.**

STEP 4



- The cone is released and reading is noted after **5 seconds** : **final reading**

Penetration, P1 =
Final reading – initial reading

STEP 5

- A portion of sample is taken for water content determination.
- Water content **(w_1)** and penetration at 5 seconds **(P_1)** are recorded.

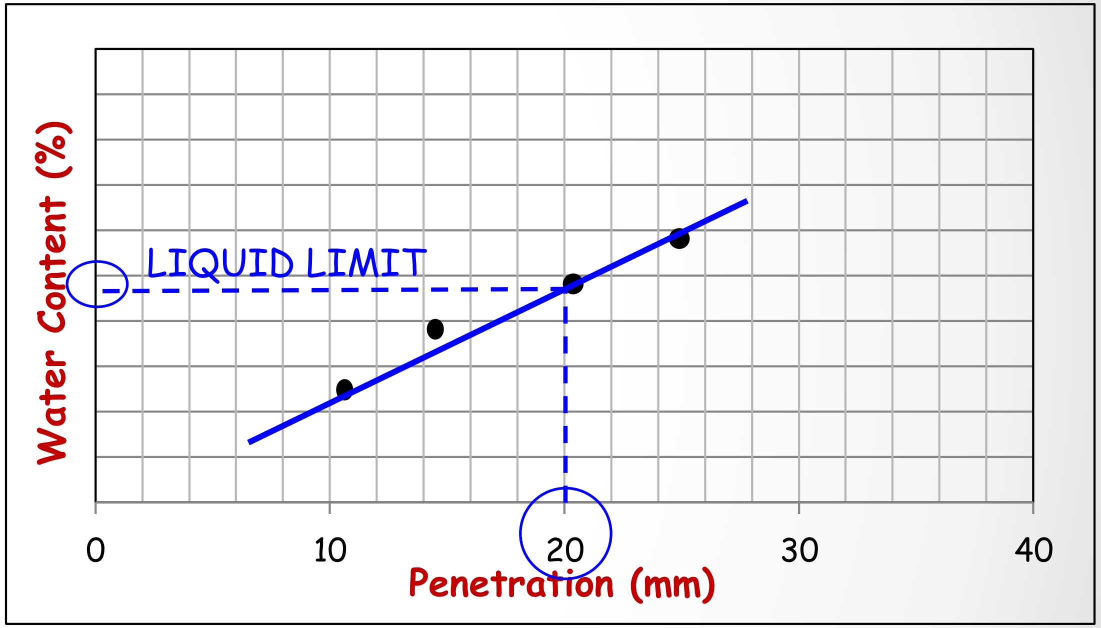
STEP 6

- Test is repeated for different water contents to get penetrations in the range 14-28 mm.

Sl.No.	Water Content	Penetra tion
1	w1	P1
2	w2	P2
3	w3	P3
4	w4	P4

STEP 7

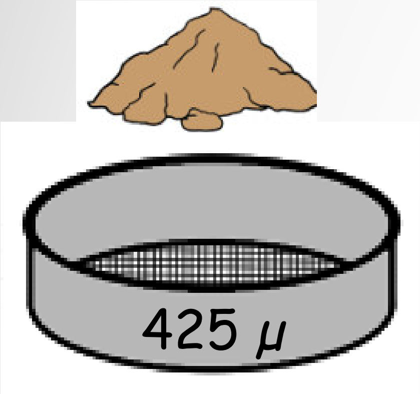
- Penetration v/s water content curve is plotted



Water content corresponding to **20mm penetration** is **LIQUID LIMIT**

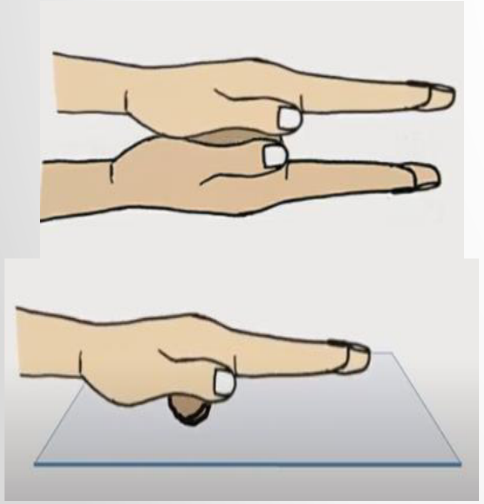
DETERMINATION OF PLASTIC LIMIT

STEP 1



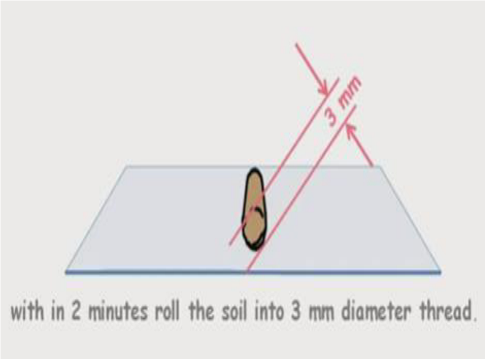
- Take air dried soil sample passing through **425 μ sieve.**
- Take **30 grams** and Mix it with distilled water to form a uniform paste

STEP 2



- Some amount (say 10g) is taken and made to a ball with hands.
- The soil balls is placed on a **glass plate** and is then rolled with hands.

STEP 4



- Rolled at the rate of **80 to 90 strokes** per minute.
- Stopped in 2 minutes when a roll of **3mm dia (uniform)** is obtained.

Does not crumble below 3 mm – Plastic state

STEP 5

- Make a ball with same soil again and roll it over the glass plate.
- Continue till the soil ***sample crumbles before reaching 3mm diameter.***

Water content at which soil crumbles is
PLASTIC LIMIT

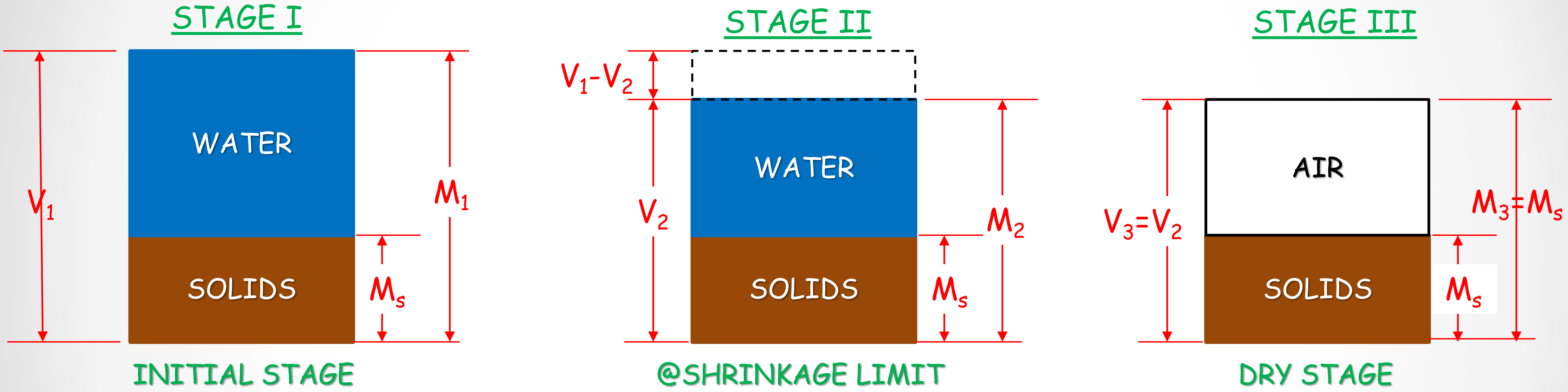
(Repeat test and take average of three values)

Image Courtesy : Elementary Engineering

DETERMINATION OF SHRINKAGE LIMIT

Shrinkage limit is water content @ semisolid- solid state boundary.

Water content, w $= \frac{M_w}{M_s}$



M_w @ stage II = M_w @ stage 1 – M_w of lost water

M_w @ stage I = $M_1 - M_s$

M_w of lost water = $(V_1 - V_2) * \rho_w$

So, M_w @ stage II = $(M_1 - M_s) - (V_1 - V_2) * \rho_w$

Shrinkage limit, $w_s = \frac{M_w \text{ @ stage II}}{M_s}$

$= \frac{(M_1 - M_s) - (V_1 - V_2) * \rho_w}{M_s}$

Shrinkage limit, $w_s = w_1 - \frac{(V_1 - V_2) * \rho_w}{M_s}$

Jyothis Paul E, Lr. in Civil Engg., GPTC Mananthavady

DETERMINATION OF SHRINKAGE LIMIT

MERCURY DISPLACEMENT METHOD

GLASS PLATE WITH PRONGS

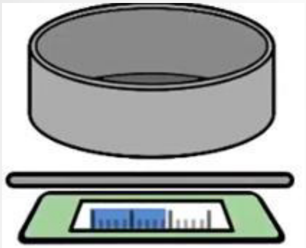
$$\text{Shrinkage limit, } w_s = w_1 - \frac{(V_1 - V_2) * \rho_w}{M_s}$$

$$\boxed{\text{Shrinkage limit, } w_s = w_1 - \frac{(V_1 - Vdry) * \rho_w}{M_{dry}}}$$

- Volume of dry soil is found by displacing soil with mercury – **MERCURY DISPLACEMENT METHOD**

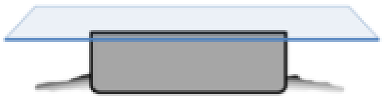
1.FINDING VOLUME OF SHRINKAGE DISH

STEP 1



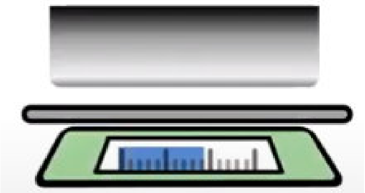
- Take empty weight of dish m_{dish}

STEP 2



- Fill the dish with Hg and remove excess using the glass plate

STEP 3



- Weight of mercury filling the dish is taken, m_{Hg}

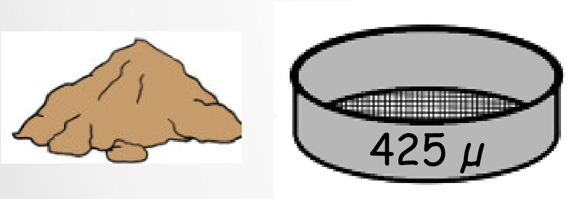
$$V_{disc} = V_{Hg}$$

$$V_{disc} = \frac{m_{Hg}}{G_{Hg}}$$

Specific gravity of Hg = 13.6

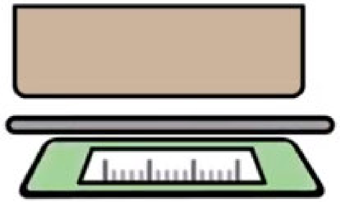
2.PREPARATION OF DRY SOIL PAT

STEP 1



- Take air dried soil sample passing through **425μ sieve**
- Take **30 g** and make a uniform paste with distilled water

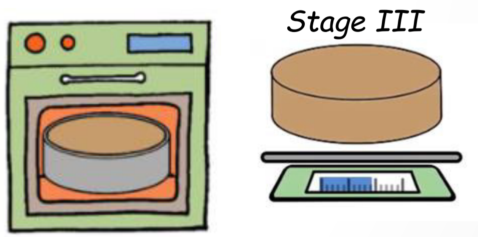
STEP 2



- The paste is filled in the dish and weight is taken, $m_{dish+soil}$
- Now, mass of sample in stage I

$$M_1 = m_{dish+soil} - m_{dish}$$

STEP 3



- The soil is dried @ 110°C in hot air oven
- Mass of dry soil pat, M_{dry}

Water content @ Stage I

$$w_1 = \frac{M_w}{M_s}$$

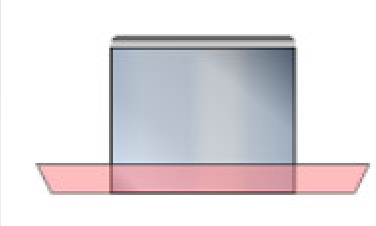
$$w_1 = \frac{M_1 - M_{dry}}{M_{dry}}$$

$$V_1 = V_{disc}$$

Image Courtesy : Elementary Engineering

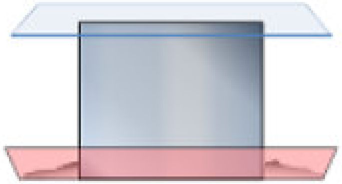
3. FINDING VOLUME OF DRY SOIL PAT

STEP 1



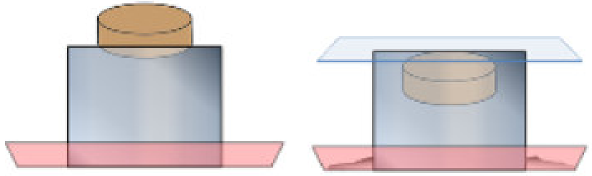
- Place the glass dish on the porcelain dish and fill it with mercury

STEP 2



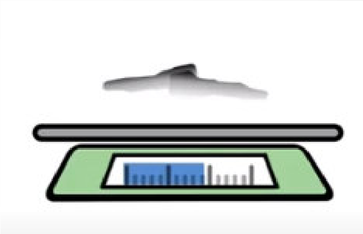
- Remove excess mercury using a glass plate.
- Clean the porcelain dish

STEP 3



- Insert the soil pat in to the glass dish
- Immerse it into the dish using the glass plate

STEP 4



- Take the mass of displaced mercury M_{Hg_dis}

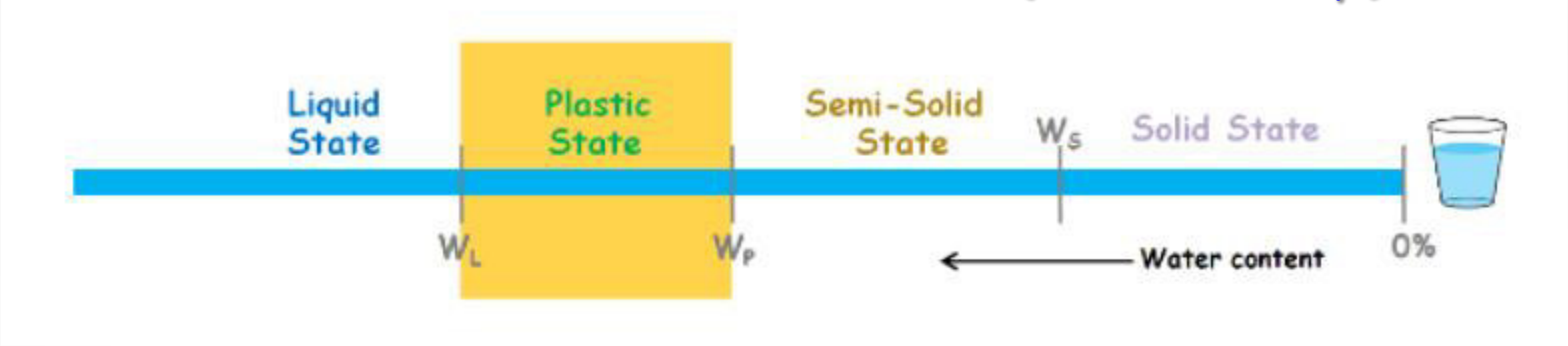
Volume of dry soil pat, V_{dry} = Volume of mercury displaced

$$V_{dry} = \frac{M_{Hg\_dis}}{G_{Hg}}$$

$$\boxed{\text{Shrinkage limit, } w_s = w_1 - \frac{(V_1 - V_{dry}) * \rho_w}{M_{dry}}}$$

Image Courtesy : Elementary Engineering

PLASTICITY INDEX (PI or I_P)



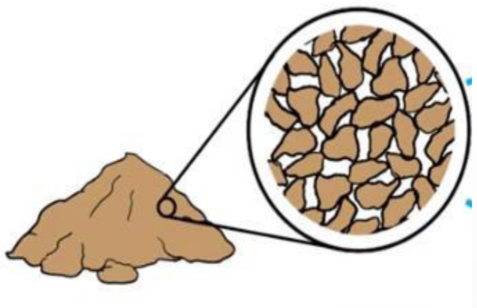
- It is the range of water content over which the soil remains in the plastic state.

Plasticity Index, I_p = LIQUID LIMIT – PLASTIC LIMIT

$$\boxed{I_p = w_L - w_P}$$

PI value	Description of Plasticity
0	Non Plastic
< 7	Less Plastic
7 - 17	Medium Plastic
7 <	High Plastic

COARSE GRAINED SOIL



Zero clay particles

Zero Plasticity

$w_L = w_P$

$I_p = 0$

CONSISTENCY INDEX (CI or I_C)

- Defined as the ratio of difference of liquid limit (w_L) and water content at natural condition (w_n) to its plasticity index (I_p).

$$I_c = \frac{w_L - w_n}{I_p} * 100 = \frac{w_L - w_n}{w_L - w_p} * 100$$

Indicates CONSISTENCY → RELATIVE CONSISTENCY

If $w_n = w_L$

$$I_c = \frac{w_L - w_L}{I_p}$$

$I_c = 0$ ⟶ Soil is not firm ⟶ Flows like liquid

$I_c < 0$ ⟶ Soil in liquid state

If $w_n = w_p$

$$I_c = \frac{w_L - w_p}{w_L - w_p}$$

$I_c = 1$ ⟶ Soil is firm ⟶ Lesser Deformation

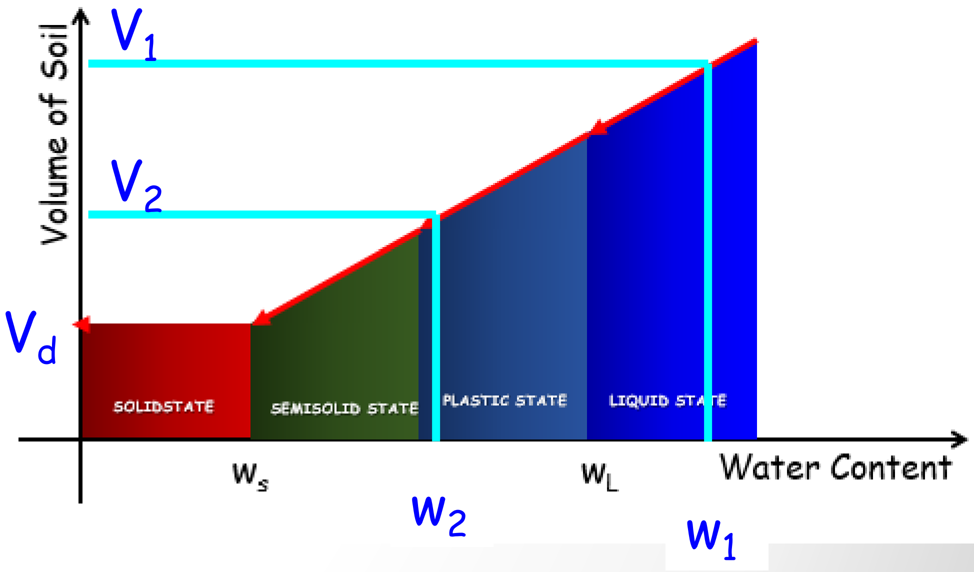
$I_c > 1$ ⟶ Soil in semi-solid or solid state

SHRINKAGE RATIO (SR)

- To indicate the **extent of change in volume** when **water content of soil sample increases**.

- Defined as ratio of a given volume change expressed as a percentage of dry volume, to the corresponding change in water content.

$$SR = \frac{(V_1 - V_2)/V_d}{w_1 - w_2} * 100$$



Classification of Soils

Soil possessing similar characteristics and properties are grouped together. This grouping is called classification

Necessity of classification

- To arrange various types of soils into groups according to their engineering or agricultural properties and various other characteristics
- Soil possessing similar characteristics can be placed in the same group
- From engineering viewpoint, the classification may be done with the objective of finding the suitability of the soil for construction of dams, highways or foundations etc

From engineering point of view, classification of soils is done so as to,

1. Ascertain the suitability of the soil for construction of embankments, sub-grades highway, foundations etc.
2. Assess the bearing capacity of soil with regards to buildings.
3. Estimate the behaviour of the soil as a construction material.

Systems of classification

1. Particle size classification
2. Textural classification
3. Highway Research Board (HRB) classification
4. Unified soil classification
5. IS classification system

Indian Standard Soil classification system, ISCS (IS : 1498 - 1970)

- First developed in 1959
- Revised in 1970
- Based on USCS with modifications
- ISCS classifies soils into 18 groups
- Based on both grain size analysis and physical properties of soil

Broad Divisions

SOILS

- Coarse Grained soil (More than half of the total material is larger than IS 75 μ sieve by mass)
- Fine Grained Soils (More than half of the total material is smaller than IS 75 μ sieve mass)
- Highly organic Soils and other soils (Soils may contain organic matter or shells, cinders etc.).

Coarse grained soils - divisions

COARSE GRAINED SOILS

Coarse (G)
(More than half of the
coarse grained soil
larger than 4.75 mm
IS sieve)

Sand (S)
(More than half of the
coarse grained soil is
smaller than 4.75 mm
IS sieve)

Sub - divisions

Both gravels and sands are further sub-divided into the following four groups.

W : Well - graded, clean

P : Poorly graded, fairly clean

M : Containing fine materials not included in other groups

C : Well graded with excellent clay binder.

The various groups into which gravels and sands are sub-divided are as follows

GROUP SYMBOL

GW - Well - graded, clean, gravels

GP - Poorly - graded gravels

GM - Silty gravels

GC - Clayey gravels

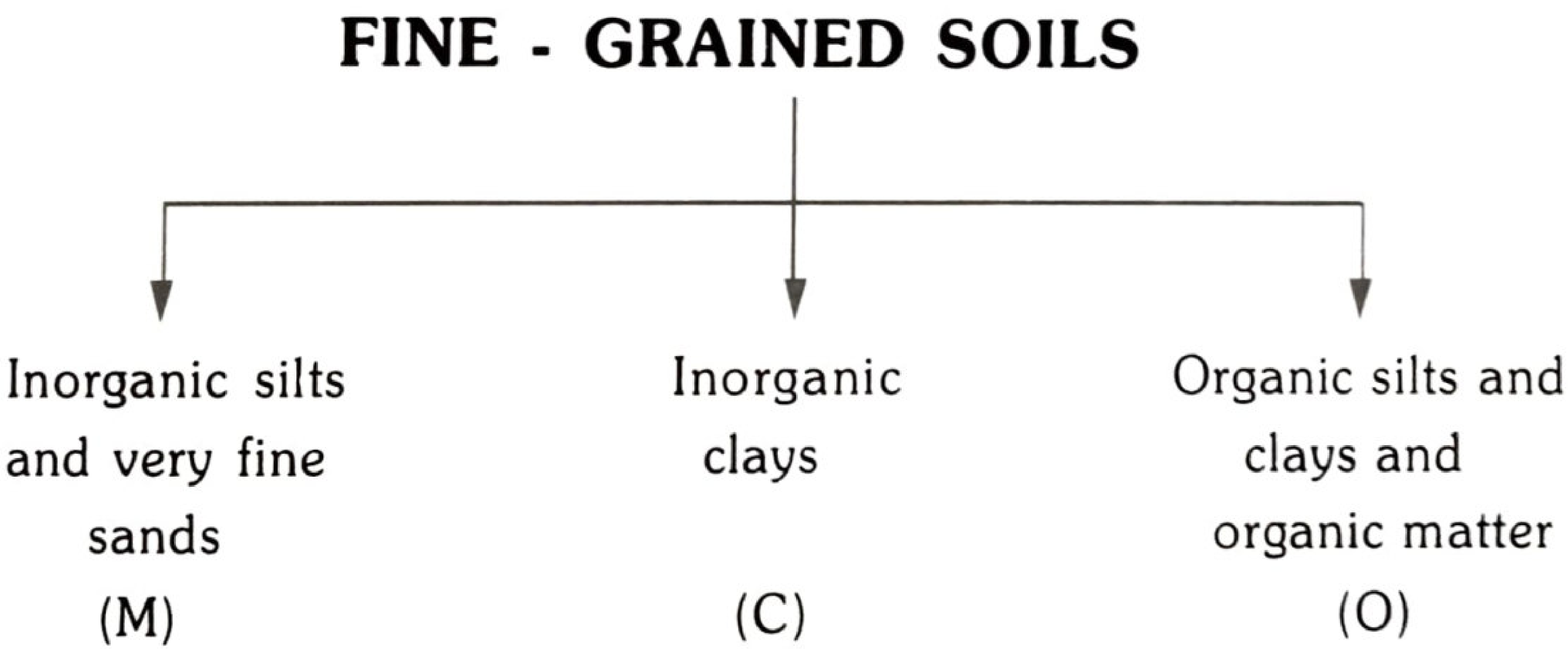
SW - Well graded, clean, sands

SP - Poorly graded, fairly clean sands

SM - Silty sands

SC - Clayey sands

Fine grained soils - divisions



Based on the compressibility of the soil, the fine- grained soils (silts and clays) are divided further as follows. Their compressibility is estimated as low, medium or high on the basis of arbitrarily selected values of liquid limit. (See plasticity chart).

FINE - GRAINED SOILS

- Silts and clays of low compressibility (L) (Liquid limit is < 35)
- Silts and clays of medium compressibility (M) (35 > Liquid limit < 50)
- Silts and clays of high compressibility (H) (Liquid Limit > 50)

The following are the group symbols for soils with varying compressibility.

GROUP SYMBOL

CL - Inorganic clays with low compressibility

CI - Inorganic clays with medium compressibility

ML - Inorganic silts and very fine sand with low compressibility

MI - Inorganic silts and very fine sands with low compressibility

MH - Inorganic silts and very fine sands with high compressibility

OL - Organic silts and clays and organic matter with low compressibility

OI - Organic silts and clays and organic matter with medium compressibility

OH - Organic silts and clays and organic matter with high compressibility.

Laboratory classification of fine grained soils

- Laboratory classification of fine grained soils is done with the help of ***Plasticity chart***
- The ***A – line*** dividing inorganic clay from silt and organic soil has the following equation

$$I_P = 0.73\ (w_L - 20)$$

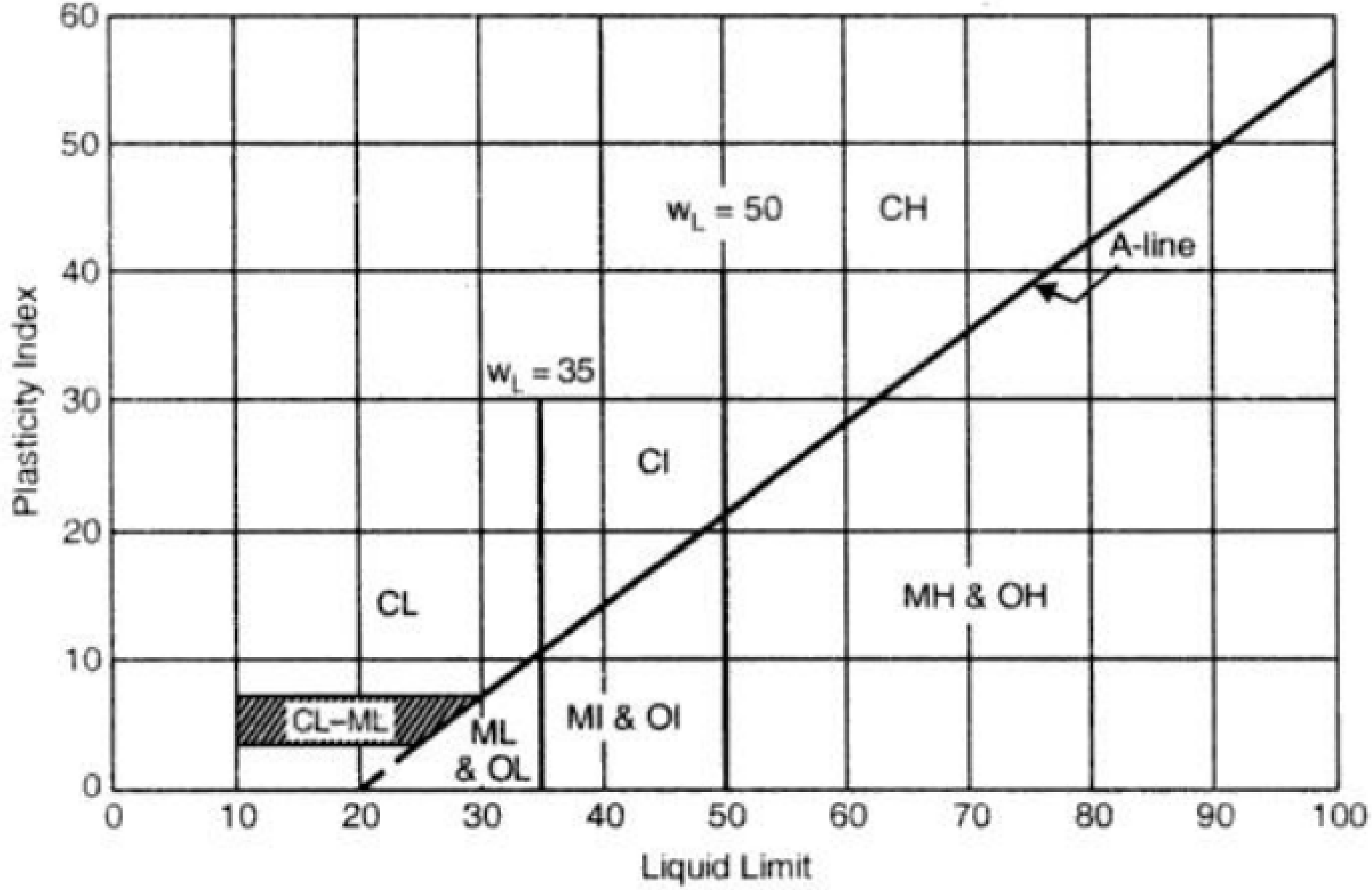


FIG. 4.4. PLASTICITY CHART (IS SOIL CLASSIFICATION SYSTEM).

- Inorganic silts and organic soils lie below the A – line
- Inorganic clays lie above the A- line
- Majority of Indian cotton soils lie above the A –Line

BOUNDARY CLASSIFICATION

Generally, dual symbols may be adopted for boundary cases. The most common boundary classifications in coarse - grained and fine - grained soils are as follows.

(a) Coarse Grained Soils :

GW - GP;	GM - GC;	GW - GM;	GW - GC;
SW - SP;	SM - SC;	SW - SM;	SW - SC;
GW - SW;	GP - SP;	GM - SM and	GC - SC.

(b) Fine - Grained Soils :

ML - MI;	CL - CI;	OL - OI;
MI - MH;	CI - CH;	OI - OH;
CL - ML;	ML - OL;	CL - OL;
CI - MI;	MI - OI;	CI - OI;
MH - CH;	MH - OH and	CH - OH;

(c) Boundary Classification between Coarse Grained Soils and Fine Grained Soils :

SM - ML and SC - CL

1.5.4.1 Laboratory Classification Criteria for Coarse Grained Soils

(As per IS : 1498 - 1970)

The percentages of gravel, sand and fines are determined from the grain size distribution curve. Based on the percentage of fines (soil fraction smaller than IS 75μ sieve) soils are classified as below.

% Fines	Classification
(a) Less than 5%	GW, GP, GM, GC
(b) 5% to 12%	Border line cases
(c) More than 12%	GM, GC, SM, SC

	Laboratory Results	Group Symbol
I	C_u greater than 4 C_c is between 1 and 3	GW
II	Not meeting the gradation requirement for GW	GP
III	When (I_p) plasticity Index is less than 4 or Atterberg limits are below "A" line.	GM
IV	When I_p is between 4 and 7 and the Atterberg limits are above "A" line.	Border line cases
V	I_p is greater than 7 and the Atterberg limits are above "A" line.	GC

VI	C_u is greater than 4, C_c is between 1 and 3.	SW
VII	Not meeting the gradation requirements for SW	SP
VIII	I_p is less than 4 or Atterberg limits below A line	SM
IX	I_p between 4 and 7 with Atterberg limits above "A" line.	Border line cases
X	I_p greater than 7 with Atterberg limits above "A" line.	SC

Example 2.1 A soil sampler of volume 1000 cm^3 is used to collect soil samples. It was found that sampler contain 2 kg soil with dry unit weight of 1800 kg/m^3. If 300 g water is mixed to the soil, then what will be the water content of the sample?

Solution:

$$\gamma_d = 1800 \text{ kg/m}^3$$

Dry weight of soil (weight of soil solids),

$$W_s = V \times \gamma_d$$

$$= 1000 \times 10^{-6} \times 1800 = 1.8 \text{ kg}$$

But actual weight of sample, $W = 2$ kg

∴ Weight of water before mixing additional water,

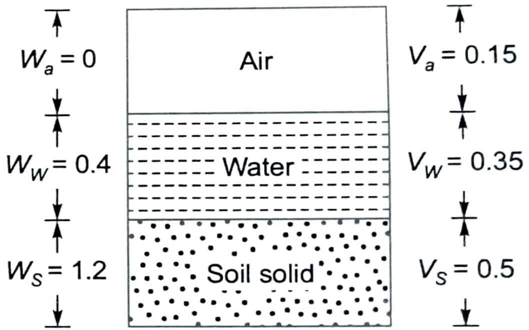
$$W_{w_1} = W - W_s = 2 - 1.8 = 0.2 \text{ kg}$$

After mixing 300 g of water, the total weight of water would be

$$W_{w_2} = 0.2 + 0.3 = 0.5 \text{ kg}$$

Thus, water content, $$w = \frac{W_{w_2}}{W_s} \times 100 = \frac{0.5}{1.8} \times 1000 = 27.8\%$$

Example 2.2 Figure shows a block diagram for a soil sample, having volumes and weights in *cc* and *g* respectively.



Consider the following statements

1. Soil is partially saturated with degree of saturation greater than 60%
2. Void ratio = 100%
3. Water content = 40%
4. Saturated unit weight = 2g/*cc*

Which of the above statements are TRUE?

(a) 1, 2 and 3
(b) 1, 2, 3 and 4
(c) 1, 2 and 4
(d) 2 and 3

Ans. (c)

1. Degree of saturation, $S = \frac{V_w}{V_v} \times 100 = \frac{0.35}{(0.15+0.35)} \times 100 = 70\%$

2. Void ratio, $e = \frac{V_v}{V_s} = \frac{0.15+0.35}{0.5} \times 100 = 100\%$

3. Water content, $w = \frac{W_w}{W_s} \times 100 = \frac{0.4}{1.2} \times 100 = 33.33\%$

4. Saturated unit weight, $\gamma_{sat} = \left(\frac{G+Se}{1+e}\right)\gamma_w$

Using, $Se = wG$

$$G = \frac{Se}{w} = \frac{1 \times 1}{0.333} = 3.0$$

$$\therefore \quad \gamma_{sat} = \left(\frac{3+1\times 1}{1+1}\right) \times 1 = 2 \text{ g/cc}$$

Hence option (c) is correct.

Example 2.3 An oven dry soil has mass specific gravity of 1.5 g/cc. If bulk density of soil in its natural state is 2.0 g/cc, then the water content of soil in natural state will be

(a) 50% (b) 25%

(c) 100% (d) 33.33%

Ans. (d)

For oven dry soil,

Mass specific gravity,
$$G_m = \frac{\gamma_d}{\gamma_w} = 1.5 \text{ g/cc}$$

$\therefore$
$$\gamma_d = 1.5 \text{ g/cc}$$

Given, bulk density,
$$\gamma_t = 2.0 \text{ g/cc}$$

Using,
$$\gamma_d = \frac{\gamma_t}{1+w}$$

$$1.5 = \frac{2.0}{1+w}$$

$$w = \frac{2.0}{1.5} - 1 = 33.33\%$$

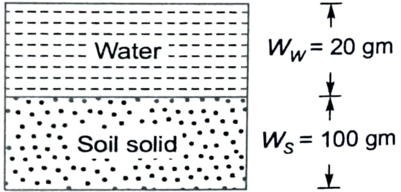
Hence option (d) is correct.

Example 2.4 Consider the phase diagram of the soil given below:

The soil is completely saturated

The specific gravity of soil solids is 2.6 (take unit weight of water as 10 kN/m^3).

Match List-I (Physical properties of soil) with List II (Corresponding values) and select the correct answer using the codes given below.



List-I		List-II
1. Water content		A. 0.34
2. Void ratio		B. 0.52
3. Porosity		C. 20.53
4. Saturated density		D. 20%

Codes:

	1	2	3	4
(a)	A	C	B	D
(b)	B	A	D	C
(c)	C	A	C	D
(d)	D	B	A	C

Ans. (d)

1. Water content, $$w = \frac{W_w}{W_s} \times 100 = \frac{20}{100} \times 100 = 20\%$$

2. Void ratio, $$e = \frac{wG}{S} = \frac{0.2 \times 2.6}{1} = 0.52$$

3. Porosity, $$n = \frac{e}{1+e} = \frac{0.52}{1+0.52} = 0.34$$

4. We know, $$\gamma_t = \left(\frac{G+Se}{1+e}\right)\gamma_w$$

For saturated density, $$\gamma_{sat} = \left(\frac{G+1\times e}{1+e}\right)\gamma_w = \left(\frac{2.6+0.52}{1+0.52}\right) \times 10 = 20.53 \text{ kN/m}^3$$

Hence option (d) is correct.

Example 2.7 A soil sample has void ratio of 35%. The specific gravity of solids is 2.7. Calculate the

(i) Porosity

(ii) Dry density

(iii) Unit weight if the soil is 75% saturated

(iv) Unit weight if the soil is submerged

Solution:

Given, Void ratio, $e = 35\%, \quad G_s = 2.7$

(i) We know, Porosity,
$$n = \frac{e}{1+e}$$

$$\therefore \quad n = \frac{0.35}{1+0.35} = 0.259$$

(ii) We know,
$$\gamma_t = \left(\frac{G_s + Se}{1+e}\right)\gamma_w$$

For dry density, $S = 0$

$$\therefore \quad \gamma_d = \frac{G_s \gamma_w}{1+e} = \frac{2.7 \times 9.81}{1+0.35}$$

$$\Rightarrow \quad \gamma_d = 19.62 \text{ kN/m}^3$$

(iii) When soil is 75% saturated i.e. $S = 0.75$

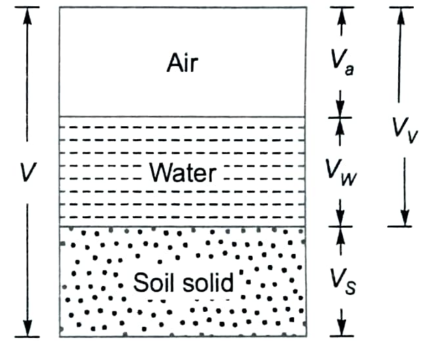
$$\therefore \qquad \gamma = \left(\frac{G_s + Se}{1+e}\right)\gamma_w = \left(\frac{2.7 + 0.75 \times 0.35}{1+0.35}\right) \times 9.81 = 21.53 \text{ kN/m}^3$$

(iv) We know, $\gamma_{sub} = \gamma_{sat} - \gamma_w$

$$= \left(\frac{G_s + 1e}{1+e}\right)\gamma_w - \gamma_w = \frac{(G_s - 1)}{1+e}\gamma_w = \frac{(2.7 - 1)}{1+0.35} \times 9.81 = 12.35 \text{ kN/m}^3$$

Example 2.8 A sampler with a volume of 60 cm³ is filled with saturated soil sample. The specific gravity of soil solids is 2.65. When the oven dry soil is poured into a graduated cylinder filled with water, it displaces 40 cm³ of water. What is the natural moisture content and dry unit weight of soil?

Solution:



Volume of soil sample = Volume of sampler

$\therefore$ $V = 60\text{ cm}^3$

When soil sample is poured into graduated cylinder, it displaces 40 cm³ of water

$\therefore$ Volume of soil solids, $V_s = 40\text{ cm}^3$

$\because$ Total volume, $V = V_v + V_s$

$\Rightarrow$ $V_v = V - V_s = 60 - 40$

$\Rightarrow$ $V_v = 20\text{ cm}^3$

$\therefore$ Void ratio, $e = \dfrac{V_v}{V_s} = \dfrac{20}{40} = 0.5$

Now, we have, $e = 0.5$, $S = 1$ and $G_s = 2.65$

Using $Se = wG_s$

Moisture content, $w = \dfrac{Se}{G_s} = \dfrac{1 \times 0.5}{2.65} = 18.86\%$

We know, $\gamma_d = \dfrac{\gamma_t}{1+w}$

where, γ_t = bulk unit weight

$$\gamma_t = \left(\frac{G+Se}{1+e}\right)\gamma_w = \left(\frac{2.65 + 1\times 0.5}{1+0.5}\right)\times 1 = 2.1\text{ g/cc}$$

Hence, $\gamma_d = \dfrac{2.1}{1+0.1886} = 1.76\text{ g/cc}$

Example 2.11 A soil sample of saturated clay has a diameter of 50 mm and the height of 100 mm. The mass of saturated sample is 220 g and its mass when oven dried is 150 g. Find

(i) Water content of the clay

(ii) Void ratio

(iii) Dry density of solid

Assume specific gravity of solid as 2.7.

Solution:

Mass of saturated soil sample, $M_{sat} = 220\text{ g}$

Mass of oven dry soil sample, $M_s = 150\text{ g}$

$\therefore$ Mass of water in soil, $M_w = 220 - 150 = 70\text{ g}$

(i) Water content of sample,

$$w = \frac{W_w}{W_s} \times 100 = \frac{M_w}{M_s} \times 100$$

$$= \frac{70}{150} \times 100 = 46.67\%$$

(ii) Volume of sample,

$$V = \frac{\pi}{4} D^2 L = \frac{\pi}{4}(5)^2 \times 10 = 196.35\text{ cc}$$

and

$$V_w = \frac{M_w}{\rho_w} = \frac{70\text{ g}}{1\text{ g/cc}} = 70\text{ cc}$$

For a saturated soil sample,

$$V_v = V_w = 70\text{ cc}$$

$\therefore$

$$\begin{aligned} V_s &= V - V_w \\ &= 196.35 - 70 \\ &= 126.35\text{ cc} \end{aligned}$$

$\therefore$ Void radio,

$$e = \frac{V_v}{V_s} = \frac{70}{126.35} = 0.55$$

(iii) Dry density,

$$\begin{aligned} \rho_d &= \frac{G\rho_w}{1+e} \\ &= \frac{2.7 \times 1}{1+0.55} \\ &= 1.74\text{ g/cc} \end{aligned}$$

...gravity of 2.70 has natural moisture content of 16%

Example 2.13 A soil sample has wet density of 20 kN/m^3 and dry density of 18 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 kN/m^3.

Solution:

Given,
$$\gamma_{wet} = \gamma_t = 20 \text{ kN/m}^3, \quad \gamma_d = 18 \text{ kN/m}^3 \quad \text{and} \quad G = 2.67$$

We know,
$$\gamma_d = \frac{G\gamma_w}{1+e}$$

$$\therefore \quad 18 = \frac{2.67 \times 10}{1+e}$$

$$\Rightarrow \quad 1 + e = \frac{2.67 \times 10}{18} = 1.483$$

$$\therefore \quad e = 0.483$$

We know that,
$$\text{Porosity, } n = \frac{e}{1+e} = \frac{0.483}{1+0.483} = 0.326$$

We have,

Dry density,
$$\gamma_d = \frac{\gamma_t}{1+w}$$

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

$$1 + w = \frac{20}{18} = 1.111$$

$$w = 0.111 \quad \text{or} \quad 11.11\%$$

Using,
$$Se = wG$$

$$S = \frac{wG}{e} = \frac{0.111 \times 2.67}{0.483} = 0.614 \quad \text{or} \quad 61.4\%$$