INDEX PROPERTIES

- Soil Classification
- To classify the soil into a group according to the soil behavior and physical shape.
- Soil classification is adopting a formal system of soil description and classification in order to describe the various materials found in ground investigation.
- Such a system must be meaningful and concise in an engineering context, so that engineers will be able to understand and interpret.

- What is soil description?

- **Description of soil** is a statement that describes the physical nature and state of the soil. It can be a description of a sample, or a soil *in situ*. It is arrived at by using visual examination, simple tests, observation of site conditions, geological history, etc.

- What is soil Classification?

- **Classification of soil** is the separation of soil into classes or groups each having specific characteristics and potentially specific behavior.

- A classification for engineering purposes should be based mainly on mechanical properties: permeability, stiffness, strength.

- The aim of a classification system is to establish a set of conditions which will allow useful comparisons to be made between different soils.

- The relevant criteria for classifying soils are the ***size distribution*** of particles and the ***plasticity*** of the soil.

- PURPOSE:
  To classified the soil into a group according to the soil behavior and physical shape

- TYPES OF CLASSIFICATION:
  - Classification by visual
  - AASHTO
  - UCS
  - IS classification

- SOIL TESTS
  - Atterberg limit
  - Sieve analysis
  - Hydrometer analysis

- Engineering properties
- The main engineering properties of soils are permeability, compressibility and shear strength.

- Permeability refers the water can flow through soils. It is required for estimation of seepage discharge through soil masses.

- Compressibility referred to the deformations produced in soils when they are subjected to compressive loads. It is required for computation of the settlements of structures founded on soils.

- Shear strength of the soil is the ability to resist shear stresses. The shear strength determines the stability of slopes, bearing capacity of soils and earth pressure on retaining structures.

- Index properties

- The test required for determination of engineering properties are required Index properties of the soils.

- Simple test required to determine the index properties are known as soil classification tests. The soils are classified and identified based on index properties.

- The main index properties of course grained soils are particle size and relative density and for fine grained soils are atterbergs limit and the consistency.

Particle Size Distribution

- The mechanical analysis, also known as particle size analysis is a method of separation of soils into different fractions based on the particle size.
- For measuring the distribution of particle sizes in a soil sample, it is necessary to conduct different **particle-size tests**. It is shown graphically on a particle size distribution curve.
- The mechanical analysis can be categorized in two types, that are sieve analysis and sedimentation analysis. The set of sieve analysis is for course grained soils which has particle size greater than 75 micron.
- **Wet sieving** is carried out for the soil specimen of fine grained soils which has the particle size less than 75 micron and also known as sedimentation analysis.

- **Dry sieve analysis** is carried out on particles coarser than 75 micron. Samples (with fines removed) are dried and shaken through a set of sieves of descending size. The weight retained in each sieve is measured. The cumulative percentage quantities finer than the sieve sizes (passing each given sieve size) are then determined.
- The course grained soils can be further sub divided into gravel fraction and sand fraction. The size greater than 4.75 mm called gravel and size between 75 micron to 4.75mm called sand.
- A set of course sieves, consisting of the sieves of size 80mm, 40mm, 20mm, 10mm and 4.75mm is required for the gravel fraction.

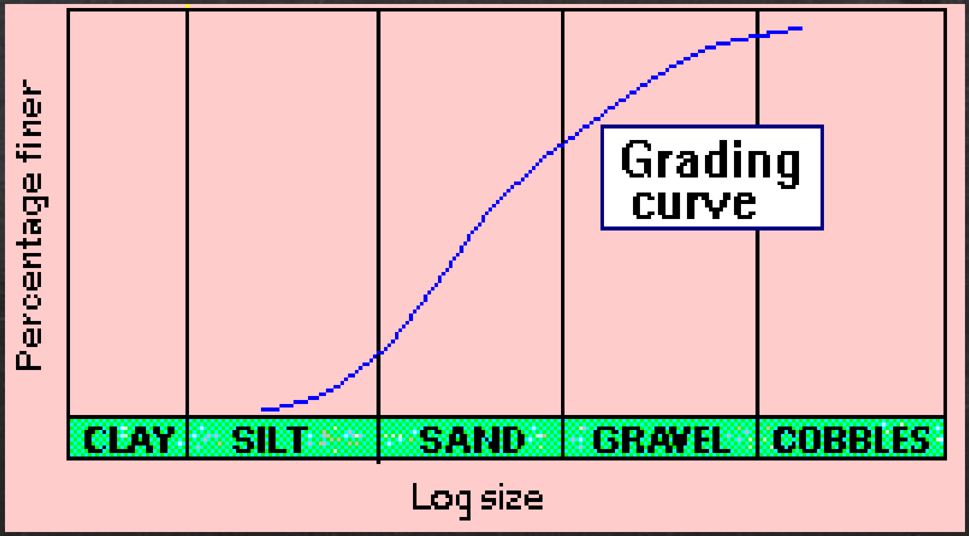
- The second set of sieves, consisting of the sieves of size 2mm, 1mm, 600µ, 425, 212, 150 and 75µ is used for sieving minus 4.75mm fraction.

- The soil is sieved through the set of course sieves manually or using a mechanical shaker. The weight of soil retained on each sieve is obtained.

- The resulting data is presented as a distribution curve with **grain size** along x-axis (log scale) and **percentage passing** along y-axis (arithmetic scale).

Grain-Size Distribution Curve

- The size distribution curves, as obtained from coarse and fine grained portions, can be combined to form one complete **grain-size distribution curve** (also known as **grading curve**). A typical grading curve is shown.



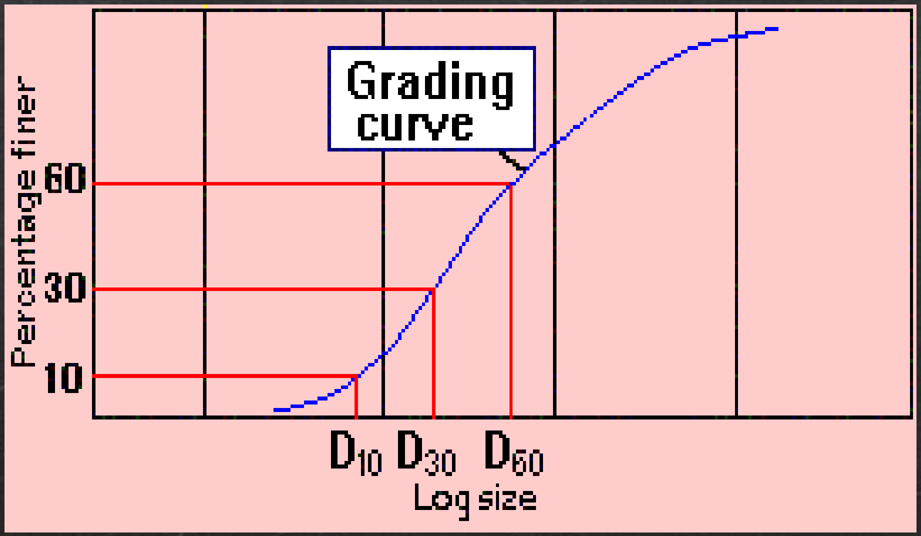
- From the complete grain-size distribution curve, useful information can be obtained such as:

- **1. Grading characteristics**, which indicate the uniformity and range in grain-size distribution.

  2. Percentages (or **fractions)** of gravel, sand, silt and clay-size.

- Grading Characteristics

- A grading curve is a useful aid to soil description. The geometric properties of a grading curve are called **grading characteristics**.



- To obtain the grading characteristics, three points are located first on the grading curve.

  D_{60} = size at 60% finer by weight
  D_{30} = size at 30% finer by weight
  D_{10} = size at 10% finer by weight

- The grading characteristics are then determined as follows.

- **Effective size** = D_{10}
- **Uniformity coefficient,** $$C_u = \frac{D_{60}}{D_{10}}$$
- **Curvature coefficient,** $$C_c = \frac{(D_{30})^2}{D_{60} \cdot D_{10}}$$
- Both C_u and C_c will be 1 for a single-sized soil.

C_u **> 5** indicates a **well-graded soil**, i.e. a soil which has a distribution of particles over a wide size range.

- C_c **between 1 and 3** also indicates a well-graded soil.

  C_u **< 3** indicates a **uniform soil**, i.e. a soil which has a very narrow particle size range.

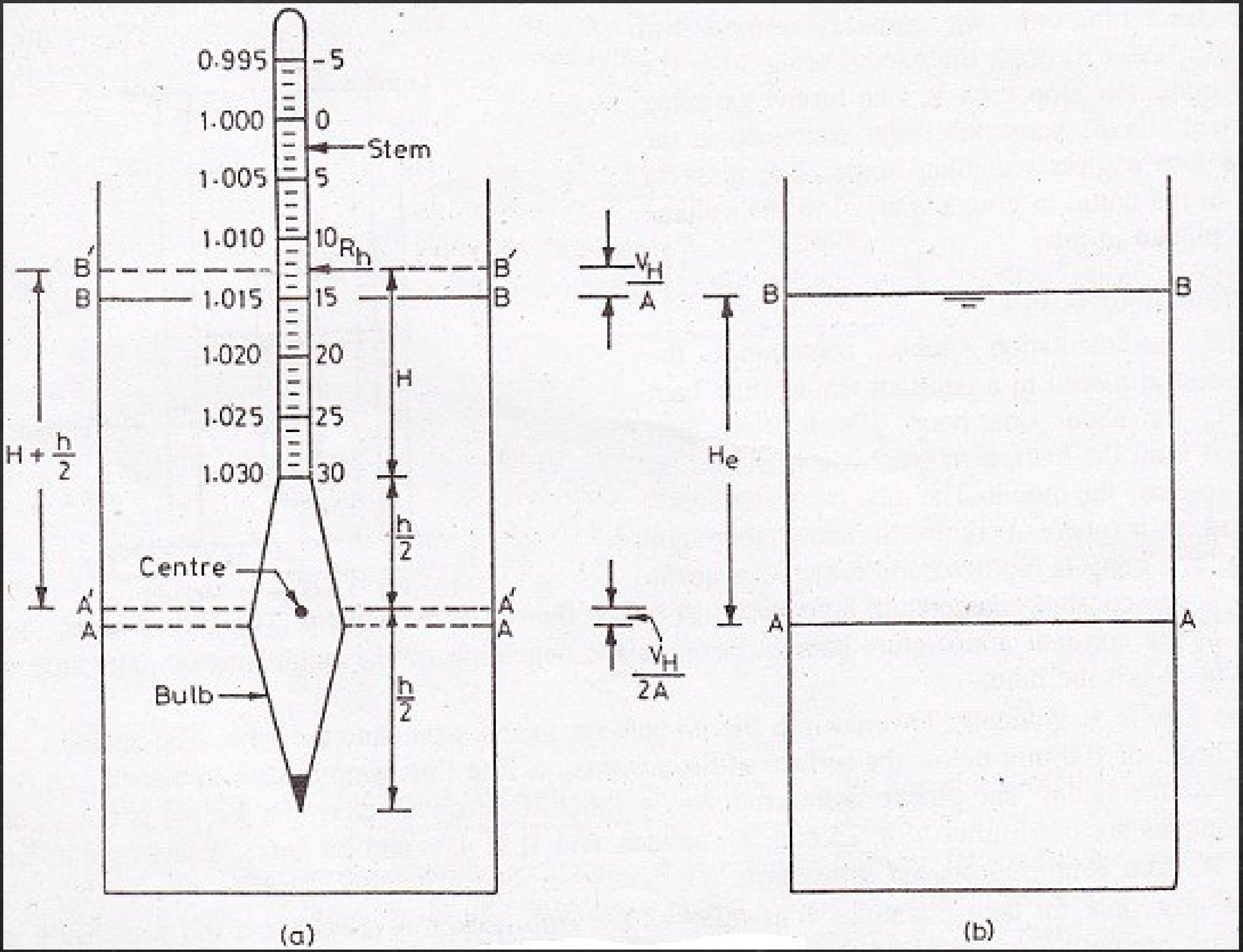
- **Stoke's law and hydrometer analysis**
- Soil particle finer than 75μ size cannot be sieved. The particle size distribution of such soils is determined by sedimentation analysis.
- The analysis is based on stokes law, which gives terminal velocity of a small sphere settling in a fluid of infinite extend.
- When a small sphere settles in a fluid, its velocity first increases under the action of gravity, but the drag force comes into action, and retards the velocity. After an initial adjustment period, steady conditions are attained and the velocity becomes constant. The velocity is attained is known as terminal velocity. The expressions for terminal velocity is,
- Assumption : All particle have rounded shape
- Stoke rule

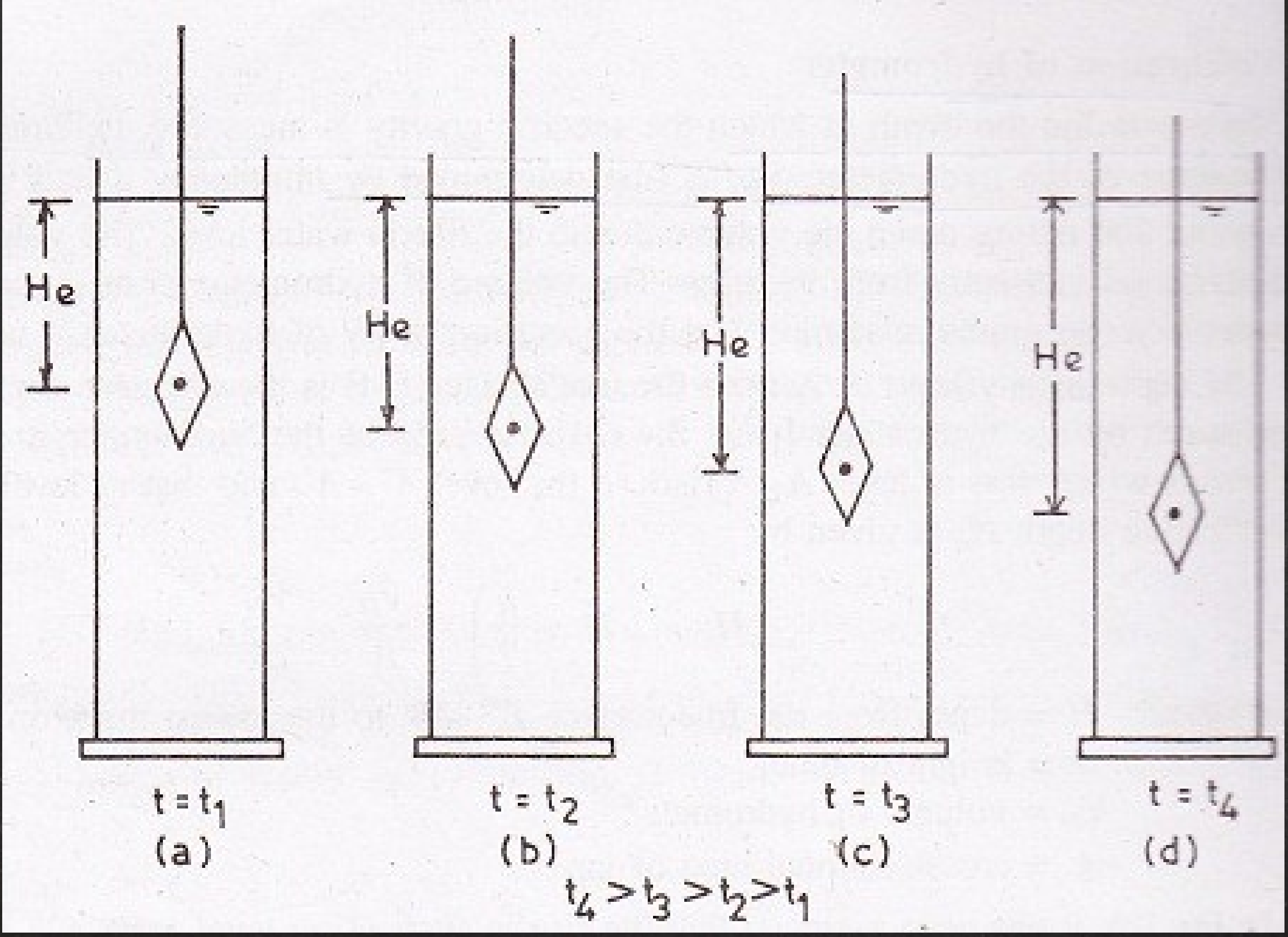
$$v = \frac{g(\gamma_s - \gamma_w)D^2}{18\eta}$$

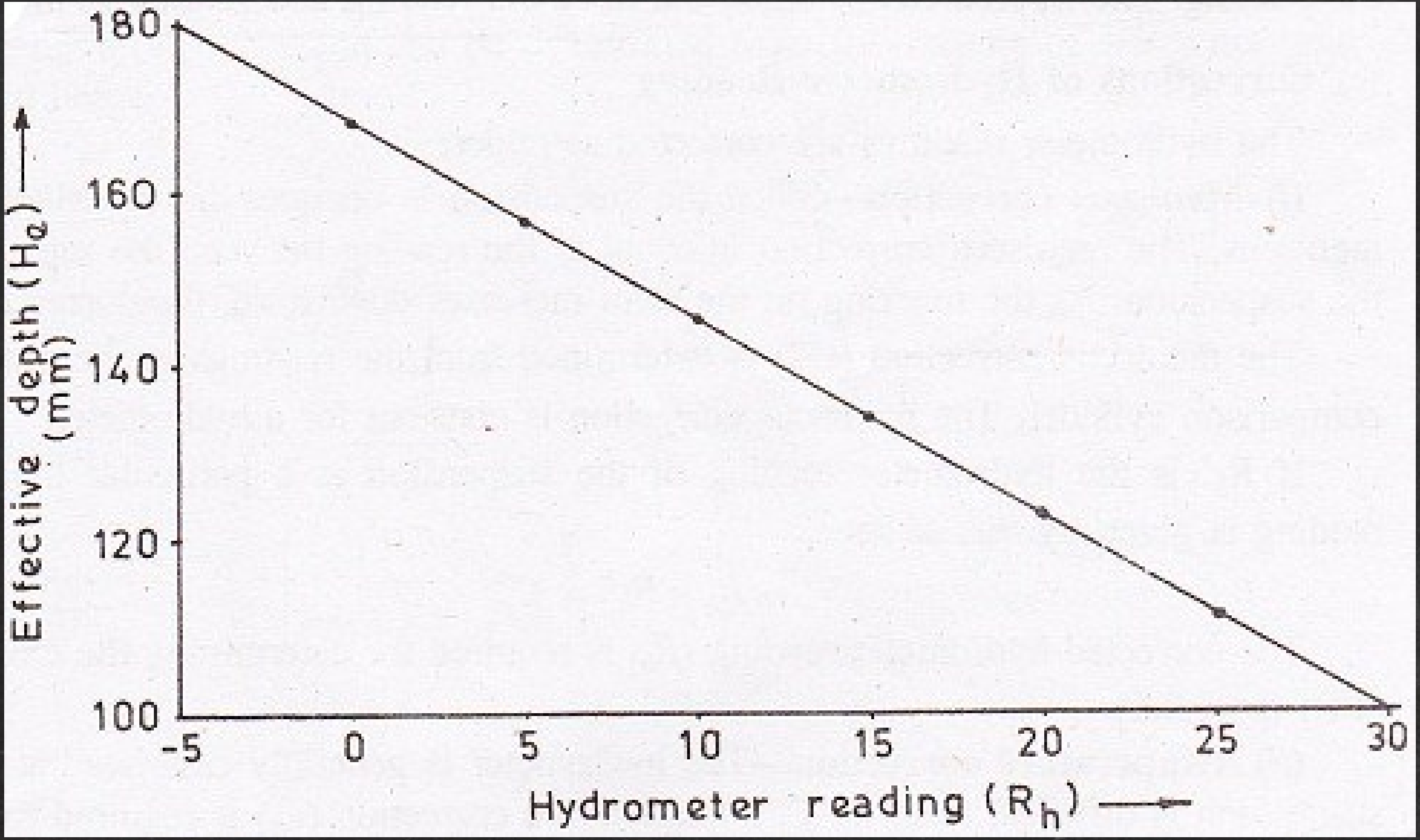
- V = Velocity
- g = Acceleration due to gravity
- D = Diameter of the particle
- gs = Density of solids
- gw = Density of water
- h = Viscosity

Hydrometer method

- A hydrometer with a long stem is marked from top to bottom, generally in the range of 0.995 to 1.030.
- The depth of any layer A-A from the surface B-B is the effective depth. As soon as the hydrometer inserted in the jar, the layer of suspension which was at level A-A rises to the level A′-A′ and that at level B-B rises to the level B′-B′.
- The effective depth He given below,
- $He = (H+h/2) - VH/A + VH/2A$.
- H = depth from the free surface B′-B′ to the lowest mark on the stem.
- h = height of the bulb


0.995
-5
1.000
0
Stem
1.005
5
1.010
10
R_h
B′
B′
B
1.015
15
B
1.020
20
H
1.025
25
$H + \frac{h}{2}$
1.030
30
$\frac{h}{2}$
Centre
A′
A′
A
A
Bulb
$\frac{h}{2}$
$\frac{V_H}{A}$
$\frac{V_H}{2A}$
B
B
H_e
A
A
(a)
(b)


He
He
He
He
t = t1
(a)
t = t2
(b)
t = t3
(c)
t = t4
(d)
t4 > t3 > t2 > t1



Effective depth (H_e) (mm)
180
160
140
120
100
-5
0
5
10
15
20
25
30
Hydrometer reading (R_h)

- VH = Volume of hydrometer
- A = Cross sectional area of jar.

- To determine the depth, calibration of the hydrometer is done by immersing it in a graduated cylinder partly filled with water and noting down the volume due to the rise in water level.

- The graduations on the right side of the stem directly give the reading Rh. As the effective depth He depends upon the hydrometer reading Rh a calibration chart can be obtained between the hydrometer reading Rh and the effective depth. Figures shows the typical calibration chart.

- Test procedure

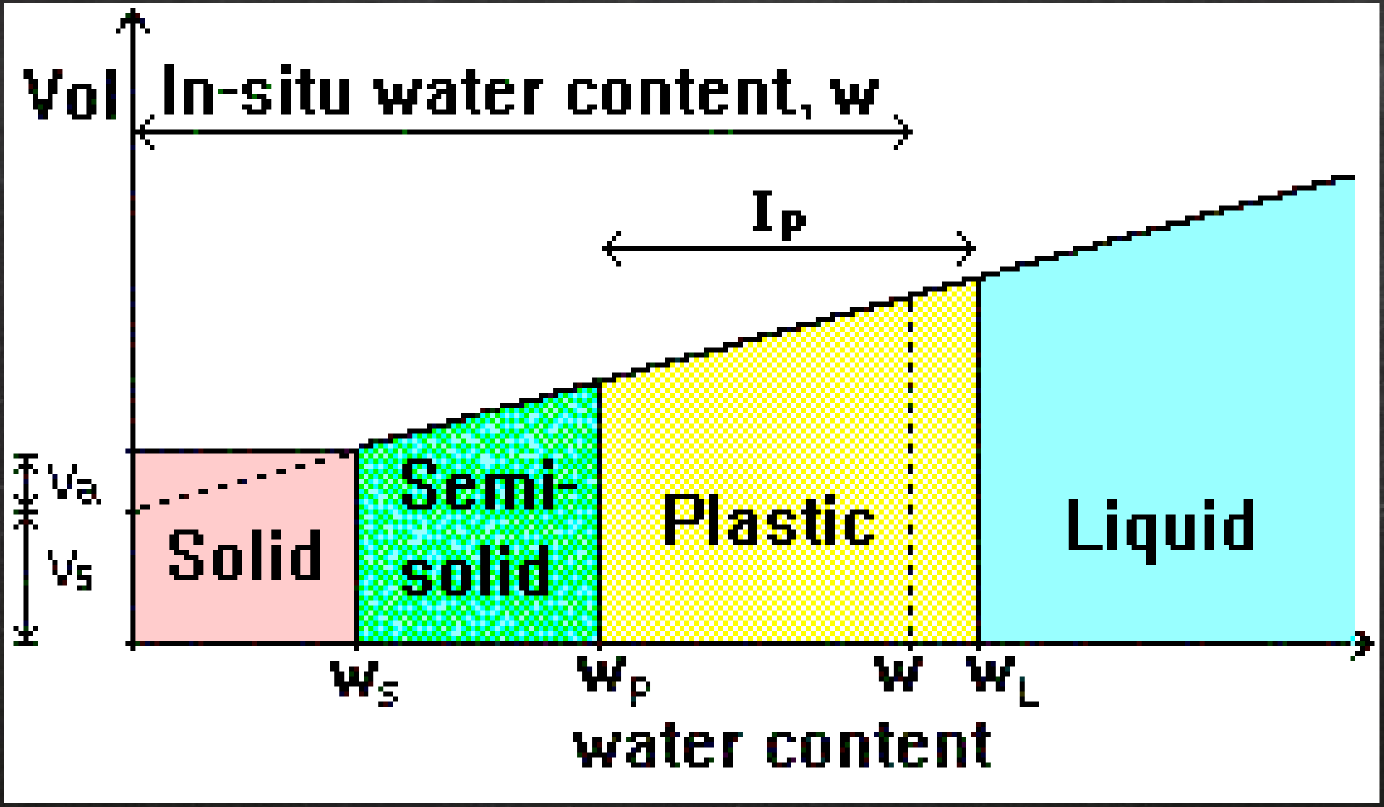
- Exactly 1000ml of suspension is prepared and placed in the jar and stop watch is started.
- The hydrometer is inserted in the suspension and the first reading is taken after ½ minute of the commencement of the sedimentation. Further readings are taken after one minute, two minutes and four minutes of the commencement of the sedimentation.
- The particle size can be expressed as,

- $D = \sqrt{0.3_h \times He / g (G - 1) \gamma w \times t}$
- D = Diameter of the particle.

Consistency of Soils

- The consistency of a fine grained soil is the physical state in which it exists. It is used to denote the degree of firmness of a soil. Consistency of a soil is indicated in terms of soft and hard.
- The **consistency** of a fine-grained soil refers to its firmness, and it varies with the water content of the soil.
- A gradual increase in water content causes the soil to change from ***solid*** to ***semi-solid*** to ***plastic*** to ***liquid*** states. The water contents at which the consistency changes from one state to the other are called **consistency limits** (or **Atterberg limits**).

- The three limits are known as the shrinkage limit (**W_S**), plastic limit (**W_P**), and liquid limit (**W_L**) as shown. The values of these limits can be obtained from laboratory tests.



- Two of these are utilised in the classification of fine soils:

- **Liquid limit** (**W_L**) - change of consistency from plastic to liquid state
  Plastic limit (**W_P**) - change of consistency from brittle/crumbly to plastic state

- Shrinkage limit (**S_L**) – The water content at which soil changes from semi solid state to the solid state is known as the shrinkage limit.

- The difference between the liquid limit and the plastic limit is known as the **plasticity index** (**I_P**), and it is in this range of water content that the soil has a plastic consistency. The consistency of most soils in the field will be plastic or semi-solid.

- Indian Standard Soil Classification System
- **Classification Based on Grain Size**
  The range of particle sizes encountered in soils is very large: from boulders with dimension of over 300 mm down to clay particles that are less than 0.002 mm. Some clays contain particles less than 0.001 mm in size which behave as colloids, i.e. do not settle in water.

- In the **Indian Standard Soil Classification System (ISSCS)**, soils are classified into groups according to size, and the groups are further divided into coarse, medium and fine sub-groups.

- The grain-size range is used as the basis for grouping soil particles into boulder, cobble, gravel, sand, silt or clay.

Very coarse soils	**Boulder size**		**> 300 mm**
	Cobble size		**80 - 300 mm**
Coarse soils	**Gravel size (G)**	***Coarse***	**20 - 80 mm**
		Fine	**4.75 - 20 mm**
	Sand size (S)	***Coarse***	**2 - 4.75 mm**
		Medium	**0.425 - 2 mm**
		Fine	**0.075 - 0.425 mm**
Fine soils	**Silt size (M)**		**0.002 - 0.075 mm**
	Clay size (C)		**< 0.002 mm**

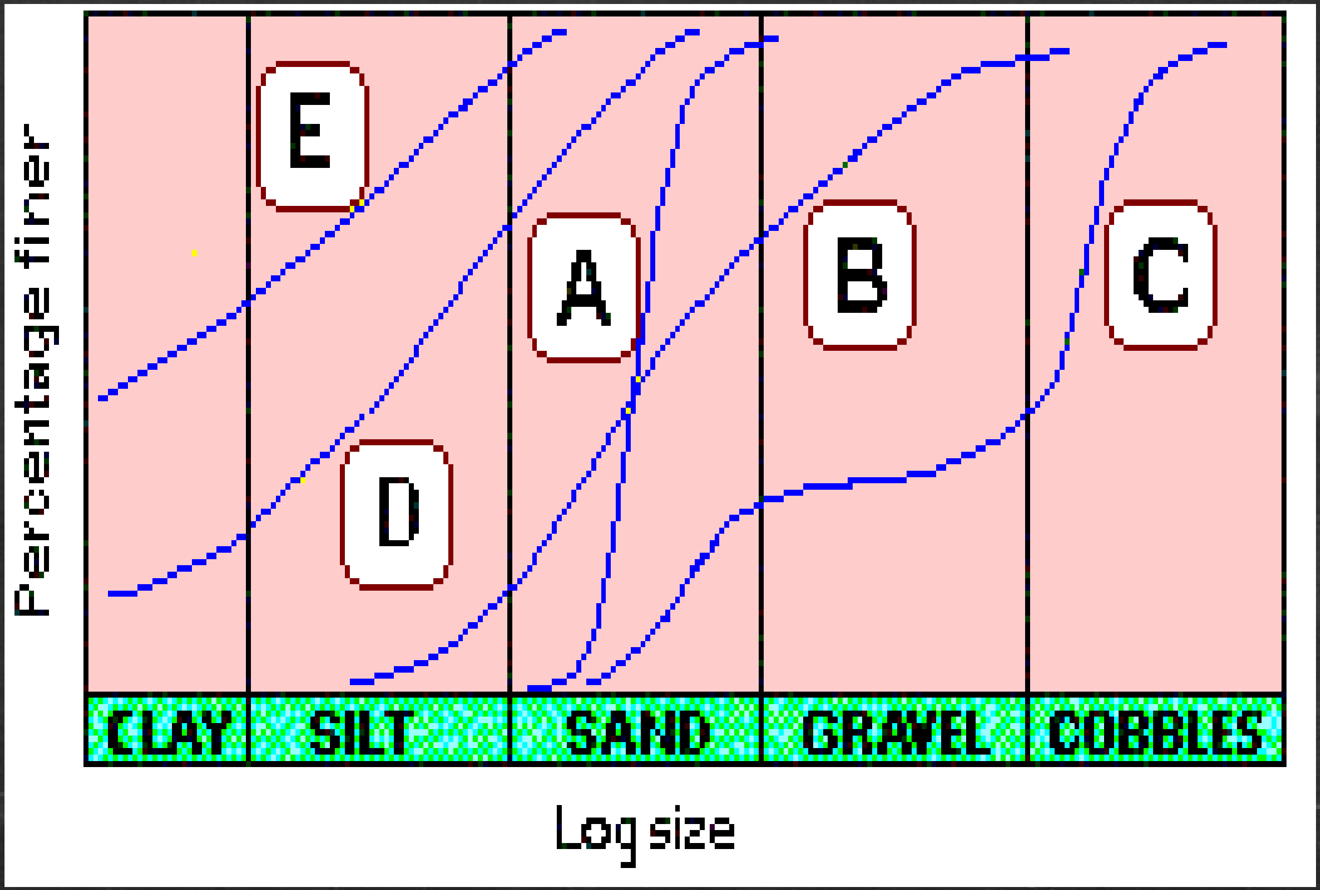
- Gravel, sand, silt, and clay are represented by **group symbols G, S, M, and C** respectively.

- **Coarse-grained soils** are those for which more than 50% of the soil material by weight has particle sizes greater than 0.075 mm. They are basically divided into either **gravels (G) or sands (S).**

- According to **gradation**, they are further grouped as well-graded (**W**) or poorly graded (**P**). If **fine soils** are present, they are grouped as containing silt fines (**M**) or as containing clay fines (**C**).

- For example, the combined symbol **SW** refers to well-graded sand with no fines.

- Both the position and the shape of the grading curve for a soil can aid in establishing its identity and description. Some typical grading curves are shown.



Percentage finer
E
A
B
C
D
CLAY
SILT
SAND
GRAVEL
COBBLES
Log size

- **Curve A** - a poorly-graded medium SAND

  Curve B - a well-graded GRAVEL-SAND (i.e. having equal amounts of gravel and sand)

  Curve C - a gap-graded COBBLES-SAND

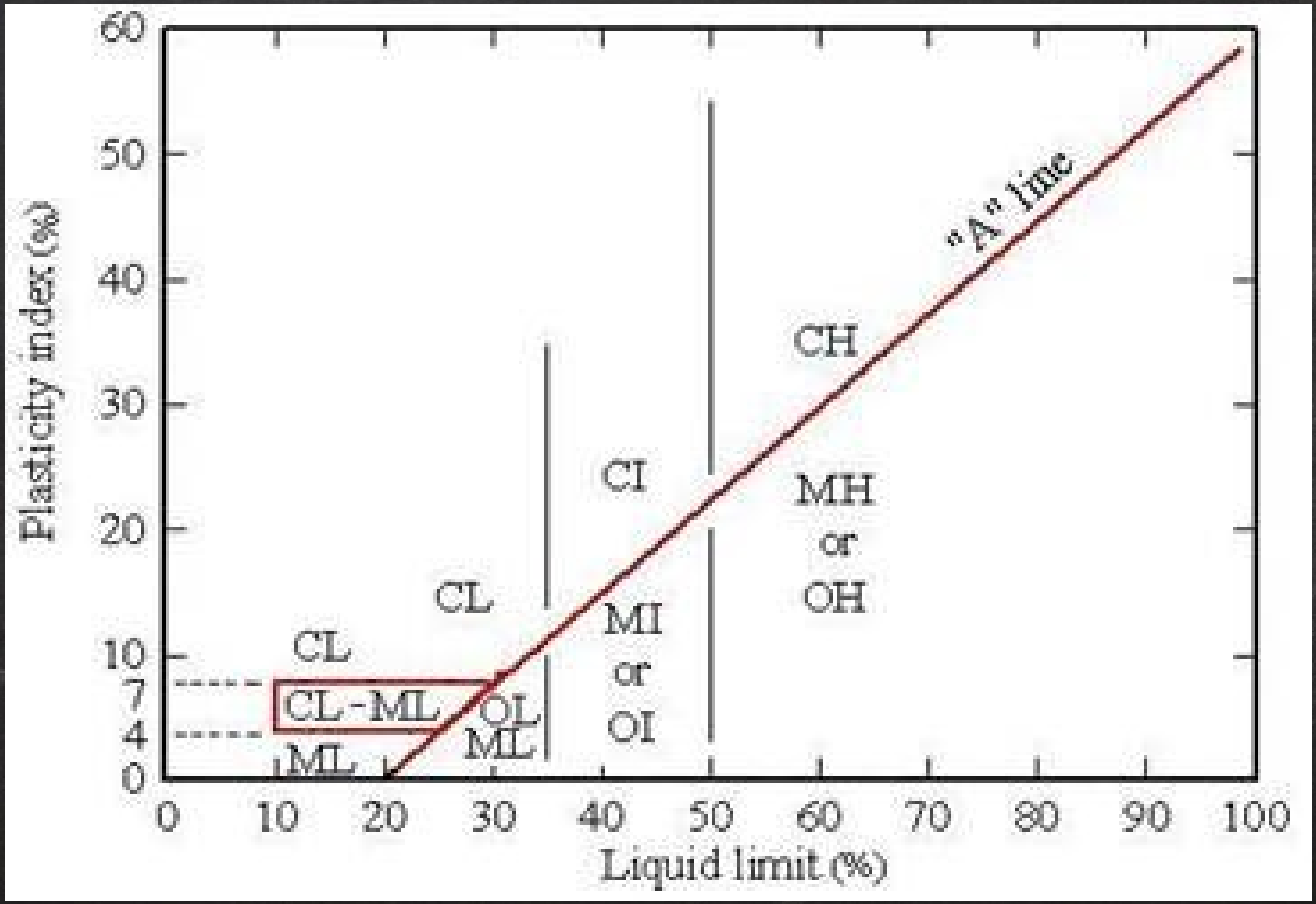
  Curve D - a sandy SILT

  Curve E - a silty CLAY (i.e. having little amount of sand)

Primary Letter	Secondary Letter
G : Gravel	W : well-graded
S : Sand	P : poorly graded
M : Silt	M : with non-plastic fines
C : Clay	C : with plastic fines
O : Organic soil	L : of low plasticity
P: Peat	I : of medium plasticity
	H : of high plasticity

- **Fine-grained soils** are those for which more than 50% of the material has particle sizes less than 0.075 mm. Clay particles have a **flaky** shape to which water adheres, thus imparting the property of **plasticity**.

- A **plasticity chart** , based on the values of liquid limit ($\mathbf{W_L}$) and plasticity index ($\mathbf{I_P}$), is provided in **ISSCS** to aid classification. The **'A' line** in this chart is expressed as $\mathbf{I_P = 0.73 (W_L - 20)}$.



60
50
40
30
20
10
7
4
0
Plasticity index (%)
"A" line
CH
CI
MH
or
OH
CL
CL
CL-ML
OL
ML
ML
MI
or
OI
0
10
20
30
40
50
60
70
80
90
100
Liquid limit (%)

- An empirical boundary known as the "A" line separates inorganic clays from silty and organic soils.

- Depending on the point in the chart, fine soils are divided into **clays (C)**, **silts (M)**, or **organic soils (O)**. Three divisions of plasticity are also defined as follows.

- **Low plasticity**
- **$W_L < 35\%$**
- **Intermediate plasticity**
- **$35\% < W_L < 50\%$**
- **High plasticity**
- **$W_L > 50\%$**

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- The **'A' line** and vertical lines at $\mathbf{W_L}$ equal to **35%** and **50%** separate the soils into various classes.

- For example, the combined symbol **CH** refers to clay of high plasticity.

- Classification as per liquidity index is:

Liquidity index	Classification
> 1	Liquid
0.75 - 1.00	Very soft
0.50 - 0.75	Soft
0.25 - 0. 50	Medium stiff
0 - 0.25	Stiff
< 0	Semi-solid

Description			Group Symbol	Laboratory criteria			Notes
				Fines (%)	Grading	Plasticity	
Coarse grained soils: Fine particles (size smaller than 75 micron) less than 50%	Gravels (particles larger than 4.75mm) more than 50% of coarse fraction	Well graded gravels, sandy gravels, with little or no fines	GW	0 - 5	Cu > 4 1 < Cc < 3		A dual symbol, if fines are 5 – 12 %. Dual symbols, if above A-line and 4 < PI < 7
		Poorly graded gravels, sandy gravels, with little or no fines	GP	0 - 5	Not satisfying GW requirements		
		Silty gravels, silty sandy gravels	GM	> 12		Below A- line or PI < 4	
		Clayey gravels, clayey sandy gravels	GC	> 12		Above A- line and PI > 7	
	Sands particles more than 50% of coarse fraction (size above 75 micron)	Well graded sands, sandy soils, with little or no fines	SW	0 - 5	Cu > 6 1 < Cc < 3		
		Poorly graded sands/,sandy soils, with little or no fines	SP	0 - 5	Not satisfying SW requirements		
		Silty sands	SM	> 12		Below A- line or PI < 4	
		Clayey sands	SC	> 12		Above A- line and PI > 7	

Fine grained soils particles (size less than 75 micron) more than 50%	Silts and clays (Liquid Limit <35)	Inorganic silts , silty or clayey fine sands, with slight plasticity	ML	Plasticity Index less than 4
		Inorganic clays, silty clays, sandy clays of low plasticity	CL	Plasticity Index more than 7
		Inorganic silt and clay of low plasticity	CL-ML	Plasticity Index between 4 and 7
	Silts and clays (Liquid limit 35-50)	Inorganic silts , clayey silt with medium plasticity	MI	Below A-line of Plasticity Chart
		Inorganic clays, silty clays of medium plasticity	CI	Above A- line of Plasticity Chart
	Silts and clays (Liquid limit > 50)	Inorganic silts of high plasticity	MH	Below A-line of Plasticity Chart
		Inorganic clays of high plasticity	CH	Above A- line of Plasticity Chart