DEPARTMENT OF CIVIL ENGINEERING
RGUKT-NUZVID

Geotechnical Engineering

CLASSIFICATION OF SOILS

UNIT- II (Classification of Soils)

- Mechanical analysis
- Atterberg Limits and related indices
- Soil classification and its significance
- Unified soil classification and IS classification based on mechanical analysis and Atterberg limits
- Engineering use chart and its significance.

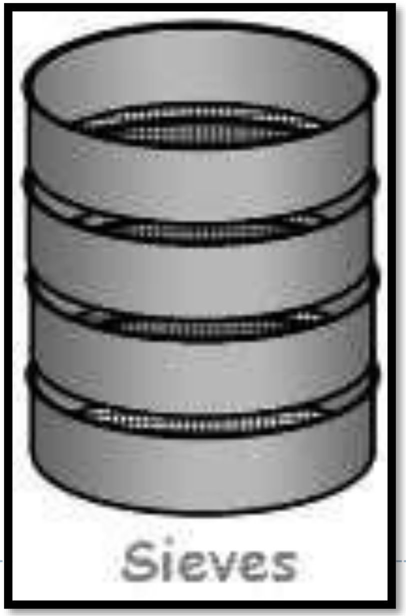
Mechanical analysis

Mechanical analysis

- The physical separation of a sample of soil by any method into two or more fractions, each containing only particles of certain sizes, is termed ***fractionation.*** The determination of the mass *of* material in fractions containing only particles of certain sizes is termed **Mechanical Analysis**.
- Mechanical analysis is one of the oldest and most common forms of soil analysis. It provides the basic information for revealing the uniformity or gradation of the materials within established size ranges and for textural classifications.
- The results of a mechanical analysis are not equally valuable in different branches of engineering. The size of the soil grains is of importance in such cases as construction of earth dams or railroad and highway embankments, where earth is used as a material that should satisfy definite specifications. In foundations of structures, data from mechanical analyses are generally illustrative; other properties such as compressibility and shearing resistance are of more importance.
- The normal method adopted for separation of particles in a fine grained soil mass is the hydrometer analysis and for the coarse grained soils is the sieve analysis.

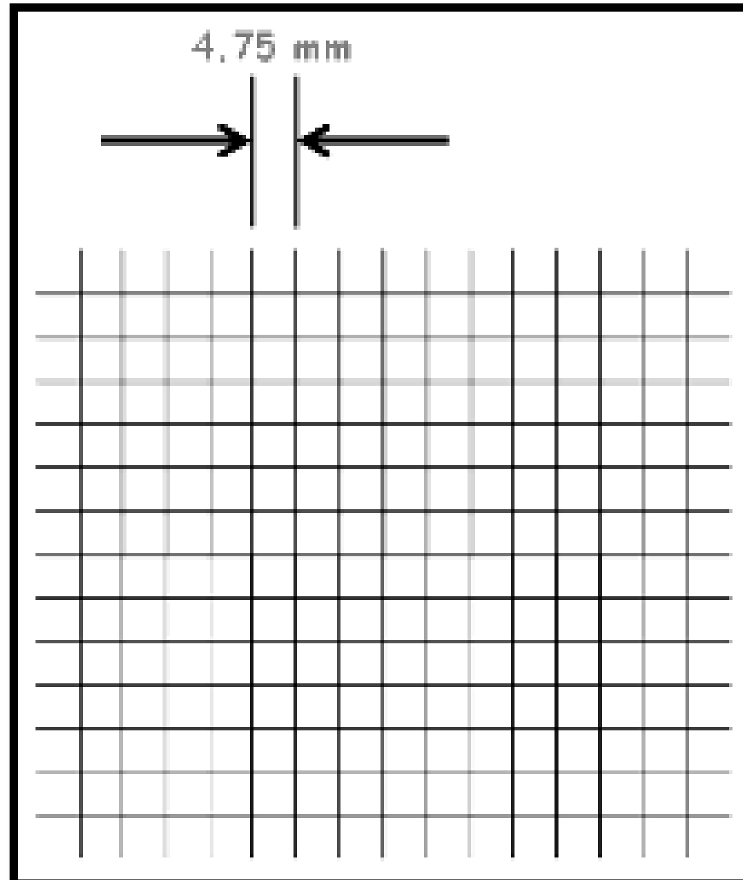
SIEVE ANALYSIS

- Sieve analysis is the method of particle size analysis, using which we determine the amount of particles of different sizes present in the soil sample.
- Sieve analysis is carried out by using a set of standard sieves. Sieves are made by weaving two sets of wires at right angles to one another.
- The square holes thus formed between the wires provide the limit which determines the size of the particles retained on a particular sieve.



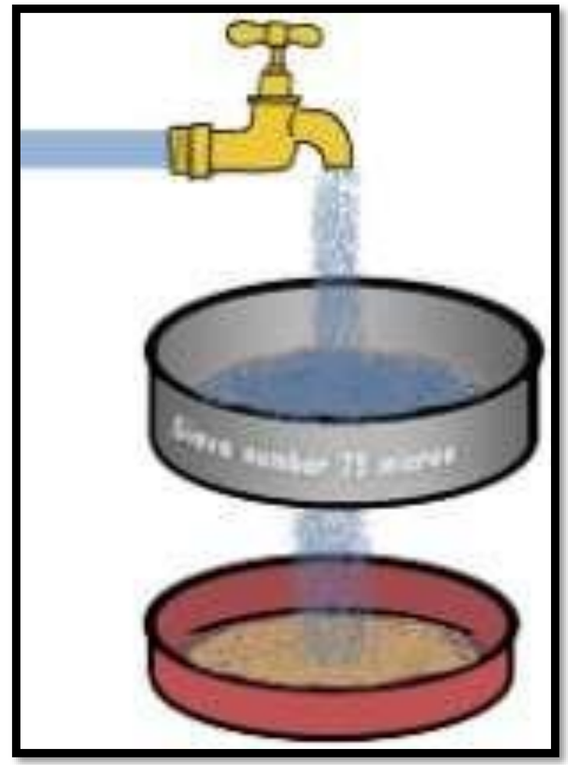
SIEVE ANALYSIS

- Sieves are wire screens having square openings.
- Size of these openings gives the sieves their name which is called **Sieve number.**
- A sieve with a mesh opening of 4.75 mm is designated as 4.75 mm Sieve (Sieve number written on sieve).
- Similarly a 600 micron sieve refers to a sieve which has a mesh opening of 0.600 mm.
- Sieve analysis itself is done in two ways:
  - Dry Sieve analysis
  - Wet Sieve analysis



Wet sieving

- **Wet sieving** is carried out for separating fine grains from coarse grains by washing the soil specimen on a ***75 micron sieve*** mesh.
- The wet soil retained on the 75 μ sieve is dried in an oven and after drying the dry sieve analysis is carried out in the usual manner.
- The finer fraction is utilized for the hydrometer or pipette analysis.

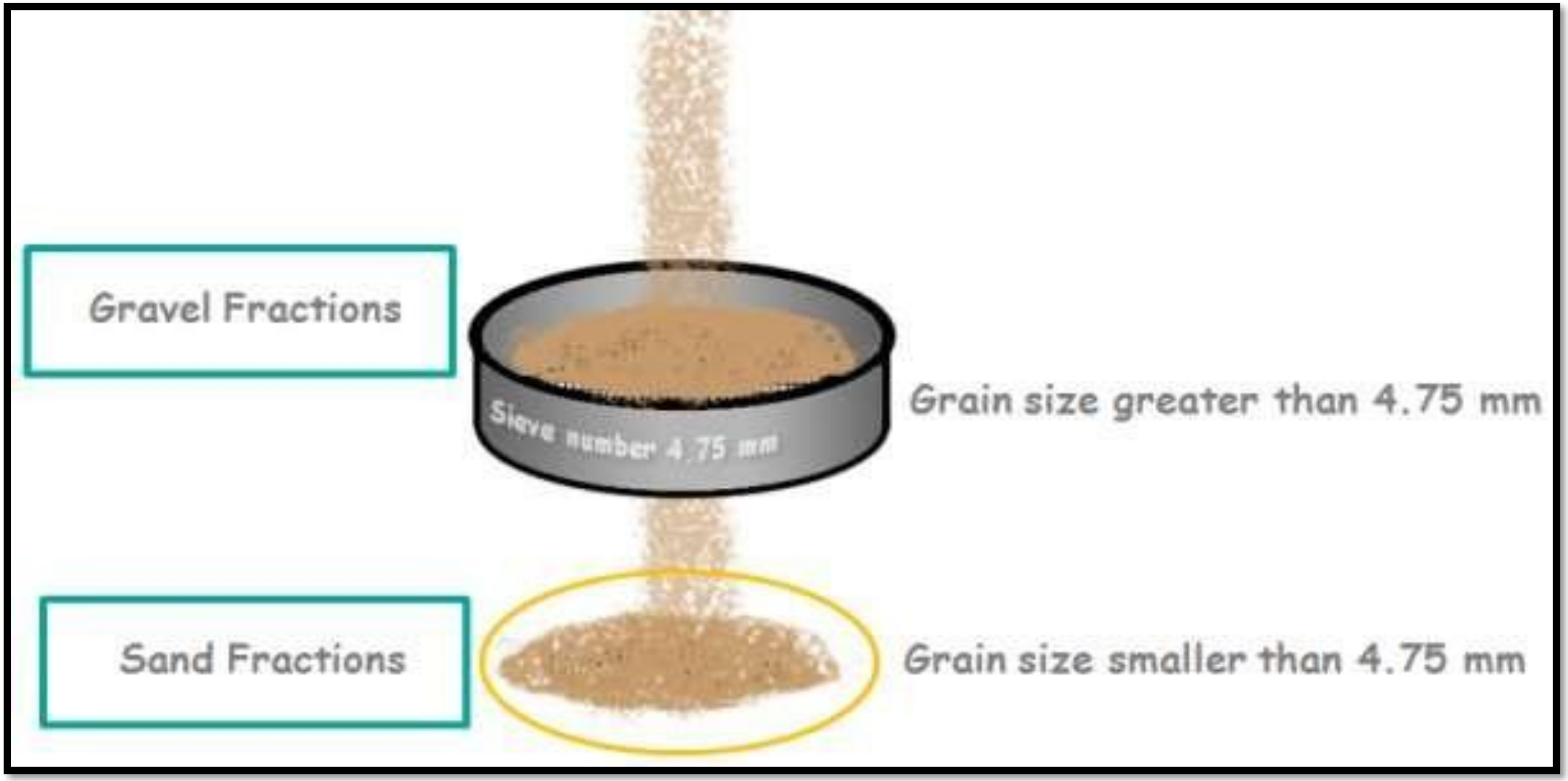


Dry sieve analysis

- 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 sample coarser than 75 micron is taken and first sieved through 4.75 mm sieve.
- The portion of soil, which contains particle size bigger than 4.75 mm is retained on the sieve. This portion is called gravel fraction.
- The portion of soil, which contains particle size less than 4.75 mm passed through the sieve. This portion is called sand fraction.

This way coarse grained soils are divided into two categories:

1. Gravels, having grain size greater than 4.75 mm and
2. Sand, having grain size smaller than 4.75 mm.



- For **gravel fractions** we require sieves of sizes 80 mm, 40 mm, 20 mm, 10 mm and 4.75 mm. This set is called set of coarse sieves as it sieves coarser part of the coarse soils.
- Second set of sieves for **sand fractions** consists sieves of sizes 4.75 mm, 2 mm, 1 mm, 600 µ, 425 µ, 300µ, 150 µ and 75 µ. This set of sieves is called set of fine sieves as it sieves finer part of the coarse soils.
- The sieves are stacked one over the other with increasing size of their mesh openings from bottom to top. Which means the sieve of largest opening is kept at the top.
- A pan which has no opening is placed below the bottom most sieve. The soil sample is placed in the top sieve and a lid to cover this arrangement is placed over the top most sieve.
- The whole arrangement is then placed on a mechanical shaker and is shaken for 10 minutes

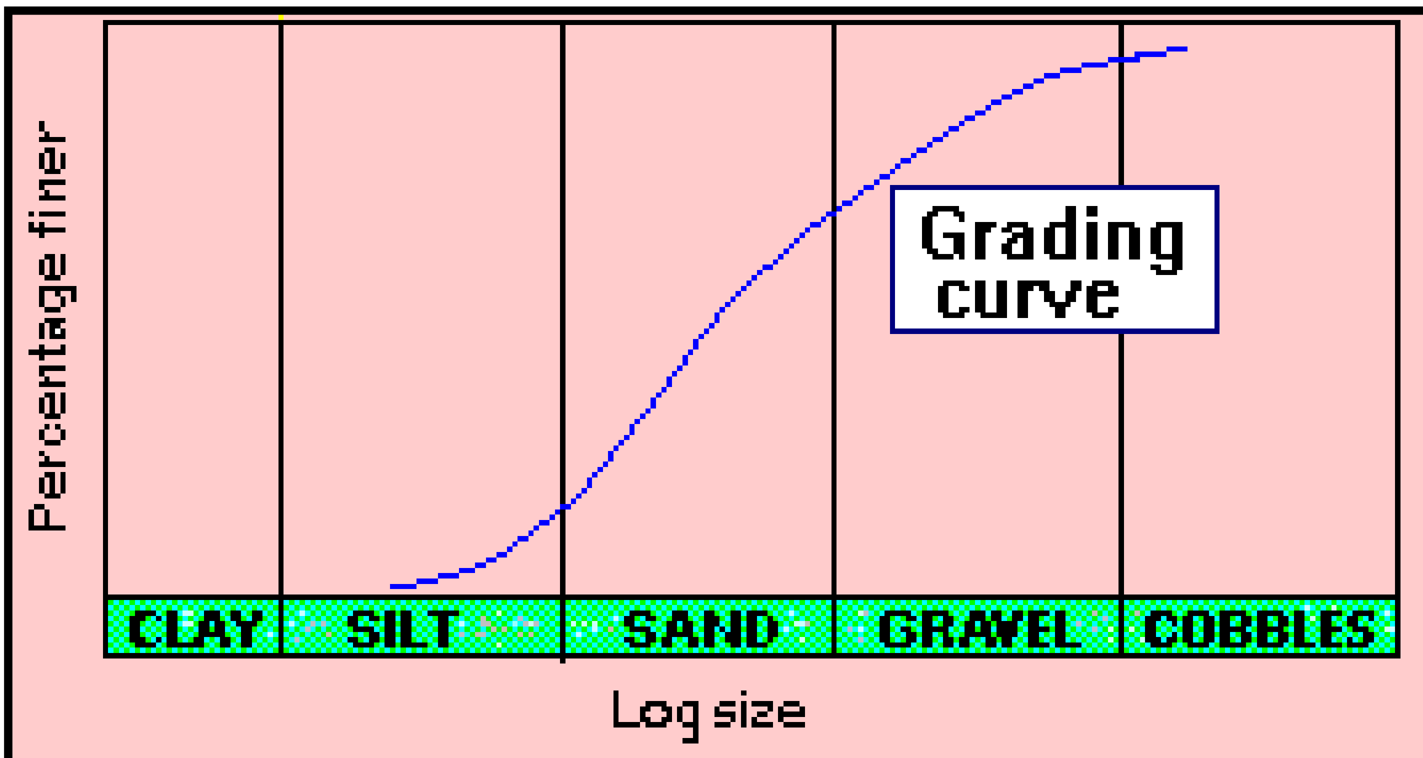
Then arrangement is taken out and the amount of soil retained on each sieve and pan is weighed with the accuracy of 0.1 gm. From which cumulative percentage retained can be calculated. The cumulative percentage quantities finer than the sieve sizes (passing each given sieve size) are then determined.

	Weight retained	% retained on sieve	cumulative % retained	% Finer
	W_1	$P_1 = \frac{W_1}{W} \times 100$	$C_1 = P_1$	$100 - C_1$
	W_2	$P_2 = \frac{W_2}{W} \times 100$	$C_2 = P_1 + P_2$	$100 - C_2$
	W_3	$P_3 = \frac{W_3}{W} \times 100$	$C_3 = P_1 + P_2 + P_3$	$100 - C_3$
	W_4	$P_4 = \frac{W_4}{W} \times 100$	$C_4 = P_1 + P_2 + P_3 + P_4$	$100 - C_4$
	W_5	$P_5 = \frac{W_5}{W} \times 100$	$C_5 = P_1 + P_2 + P_3 + P_4 + P_5$	$100 - C_5$
	W_{pan}	$P_{pan} = \frac{W_{pan}}{W} \times 100$	$C_{pan} = P_1 + P_2 + P_3 + P_4 + P_5 + P_{pan}$	$100 - C_{pan}$

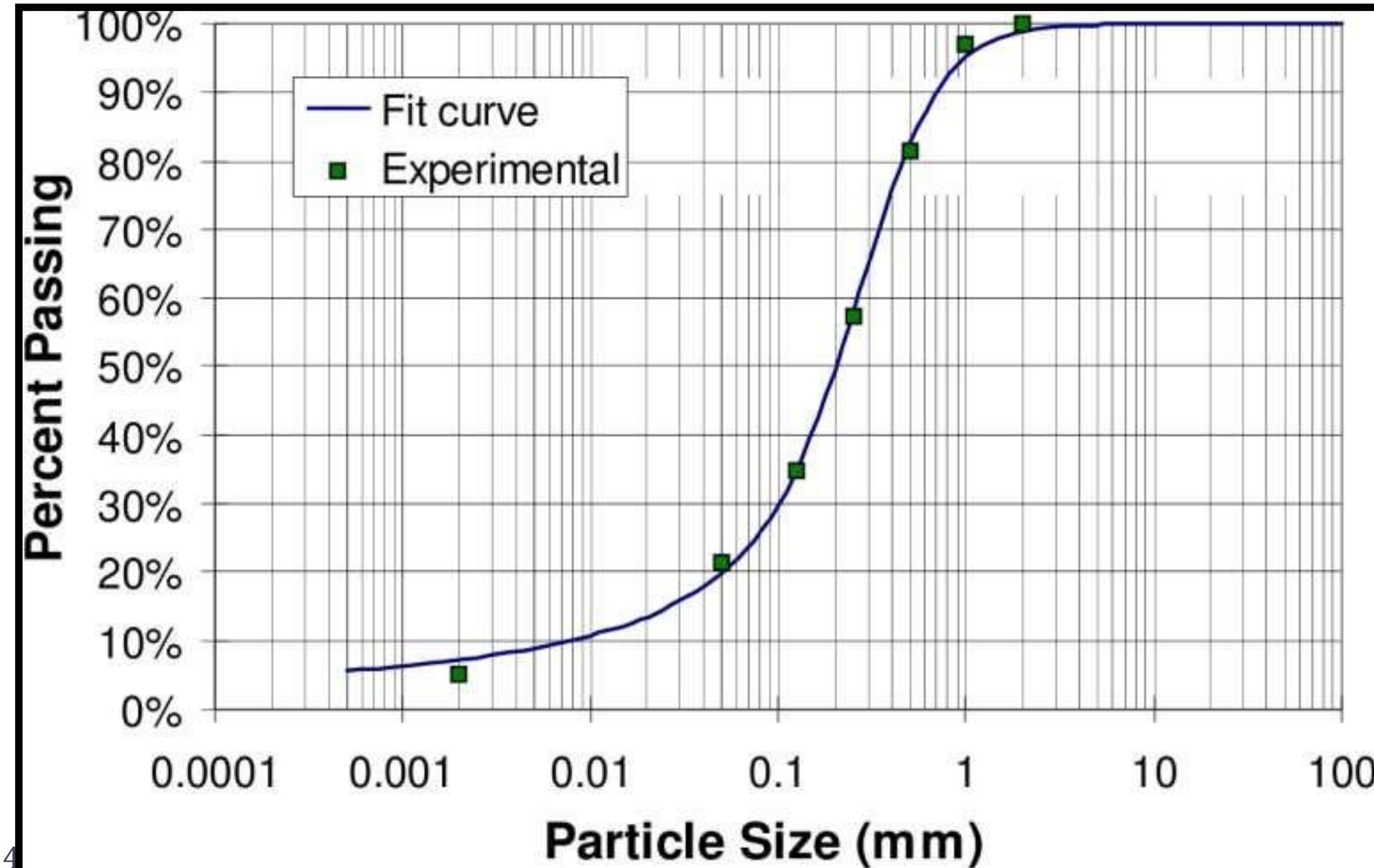
Sedimentation analysis

- Sedimentation analysis is used only for the soil fraction finer than 75 microns.
- Soil particles are allowed to settle from a suspension. The decreasing density of the suspension is measured at various time intervals.
- The procedure is based on the principle (Stoke's Law) that in a suspension, the terminal velocity of a spherical particle is governed by the diameter of the particle and the properties of the suspension.
- In this method, the soil is placed as a suspension in a jar filled with distilled water to which a deflocculating agent is added. The soil particles are then allowed to settle down. The concentration of particles remaining in the suspension at a particular level can be determined by using a hydrometer.
- Specific gravity readings of the solution at that same level at different time intervals provide information about the size of particles that have settled down and the mass of soil remaining in solution.
- The results are then plotted between **% finer (passing)** and **log size**.

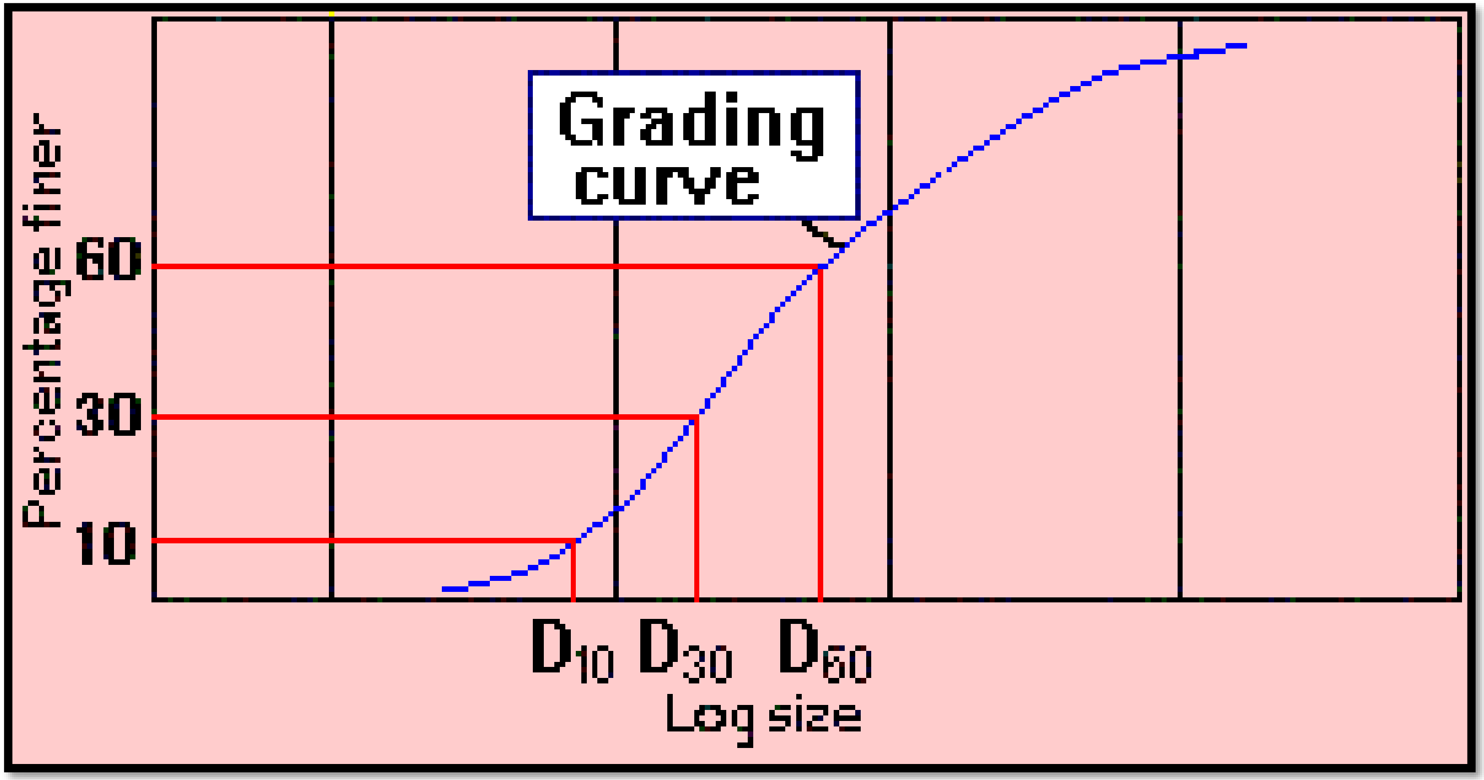
- The resulting data is presented as a distribution curve with **grain size** along x-axis (log scale) and **percentage passing** along y-axis (arithmetic scale).
- The grain size distribution curves, as obtained from coarse and fine grained portions, can be combined to form one complete **grain-size 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.



- 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



Grading Characteristics

- The grading characteristics are then determined as follows:
- **1. Effective size** = D_{10}
- **2. Uniformity coefficient,** $C_u = \frac{D_{60}}{D_{10}}$
- **3. Curvature coefficient,** $C_c = \frac{(D_{30})^2}{D_{60} . D_{10}}$
- Both $\mathbf{C_u}$ and $\mathbf{C_c}$ will be 1 for a single-sized soil.
- $\mathbf{C_u > 6}$ and $\mathbf{C_u > 4}$ indicates as **well-graded** for **Sand** and **Gravel** respectively, i.e. a soil which has a distribution of particles over a wide size range.
- $\mathbf{C_c}$ **between 1 and 3** also indicates a **well-graded** soil both for Sand and gravel.

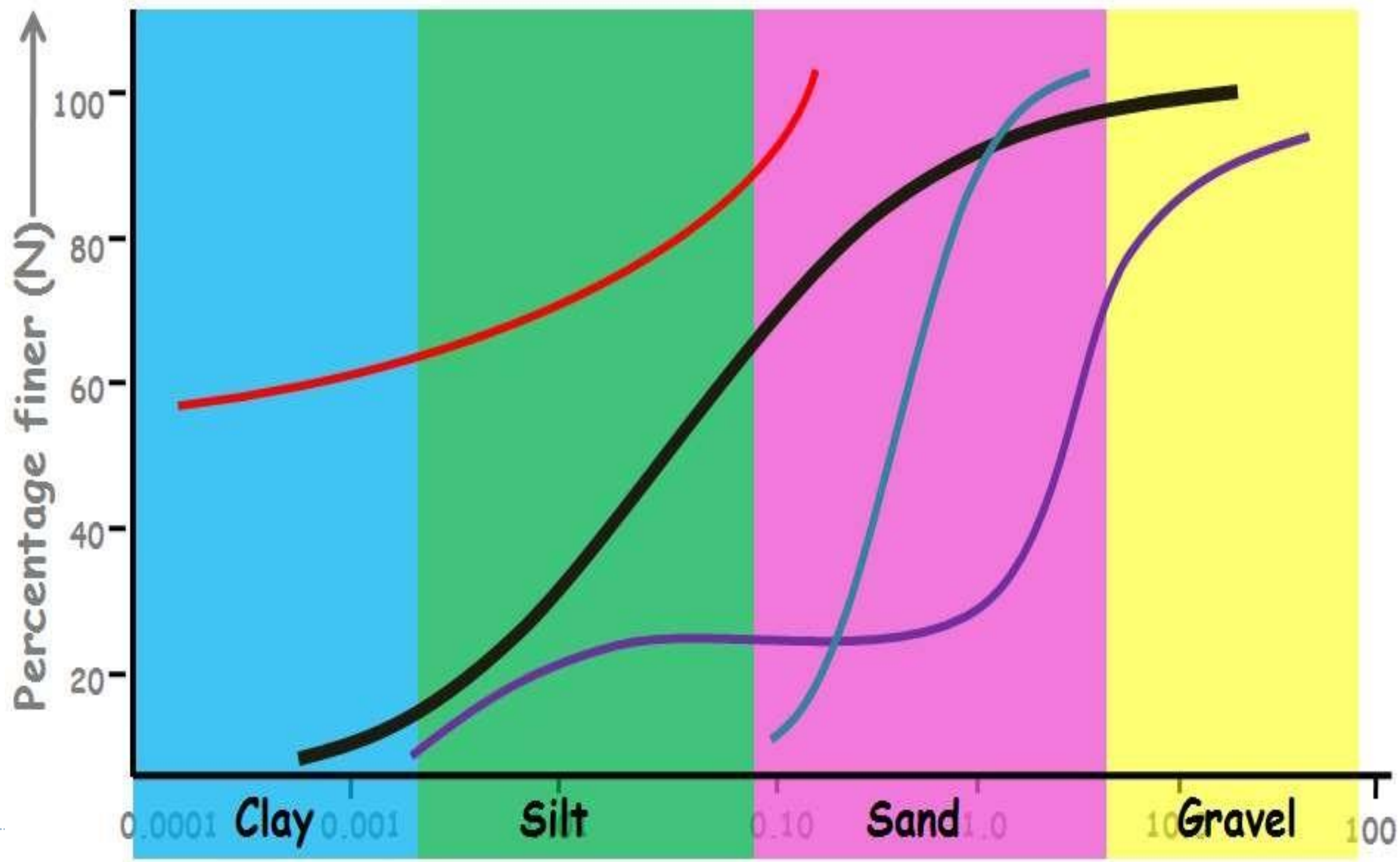
GRAIN SIZE DISTRIBUTION CURVES

There can be many others of different shapes. Each curve represents the different soil's gradation. The shapes of the curves indicate the nature of the soil tested. On the basis of the shapes we can classify soils as:

1 . Uniformly graded or poorly graded.

2. Well graded.

3. Gap graded.



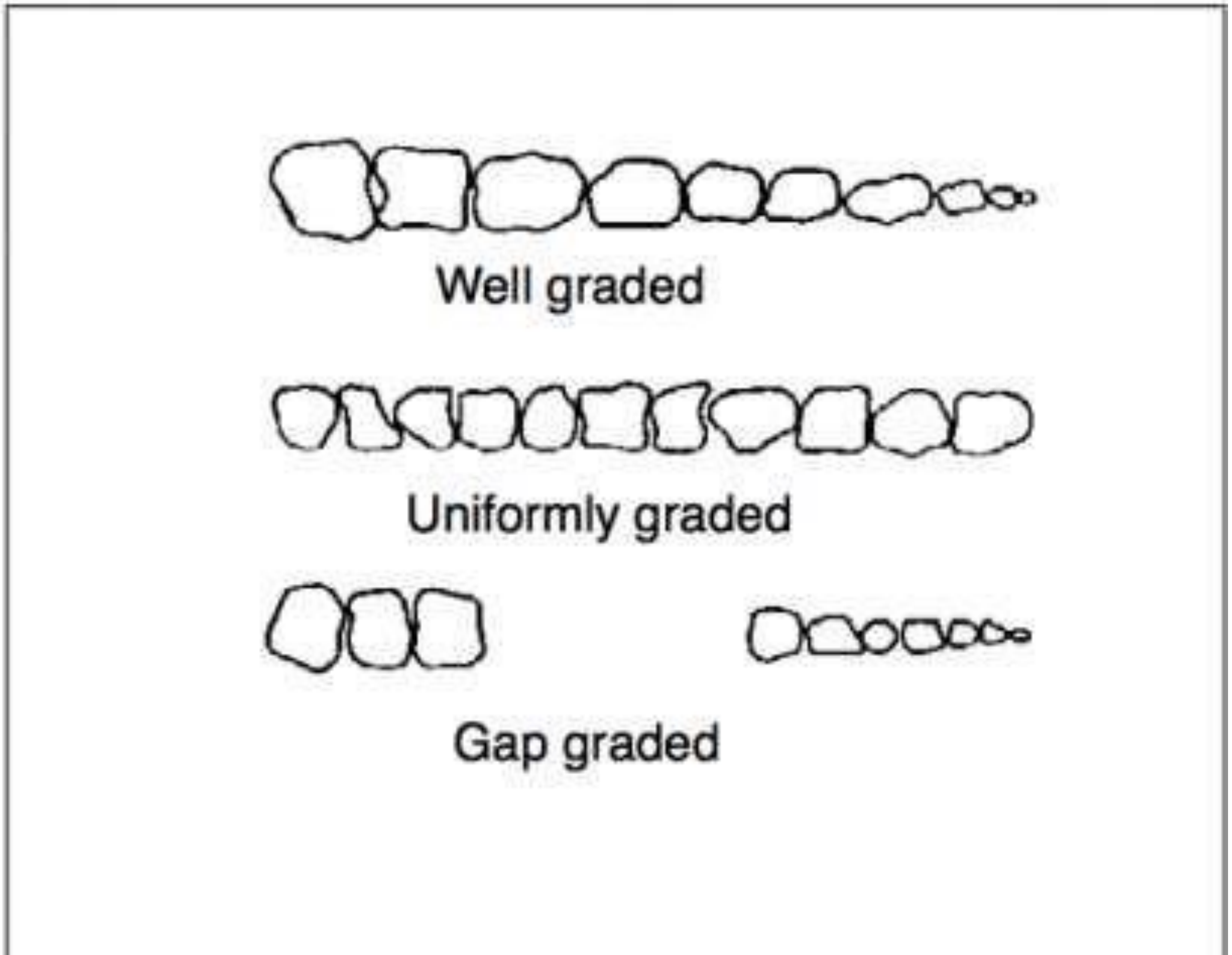
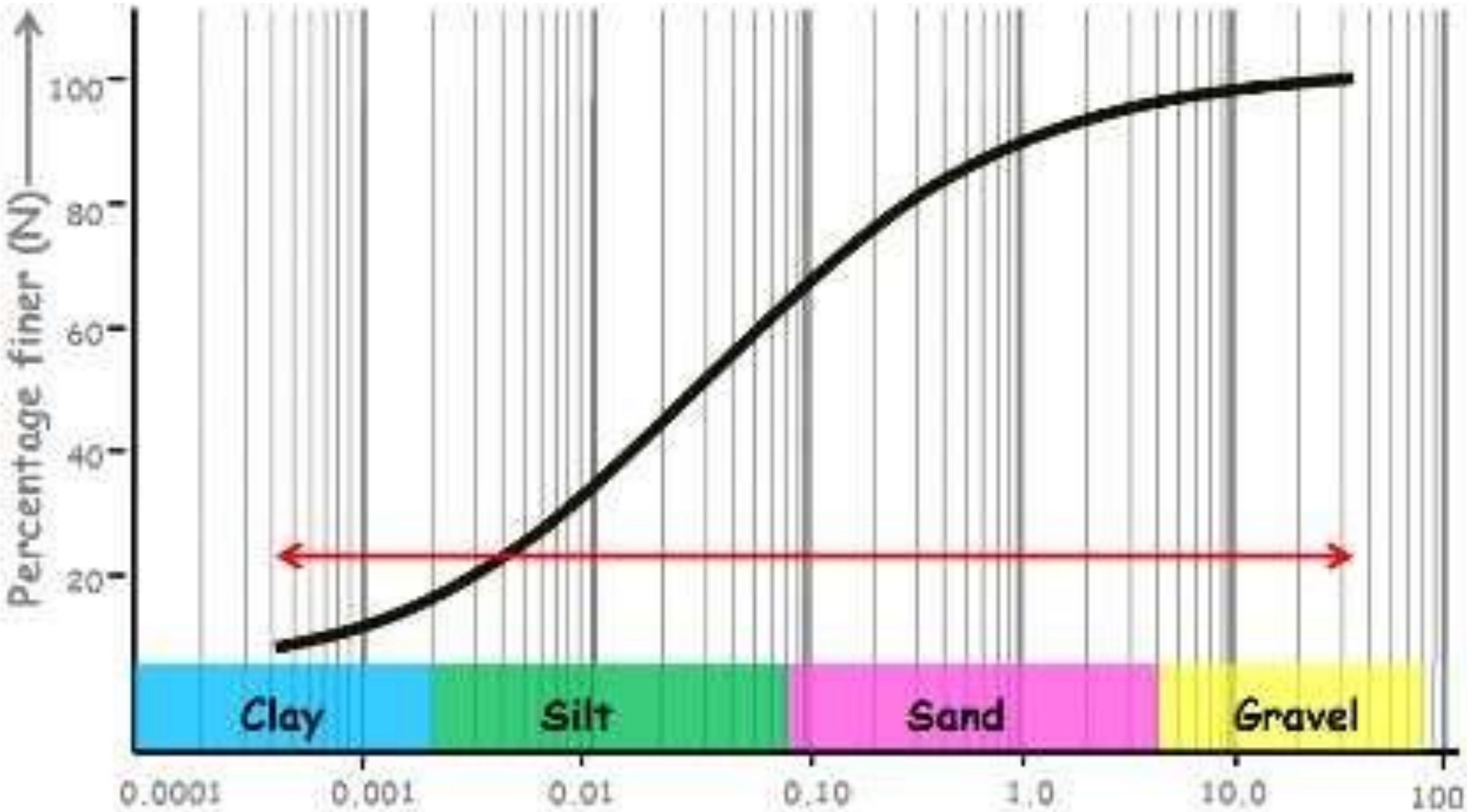
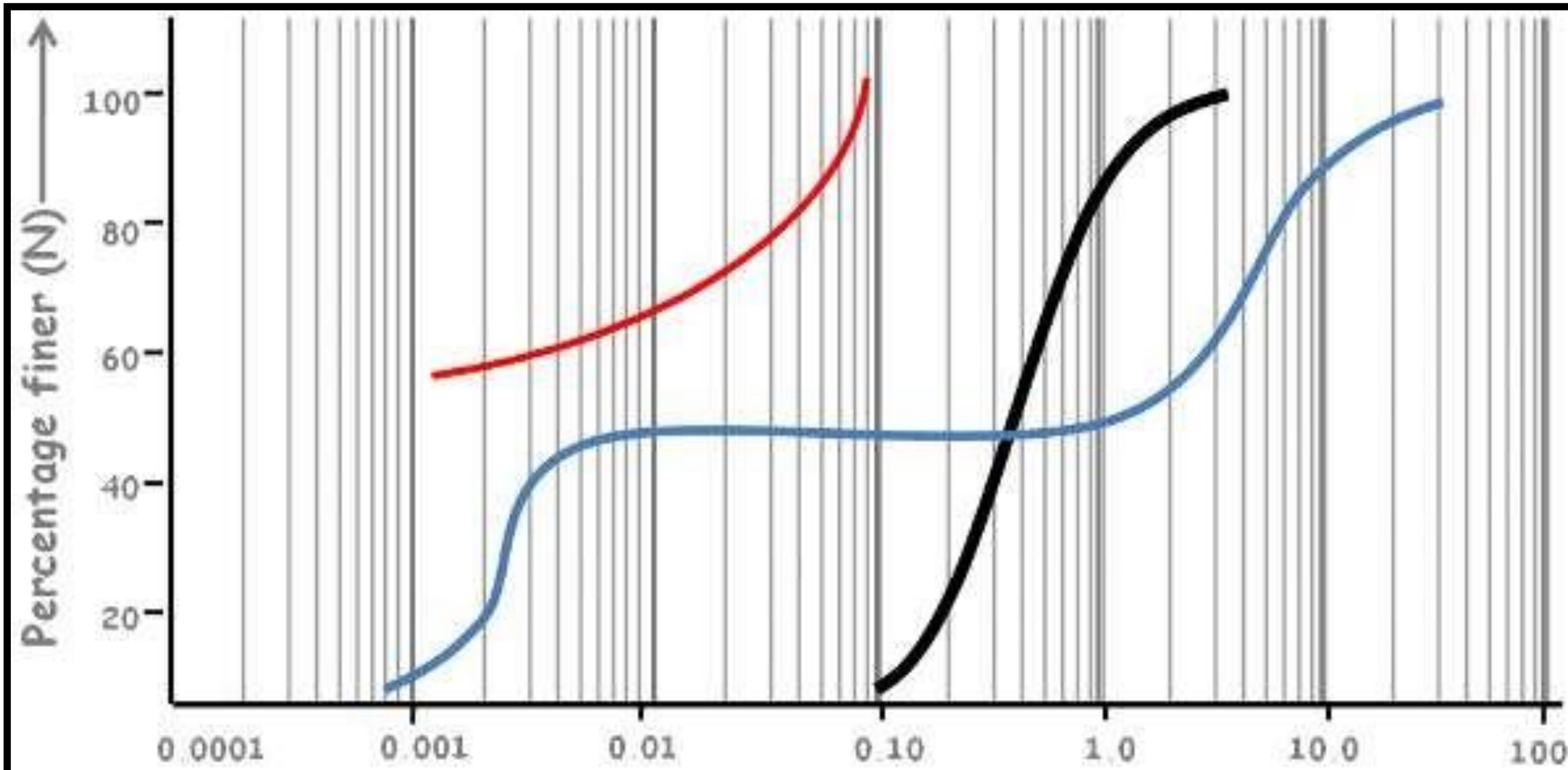


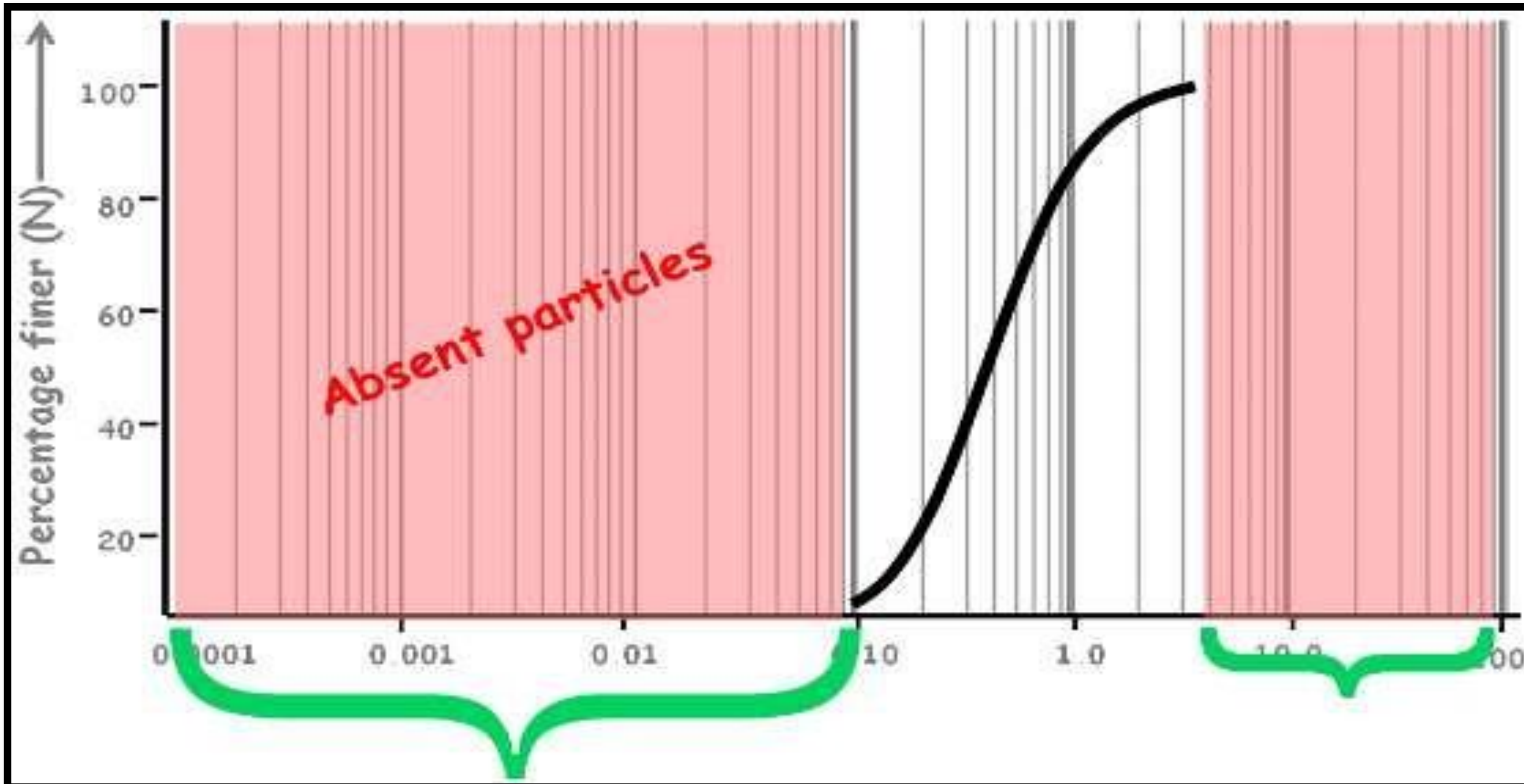
Figure 2-2. Soil gradation



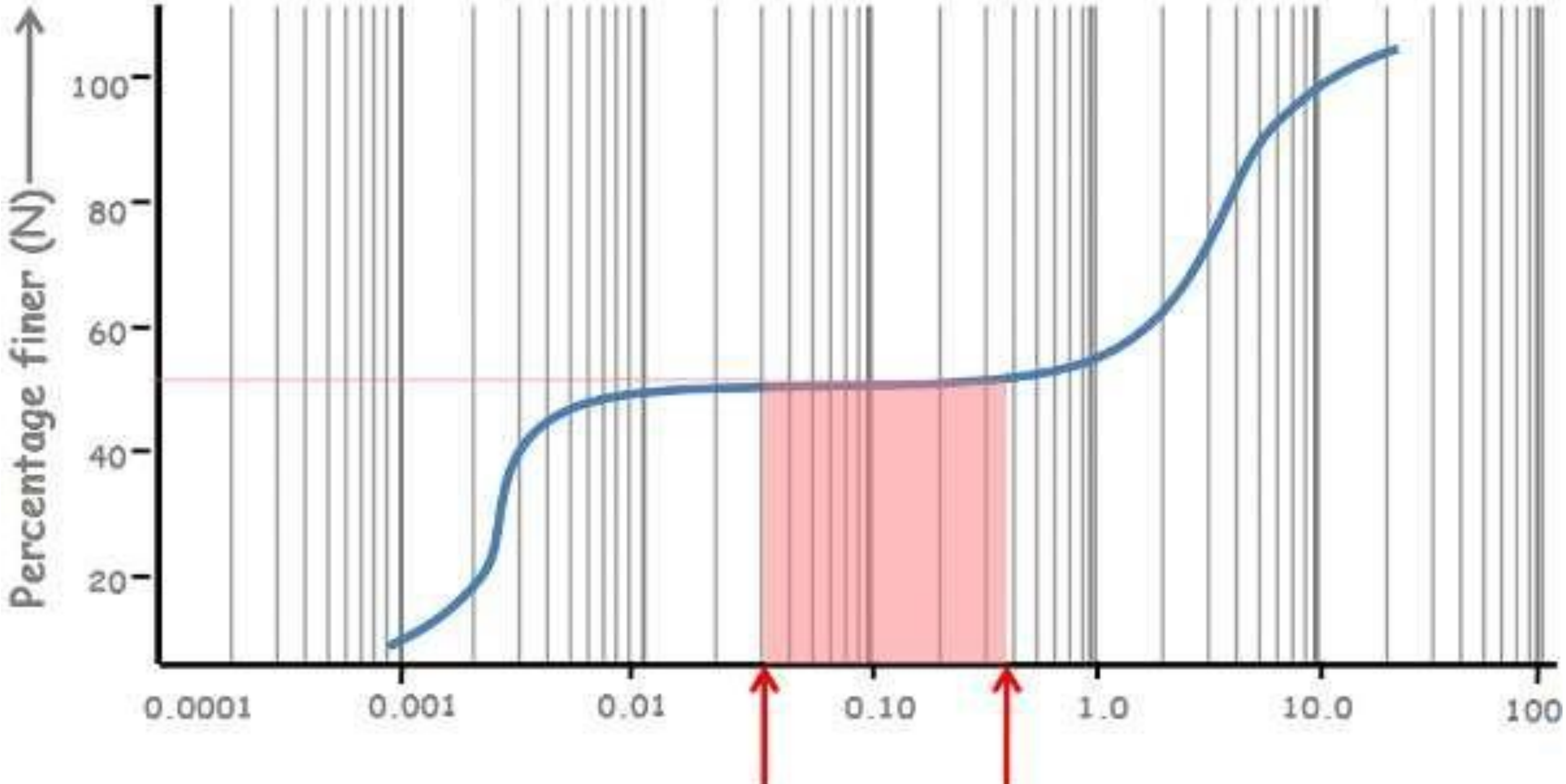
1. This shows that this particular soil graph represents a soil which **contains almost all the particles of different sizes**. That is why this curve is said to be representing a **well graded soil.**
2. Well means good and gradation means distribution of particles.

- A poorly graded soil either has a **deficiency or an excess** of certain particle sizes or has most of the particles of about same size.
- All these curves represent the **poorly graded soil**.





1. In this curve there are many particle sizes which doesn't have their representation in the soil curve hence these sized particles are not present in the soil sample. **Uniformly graded** soils are represented by nearly vertical lines
2. This clearly shows that this soil sample does not have a good representation of all particle sizes. Hence this curve is said to be representing **a poorly graded soil**.



There is one more different kind of curve in which some of the particle sizes are missing in between are called **gap graded**.

Illustrative Example 3.1. *The results of a sieve analysis of a soil are given below:*
Total mass of sample = 900 gm.

IS Sieve	20 *mm*	10 *mm*	4.75 *mm*	2 *mm*	1.0 *mm*	0.6 *mm*	4.25 μ	212 μ	150 μ	75 μ	*Pan*
Mass of soil retained (gm)	35	40	80	150	150	140	115	55	35	25	75

Draw the particle size distribution curve and hence determine the uniformity coefficient and the coefficient of curvature.

Table E-3.1

IS Sieve (1)	*Mass retained* (2)	*Percentage retained* $= \frac{(2)}{(900)} \times 100$ (3)	*Cumulative percentage retained* (4)	*Pereentage Finer (N)* = 100 – (4) (5)
20 mm	35 gm	3.89	3.89	96.11
10	40	4.44	8.33	91.67
4.75	80	8.89	17.22	82.78
2.0	150	16.67	33.89	66.11
1.0	150	16.67	50.56	49.44
0.6	140	15.56	66.12	33.88
425 μ	115	12.78	78.90	21.10
212 μ	55	6.11	85.01	14.99
150 μ	35	3.89	88.90	11.10
75 μ	25	2.78	91.68	8.32
Pan	75	8.32	100.00	

Σ = 900.0 gm

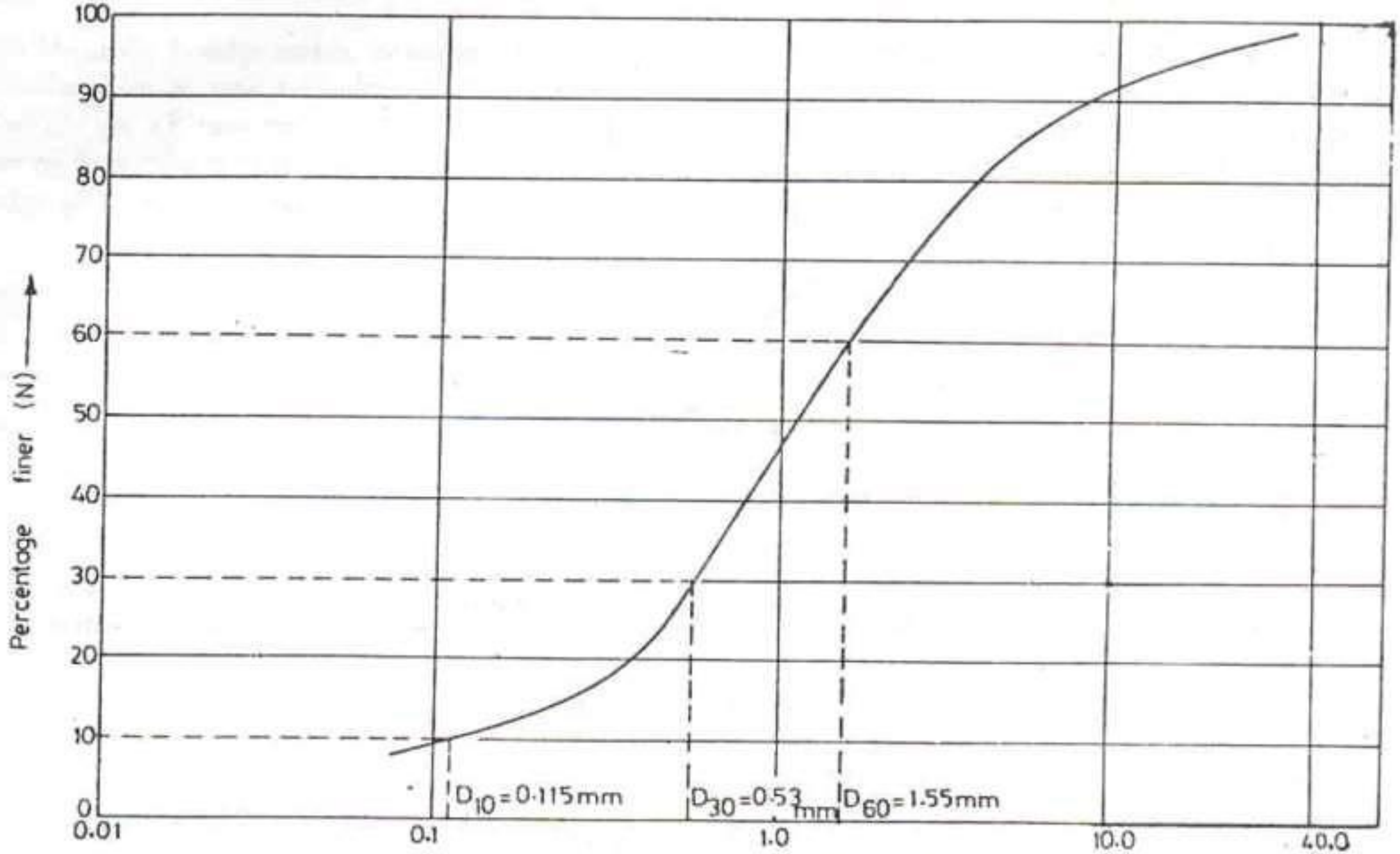


Fig. E-3.1 Particle size (mm)

From plot, D_{60} = 1.55 mm; D_{30} = 0.53 mm; D_{10} = 0.115 mm

$$C_u = \frac{D_{60}}{D_{10}} = \frac{1.55}{0.115} = 13.48$$

$$C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}} = \frac{(0.53)^2}{1.55 \times 0.115} = 1.58$$

Atterberg Limits

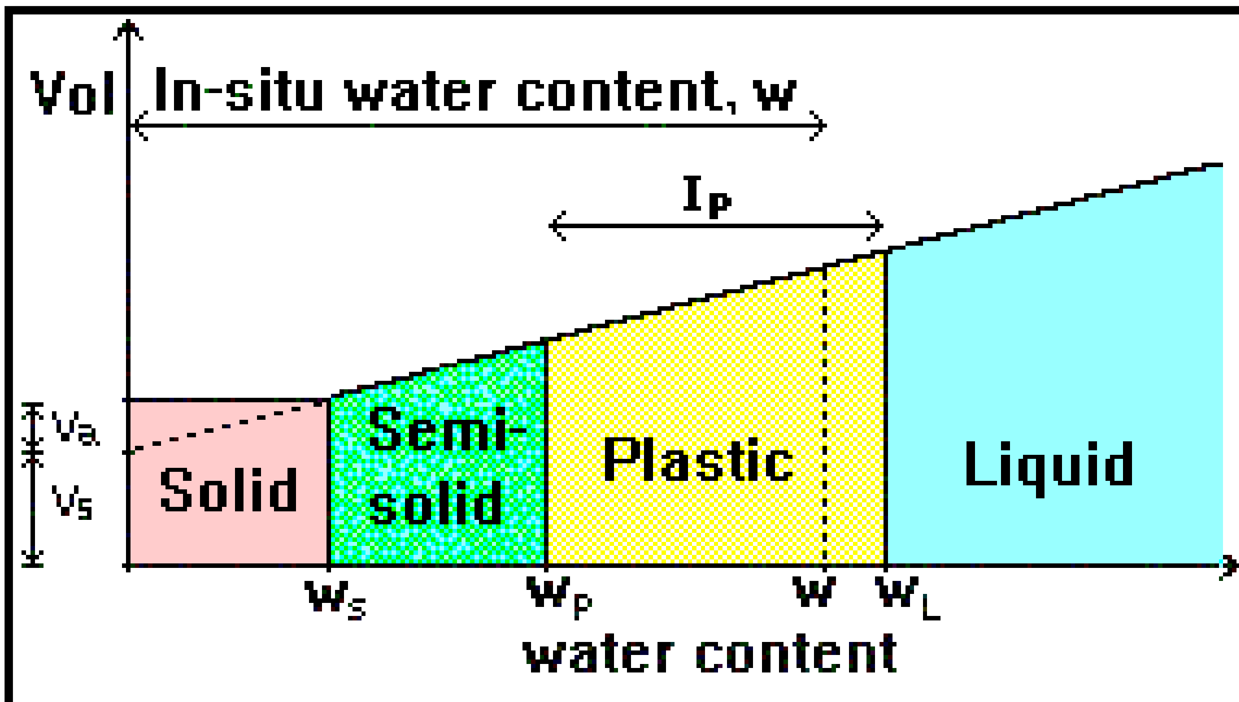
Consistency of Soils

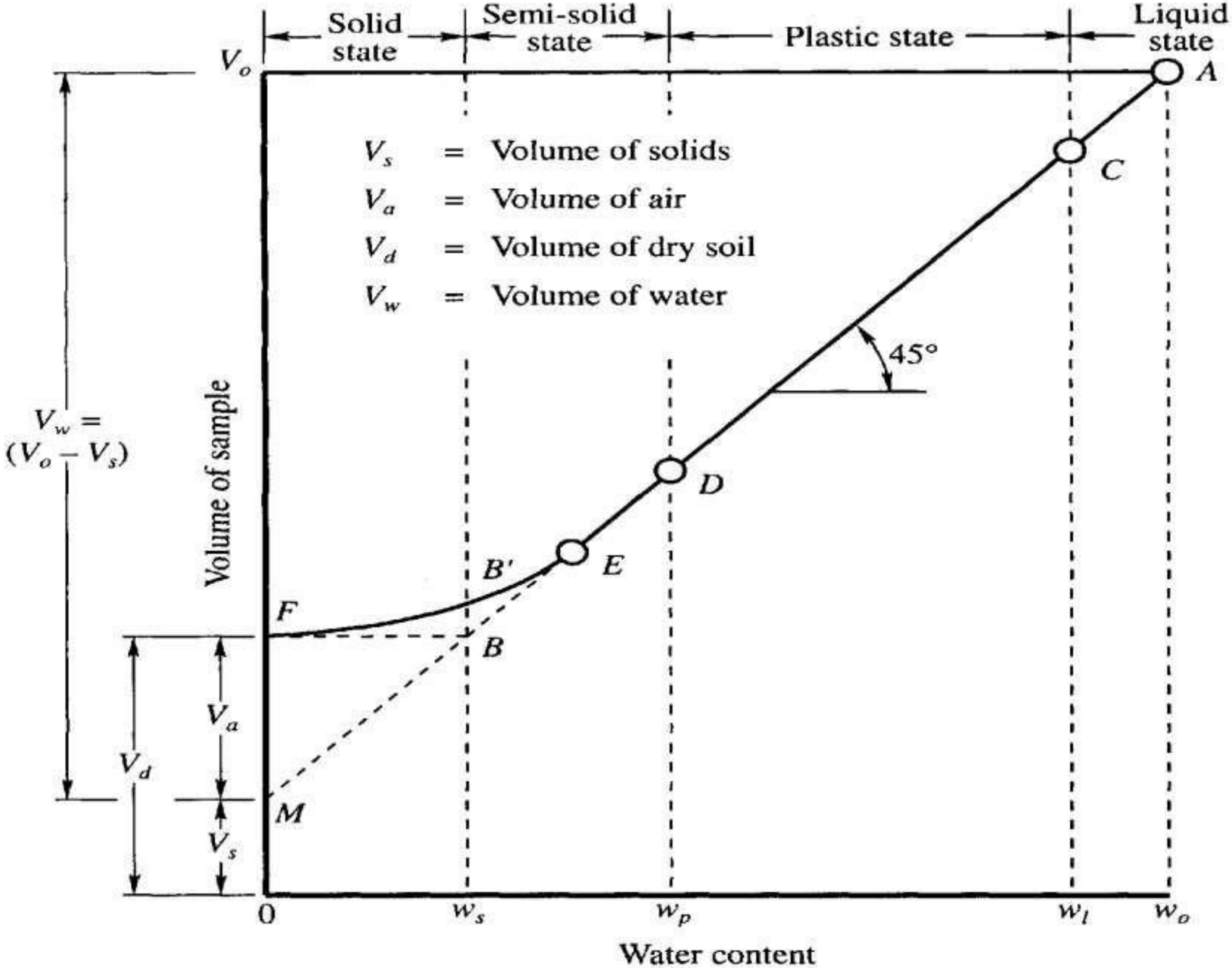
- The **consistency** of a fine-grained soil refers to its firmness, and it varies with the water content of the soil.
- The consistency of natural cohesive soil deposits is expressed qualitatively by such terms as very soft, soft, stiff, very stiff and hard.
- The physical properties of clays greatly differ at different water contents.
- A soil which is very soft at a higher percentage of water content becomes very hard with a decrease in water content.
- However, it has been found that at the same water content, two samples of clay of different origins may possess different consistency. One clay may be relatively soft while the other may be hard.
- Further, a decrease in water content may have little effect on one sample of clay but may transform the other sample from almost a liquid to a very firm condition.
- Water content alone, therefore, is not an adequate index of consistency for engineering and many other purposes.

- Consistency of a soil can be expressed in terms of:
  - Atterberg limits of soils
  - Unconfined compressive strengths of soils.

- 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 ($\mathbf{w_S}$), plastic limit ($\mathbf{w_P}$), and liquid limit ($\mathbf{w_L}$) as shown. The values of these limits can be obtained from laboratory tests.





Solid state
Semi-solid state
Plastic state
Liquid state
V_o
A
C
V_s = Volume of solids
V_a = Volume of air
V_d = Volume of dry soil
V_w = Volume of water
45°
$V_w = (V_o - V_s)$
Volume of sample
D
E
B'
F
B
V_a
V_d
M
V_s
0
w_s
w_p
w_l
w_o
Water content

- The transition state from the liquid state to a plastic state is called the ***liquid limit*, $\mathbf{w_L}$**. *At this* stage all soils possess a certain small shear strength (2.7kPa). This arbitrarily chosen shear strength is probably the smallest value that is feasible to measure in a standardized procedure.
- The transition from the plastic state to the semisolid state is termed *the* ***plastic limit*, $\mathbf{w_P}$** . *At this state the soil rolled* into threads of about 3 mm diameter just crumbles.
- Further decrease of the water contents of the same will lead finally to the point where the sample can no further decrease in volume. At this point the sample begins to dry at the surface, saturation is no longer complete, and further decrease in water in the voids occurs without change in the void volume. The color of the soil begins to change from dark to light. This water content is called the ***shrinkage limit*, $\mathbf{w_S}$**.
- The limits expressed above are all expressed by their percentages of water contents.

- Two of these are utilized in the classification of fine soils: **Liquid limit** ($\mathbf{w_L}$) - change of consistency from plastic to liquid state **Plastic limit** ($\mathbf{w_P}$) - change of consistency from brittle/crumbly to plastic state
- The difference between the liquid limit and the plastic limit is known as the **plasticity index** ($\mathbf{I_P}$), 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.

$$\mathbf{I_P = w_L - w_P}$$

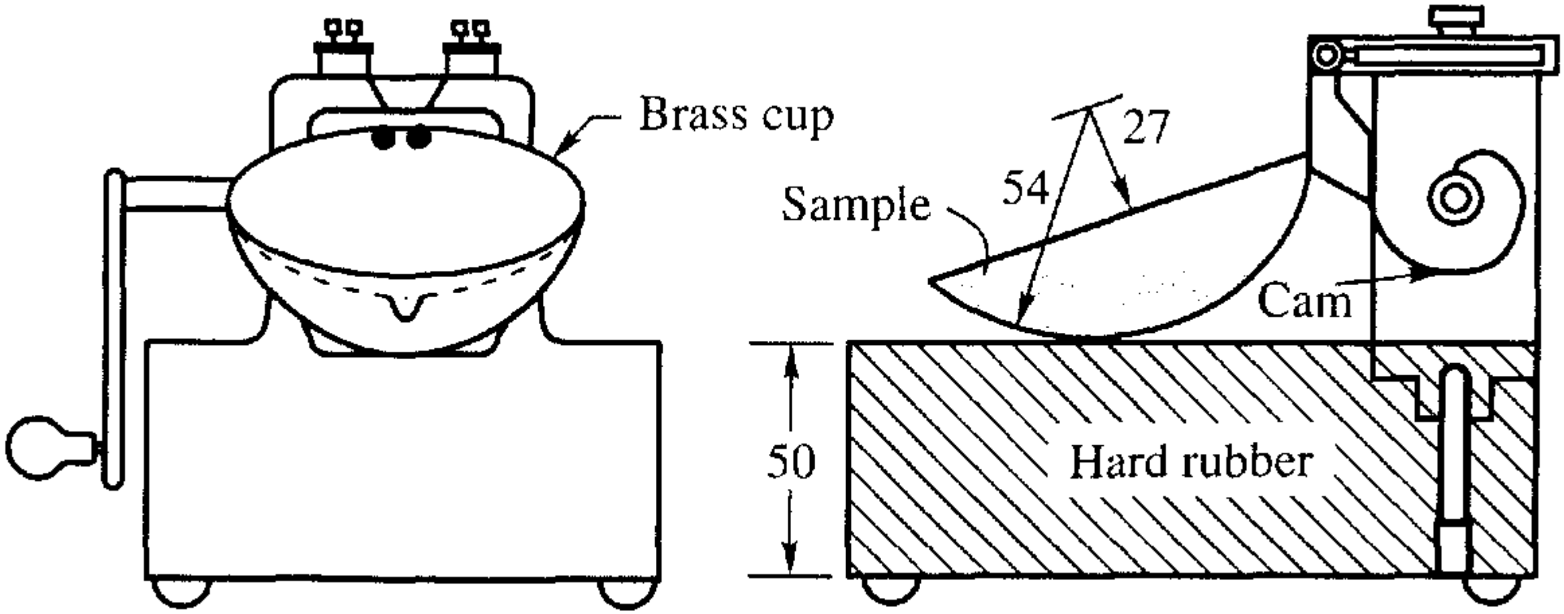
DETERMINATION OF ATTERBERG LIMITS

- We can determine **liquid limit** by two laboratory methods.
- 1. Casagrande Method

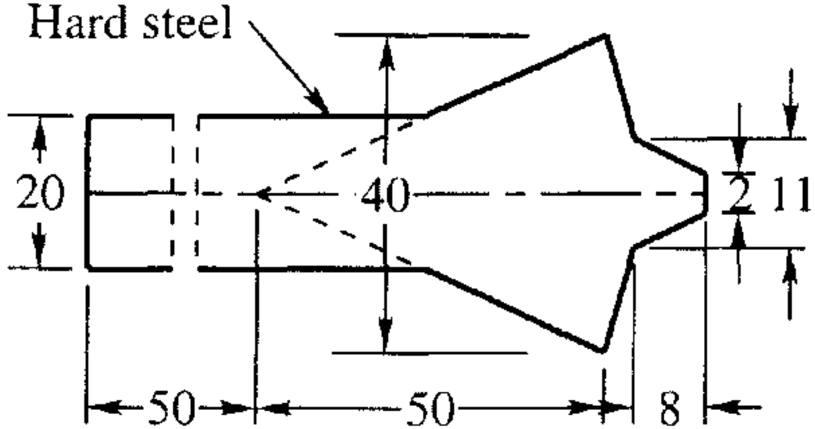
2. Cone penetration Method

1. Casagrande Method

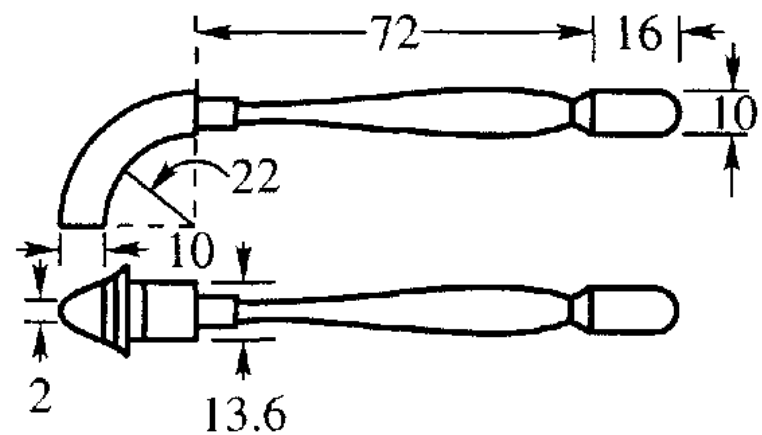
- The device contains a brass cup which can be raised and allowed to fall on a hard rubber base by turning the handle. The cup is raised by **1 cm.**
- To begin with the soil sample is taken and air dried. Then it is passed through 425 micron IS sieve to get fine grained soil only. These particles include fine sand, silts and clays.
- Take about 120 gm of this sieved soil in a dish and mix it with distilled water to form a uniform soil paste.
- A portion of this soil paste is placed in the cup of Casagrande apparatus and the surface is smoothened and leveled.
- Then a sharp groove is cut symmetrically through the sample using a standard grooving tool.
- There are two types of standard grooving tools available. One is **Casagrande tool** and other is **ASTM tool.**
- Casagrande tool cuts the groove of width 2 mm at the bottom and 11 mm at the top and 8 mm deep.
- ASTM tool cuts the groove of width 2 mm at the bottom, 13.6 mm at the top and 10 mm deep.



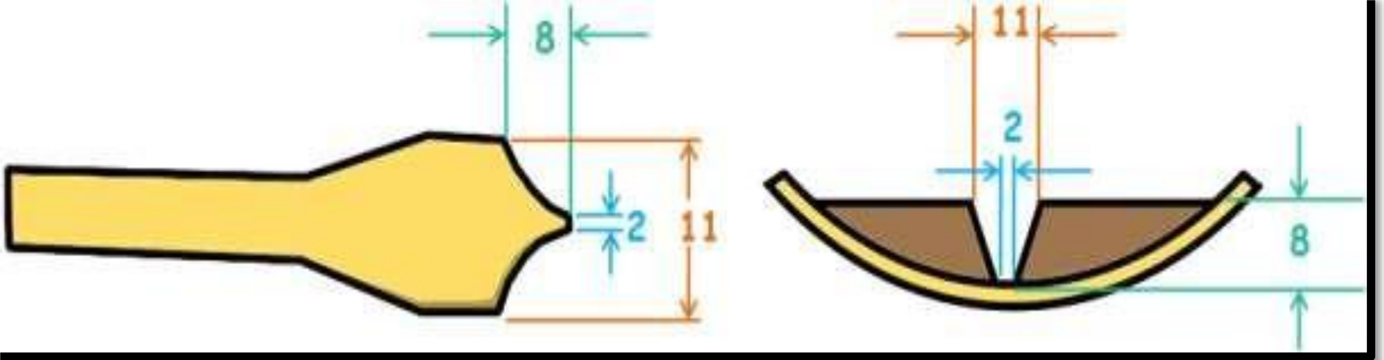
Liquid limit device



Casagrandes grooving tool

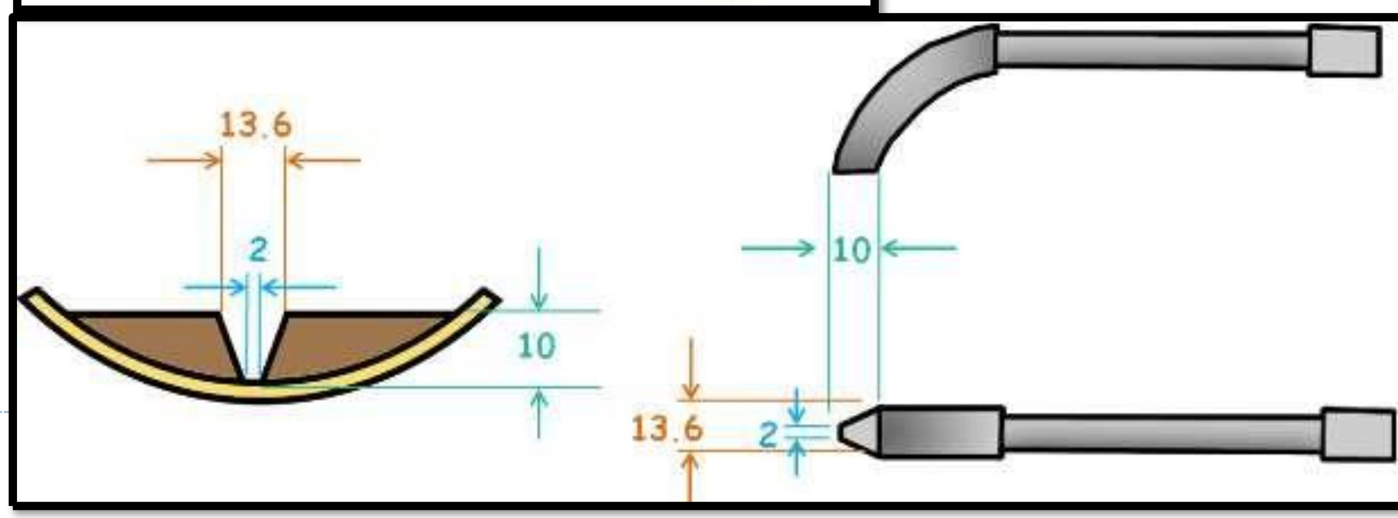


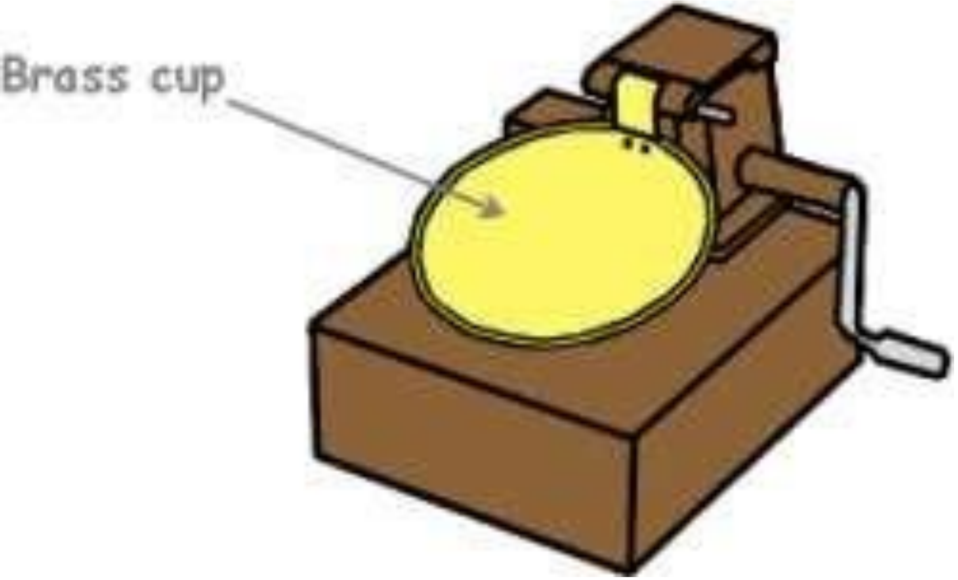
ASTM grooving tool

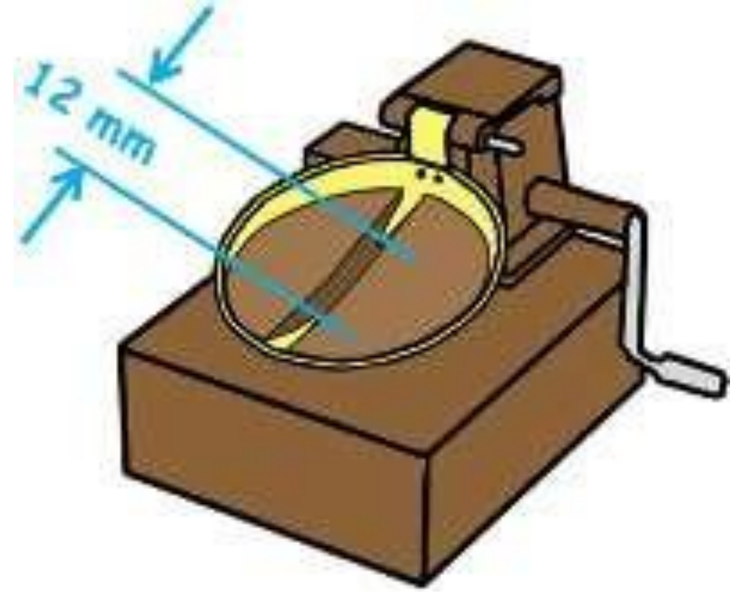


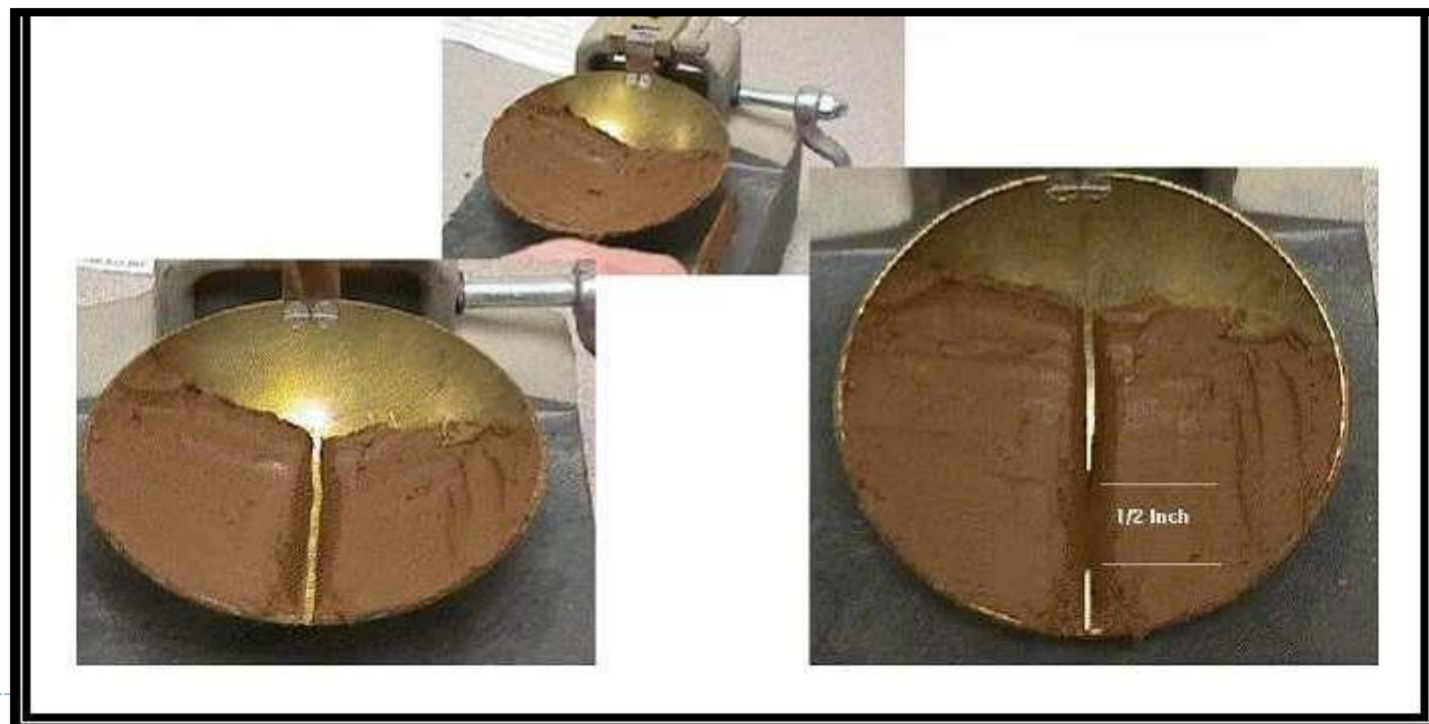
Casagrande tool

ASTM tool



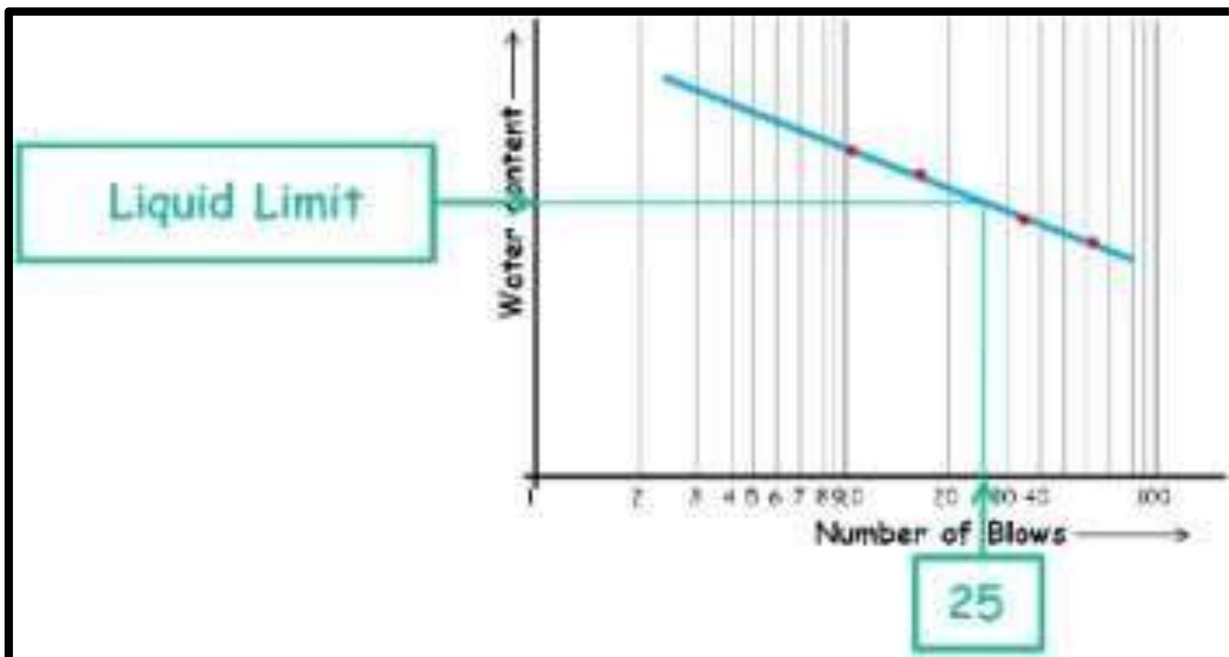

Brass cup


12 mm


1/2 Inch

- The Casagrande tool is recommended for normal fine grained soils.
- After the soil pat has been cut the handle of the apparatus is turned at a **rate of 2 revolutions per second**, which applies blows to the grooved soil pat. And due to which two halves of the soil pat comes into contact. And when the **contact length of 12 mm** is achieved we stop turning the handle.
- We should take care that the groove should close by flow of soil not by slippage of it. And if slippage occurs then we should discard that soil pat and re-do the whole procedure.
- The number of blows required to close the groove for the length of 12 mm is noted as **N1**.
- About 10 gm of soil near the closed groove is taken for the water content determination. Water content is determined using any of the water content determination methods. Determined water content is noted as **w1**.
- The experiment is repeated after adding more water to the soil and each time recording the number of blows to close the groove for a distance of 12 mm and determining the corresponding water content.
- **The liquid limit has been defined as the water content of the soil at which the groove closes to 12 mm in 25 number of blows.**
- The test is conducted for different water contents so as to get the number of blows in the range of **10 to 40.**

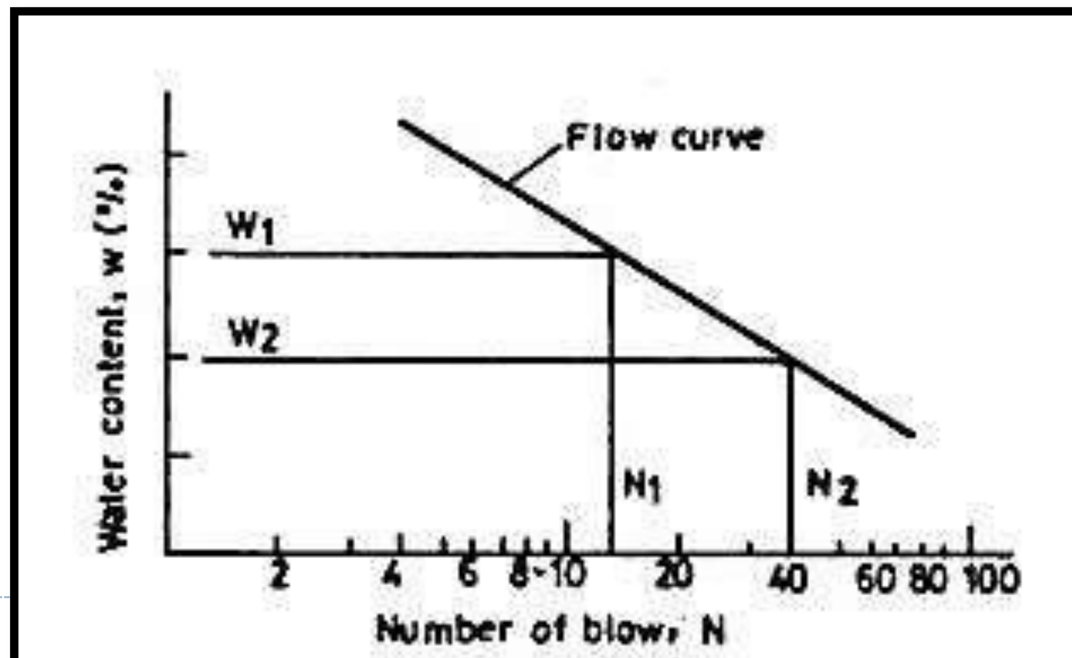
- Soil with low water content would yield more number of blows as the soil paste will be stiffer and soil with higher water content would yield less number of blows.
- We plot a graph between these experimentally obtained values of number of blows and their corresponding water content. Number of blows are plotted on log scale.
- A best-fitting curve is drawn through the experimental points. And we will observe the graph will be approximately a straight line. This curve is known as Flow Curve of soil.
- The water content corresponding to 25 blows is read from the graph (flow curve) and is taken as the liquid limit.
- The liquid limit is expressed as the nearest whole number.



Flow Index (I_f)

- The flow curve (straight line) plotted on semi-logarithmic graph shall be extended at either end so as to intersect the ordinates corresponding to 10 and 100 drops.
- The slope of this line expressed as the difference in water contents as 10 drops and at 100 drops shall be reported as the flow index.
- The flow index may be calculated from the following equation also:

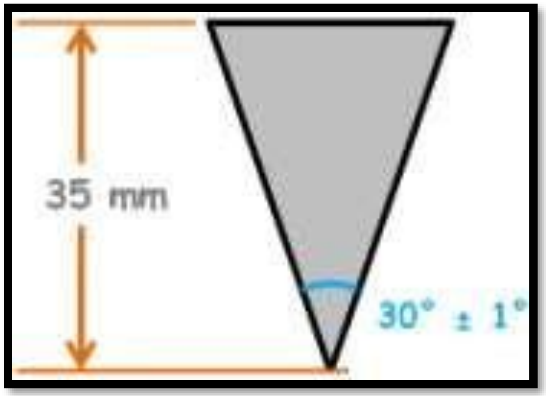
$$\mathbf{I_f = (w_1 - w_2) / \log_{10} (N_2 / N_1)}$$

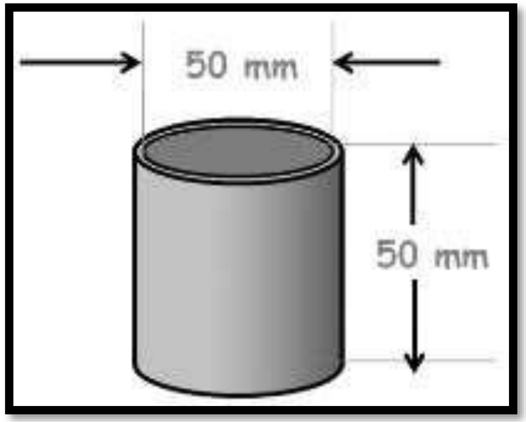


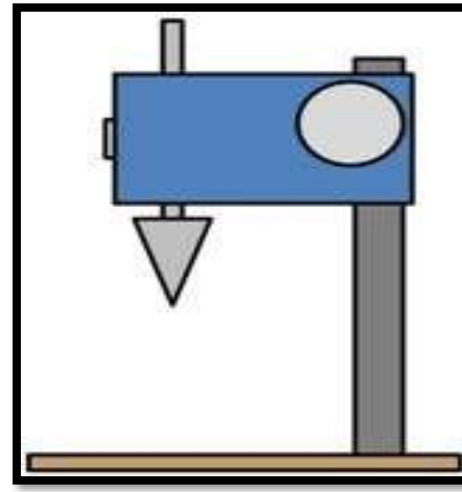
2. Cone Penetrometer

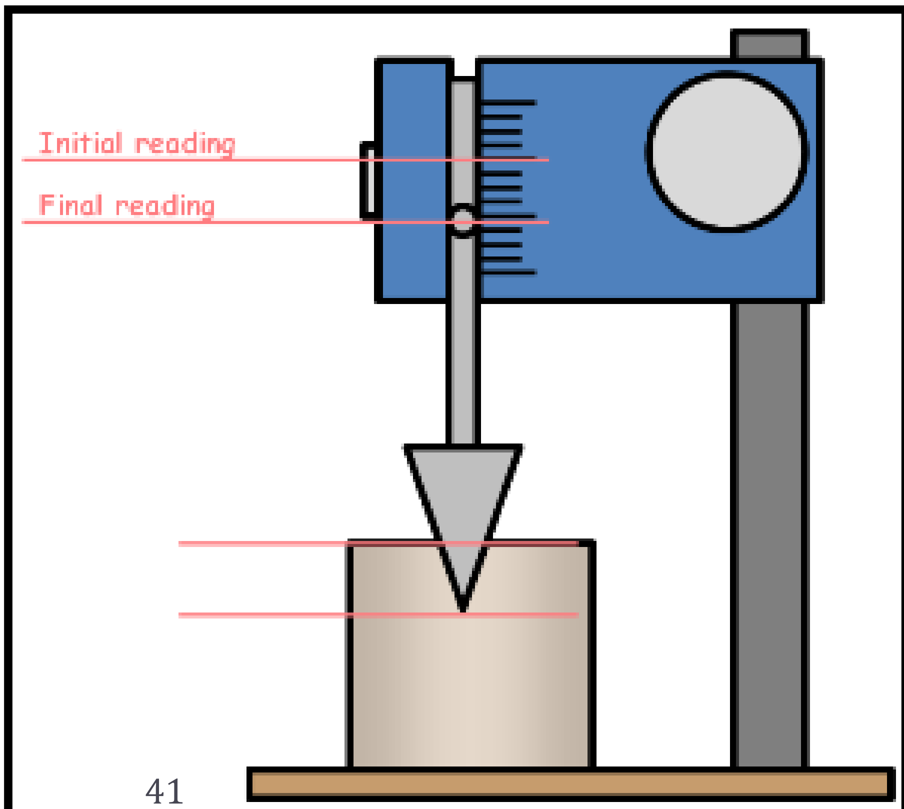
- It consists of a stainless steel cone which has its apex angle of 30°.
- This cone has a length of 35 mm.
- It is attached to the base of a steel plunger rod. Weight of this assembly is 80 gm.
- This arrangement can slide vertically on pressing a push button. And it all fixed to a stand with a base by a clamping screw.
- There is also a graduated scale attached to the instrument to take the readings of the amount of cone penetration.
- In this test, the liquid limit is correlated to the penetration of a freely falling calibrated cone into the wet soil mass.
- The soil sample is prepared in the similar manner as we did for the Casagrande Method.

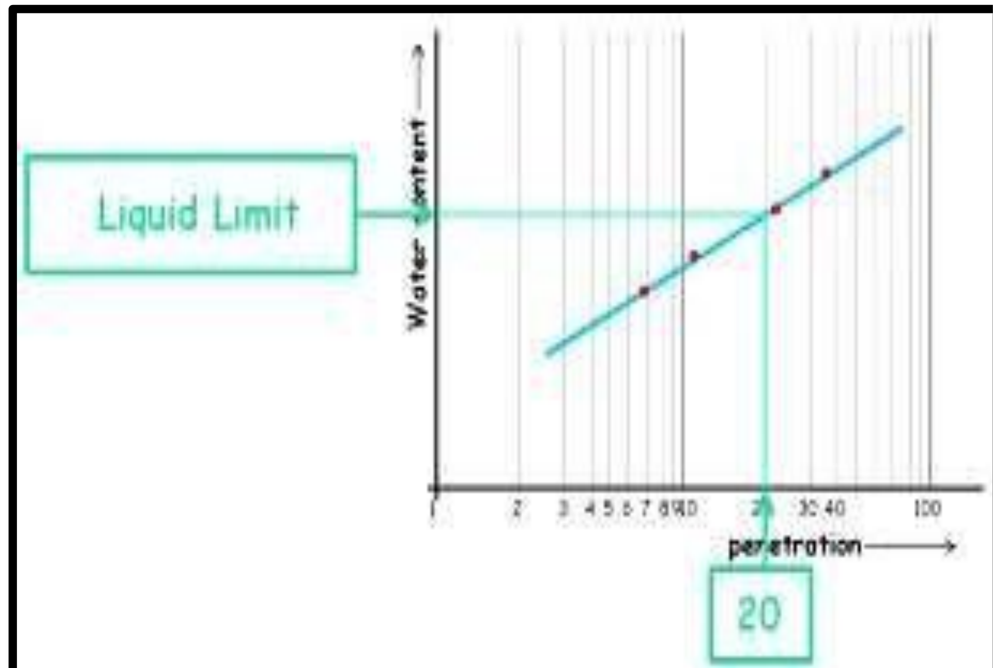
- We take about 150 g of this sieved soil in evaporating dish and thoroughly mix distilled water to form a uniform paste.
- Enough amount of soil is placed in the brass cup of 50 mm internal diameter and 50 mm height. We need to ensure that no air is entrapped in the cup. Surface of the soil is leveled and the cup is placed below the cone.
- The cone is gradually lowered so as to just touch the surface of the soil in the cup. On the Graduated scale reading is noted as the initial reading.
- The cone is allowed to penetrate the soil for 5 seconds. After 5 seconds the reading on the graduated scale in noted down as the final reading.
- The depth up to which the cone has penetrated the soil sample can be known by the difference of the initial and final reading of the scale.
- The penetration is noted down to the nearest millimeter. Let's say this penetration is P_1 mm.
- Some amount of soil is taken from the top of the cup and its water content is determined using any of the water content determination methods. Say the determined water content is w_1.
- ***Liquid limit of a particular soil is defined as the water content at which cone penetrates the soil up to 20 mm in 5 seconds***


35 mm
30° ± 1°


50 mm
50 mm



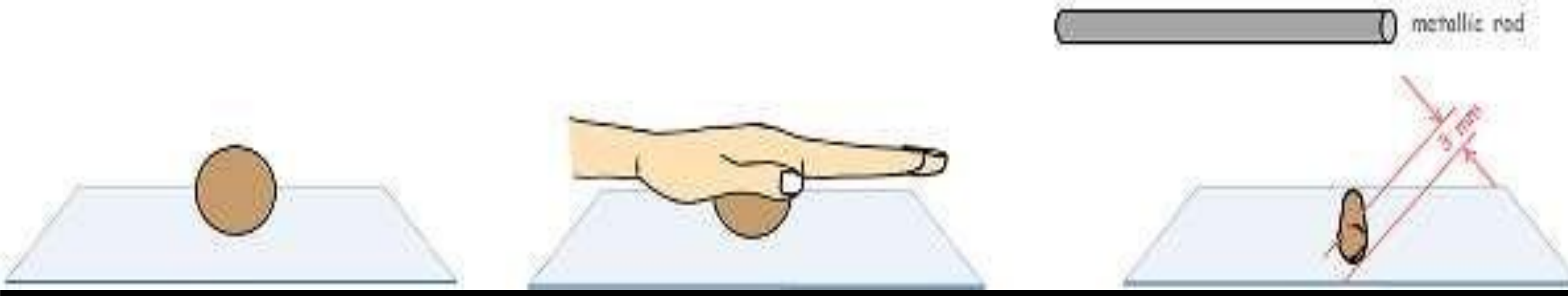

Initial reading
Final reading

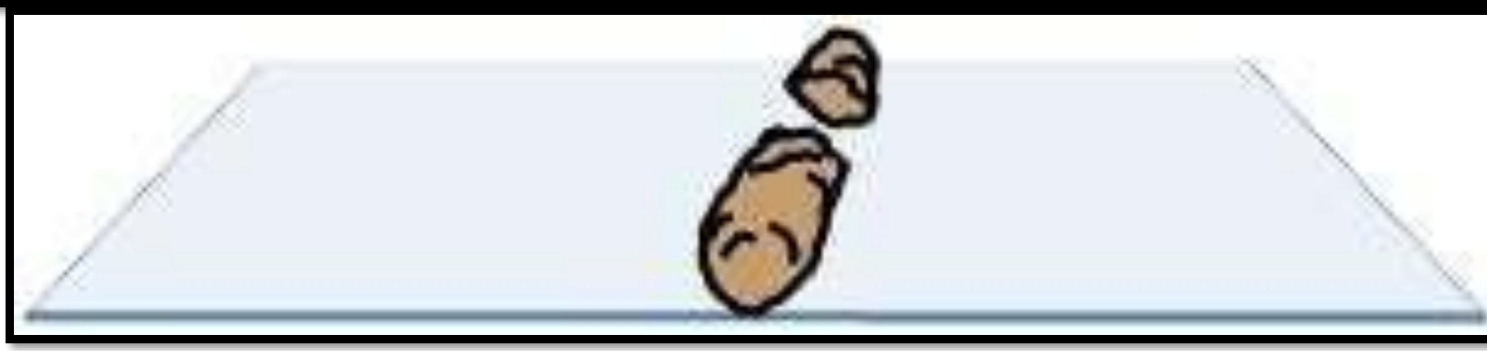

Liquid Limit
Water content
penetration
20

- The remaining soil in the cup is removed and mixed in the dish again. The cup and the cone are cleaned.
- Now we add more water to the soil, and again make a uniform paste. Then we repeat the experiment and the values of penetration (P_2, P_3, P_4) and their corresponding water contents (w_2, w_3, w_4) are determined.
- Soil with low water content would yield less penetration value as the soil paste will be stiffer and soil with higher water content would yield higher penetration value.
- Using these values we plot a graph. Water content is plotted on normal scale and penetration is plotted on log scale. A best-fitting line is drawn through these experimental points.
- Now from this graph the water content value corresponding to 20 mm of cone penetration is read and that value is taken as the liquid limit of that soil.
- The liquid limit is expressed as the nearest whole number.

Determination of plastic limit

- About 30 gm of 425micron sieved soil is taken in an evaporating dish. It is thoroughly mixed with distilled water till it is reached at a consistency at which it can be rolled without sticking to the hands.
- The soil is rolled on a glass plate with the hand, until it is about 3 mm in diameter.
- This procedure of mixing and rolling is repeated till the soil shows signs of crumbling.
- The water content of the crumbled portion of the thread is determined. This is called the plastic limit.
- If rolled soil thread does not crumble while reaching at 3 mm diameter then it is kneaded into ball again and its water content is reduced by continuously spreading and mixing the soil on the glass plate.
- After that soil is re-rolled into a thread and the procedure of kneading and rolling is repeated until the thread begins to crumble.

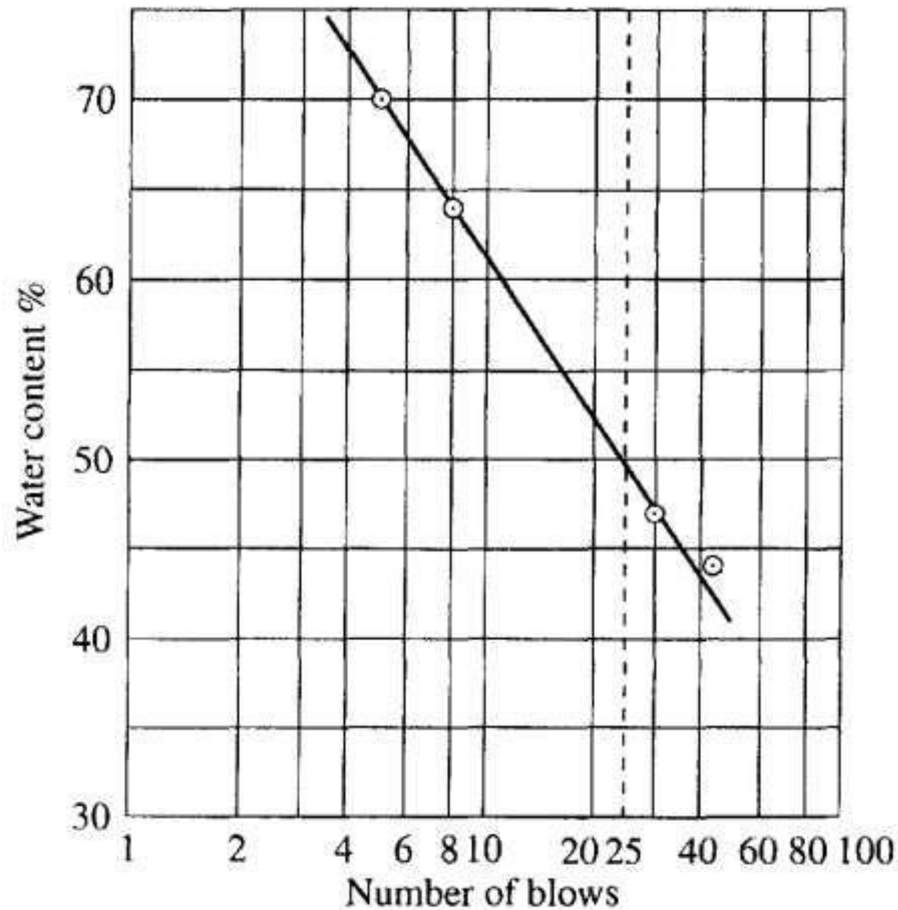

metallic rod
3 mm



Liquid limit tests on a given sample of clay were carried out. The data obtained are as given below.

Test No.	1	2	3	4
Water content, %	70	64	47	44
Number of blows, N	5	8	30	45

Draw the flow curve on semi-log paper and determine the liquid limit and flow index of the soil.

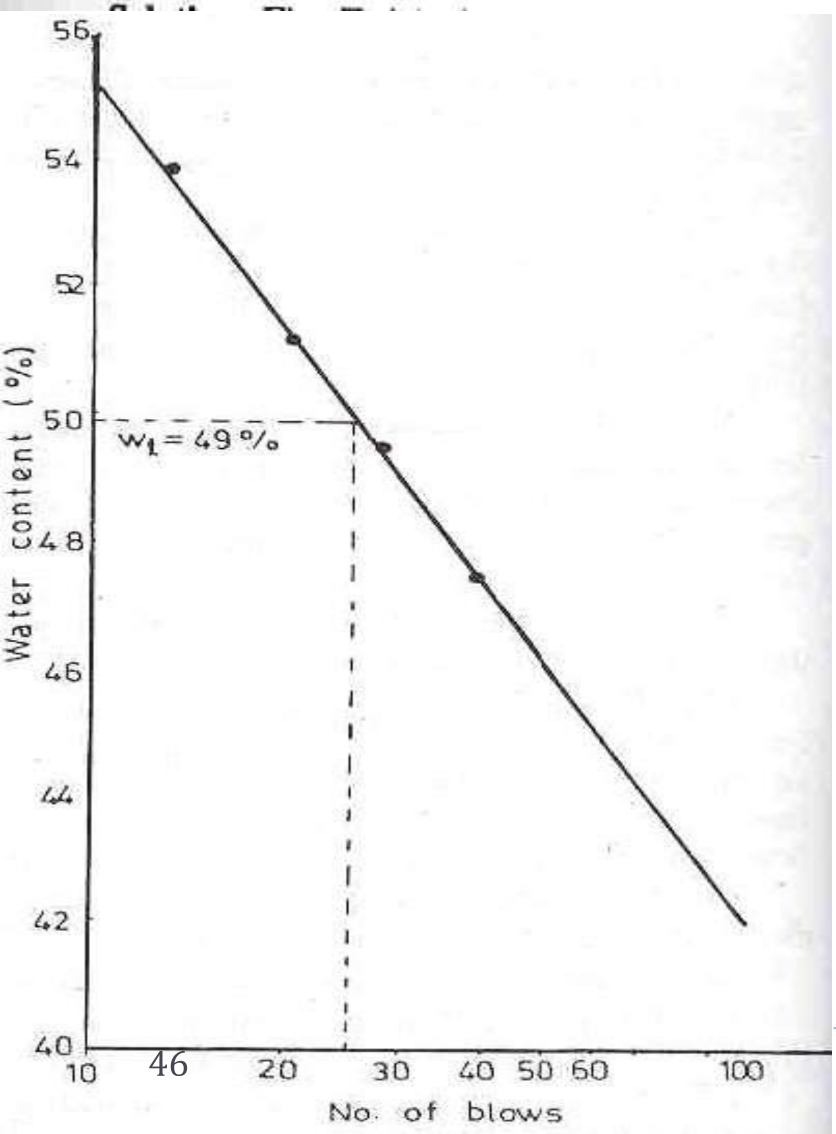


Liquid limit, $w_l = 50\%$

Flow index, $I_f = 29$

Illustrative Example 4.1. *A test for the determination for the liquid limit was carried on a soil sample. The following sets of observations were taken. Plot the flow curve and determine the liquid limit and the flow index.*

No. of Blows (N)	38	27	20	13
Wateer content (w) %	47.5	49.5	51.9	53.9



For $N = 25$, $w_l = 49\%$.

$$\text{for } \frac{N_2}{N_1} = \frac{100}{10} = 10.$$

$$I_f = w_1 - w_3 = 55.0 - 42.0 = 13.0\%$$

0.1

Illustrative Example 4.3. *A cone penetrometer test was conducted on a sample of soil for the determination of the liquid limit, and the following observations were recorded.*

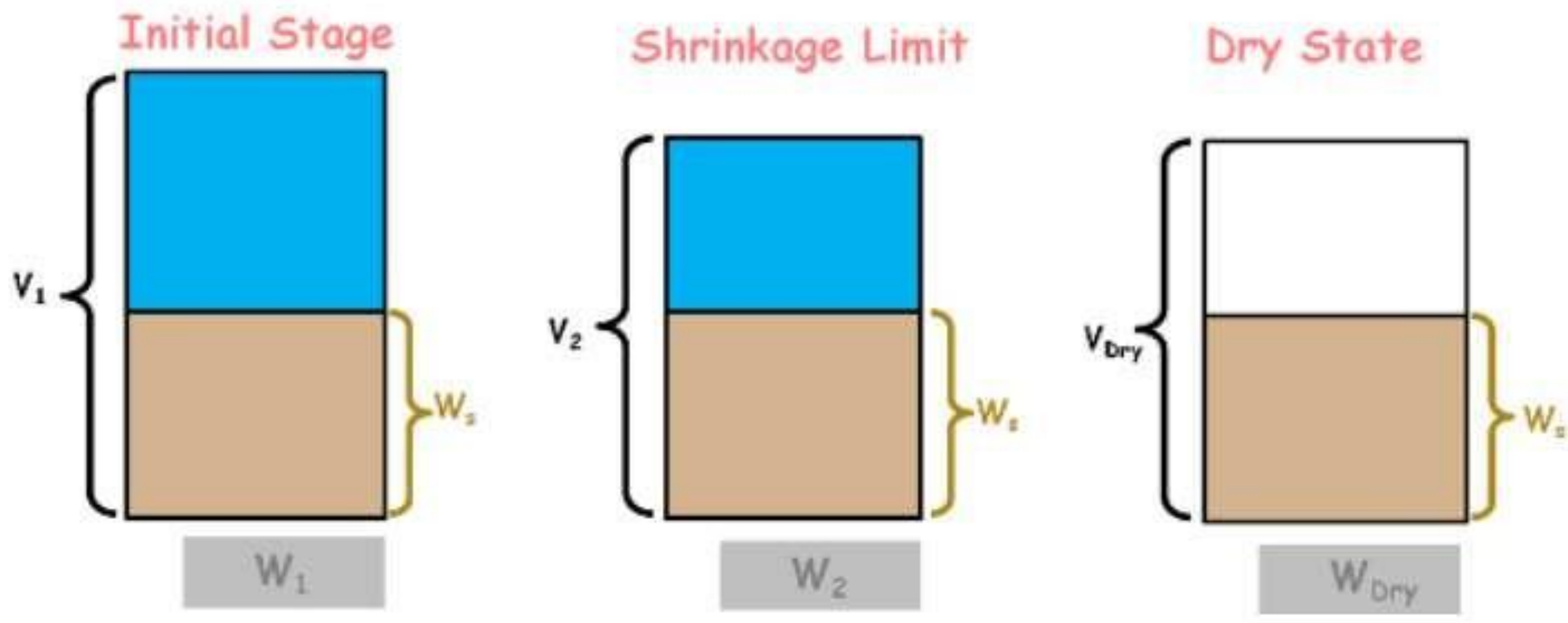
Cone penetration (mm)	19.1	20.5	22.2	25.2	26.3
Water content (w)%	51.5	53.2	55.2	58.1	59.5

Determine the liquid limit.

Determination of Shrinkage Limit

- Three block diagrams of a sample of soil having the same weight of solids W_s.
- Block diagram (a) represents a specimen in the plastic state, which just fills a container of known volume, V_1. The weight of the specimen is W_1.
- The specimen is then dried gradually, and as it reaches the shrinkage limit, the specimen is represented by block diagram (b).
- The specimen remains saturated up to this limit but reaches a constant volume V_d.
- When the specimen is completely dried, its weight will be W_s whereas its volume remains as $V_{d,}$ the specimen is represented by block diagram (c).
  - Shrinkage limit is nothing but the water content value and water content is defined as the weight of water present in the soil divided by weight of solids presents.

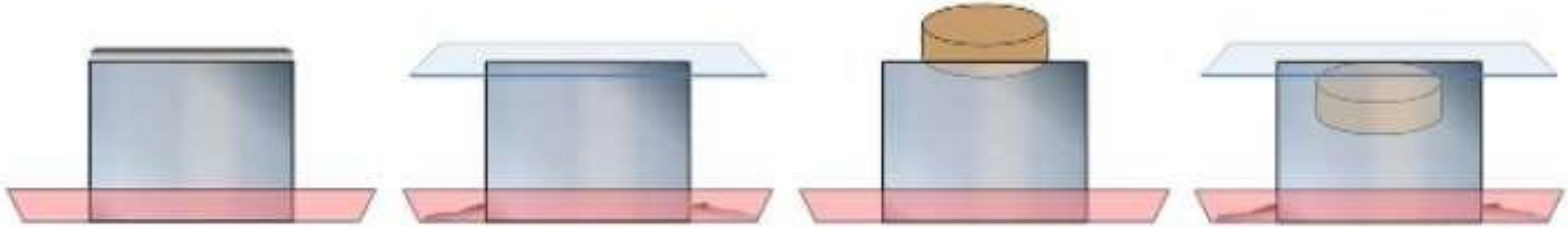
$$\boxed{\text{water content} = \frac{W_{water}}{W_{solids}}}$$



Weight of water at shrinkage limit $(W_s) = (W_1 - W_{dry}) - (V_1 - V_2)\,\gamma_w$

Determination of Dry Volume V_d of Sample by Displacement in Mercury

- The volume of the dry specimen can be determined either by the displacement of mercury method or wax method.
- Place a small dish filled with mercury up to the top in a big dish.
- Cover the dish with a glass plate containing three metal prongs in such a way that the plate is entrapped.
- Remove the mercury spilt over into the big dish and take out the cover plate from the small dish.
- Place the soil sample on the mercury. Submerge the sample with the pronged glass plate and make the glass plate flush with the top of the dish.
- Weigh the mercury that is spilt over due to displacement. The volume of the sample is obtained by dividing the weight of the mercury by its specific gravity which may be taken as 13.6.



$$V_{soil\ pat} = V_{mercury} = \frac{W_{Mercury}}{G_{mercury}}$$

$$\text{water content} = \frac{(W_1 - W_{dry}) - (V_1 - V_2)\gamma_w}{W_{Dry}}$$

A shrinkage limit test on a clay soil gave the following data. Compute the shrinkage limit. Assuming that the total volume of dry soil cake is equal to its total volume at the shrinkage limit, what is the degree of shrinkage?

Mass of shrinkage dish and saturated soil $M_1 = 38.78$ g

Mass of shrinkage dish and oven dry soil $M_2 = 30.46$ g

Mass of shrinkage dish $M_3 = 10.65$ g

Volume of shrinkage dish $V_o = 16.29$ cm^3

Total volume of oven dry soil cake $V_d = 10.00$ cm^3

The equation for shrinkage limit $w_s = \dfrac{M_w}{M_s}$

where M_w = mass of water in the voids at the shrinkage limit.

M_o = mass of sample at the plastic state = $M_1 - M_3 = 38.78 - 10.65 = 28.13$ g

Volume of water lost from the plastic state to the shrinkage limit $\Delta V = (V_o - V_d)$

or $\Delta V = 16.29 - 10.00 = 6.29 \text{ cm}^3$

Mass of dry soil $= M_s = M_2 - M_3 = 30.46 - 10.65 = 19.81$ g

Now, $M_w = M_o - M_s - (V_o - V_d)\,\rho_w = 28.13 - 19.81 - (6.29)(1) = 2.03$ g

From Eq. (3.41), $w_s = \dfrac{(M_o - M_s) - (V_o - V_d)\rho_w}{M_s} = \dfrac{M_w}{M_s} = \dfrac{2.03}{19.81} = 0.102 = 10.2\%$

As per Eq. (3.48a), the degree of shrinkage, S_r is

$$S_r = \frac{V_o - V_d}{V_o} \times 100 = \frac{(16.29 - 10.0) \times 100}{16.29} = 38.6\%$$

Indices

Plasticity Index I_p

- 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.

$$I_P = w_L - w_P$$

- Plasticity index indicates the degree of plasticity of a soil. The greater the difference between liquid and plastic limits, the greater is the plasticity of the soil.
- A cohesionless soil has zero plasticity index. Such soils are termed non-plastic.
- Fat clays are highly plastic and possess a high plasticity index. Soils possessing large values of w_L and I_P are said to be highly plastic or fat.
- Those with low values are described as slightly plastic or lean.

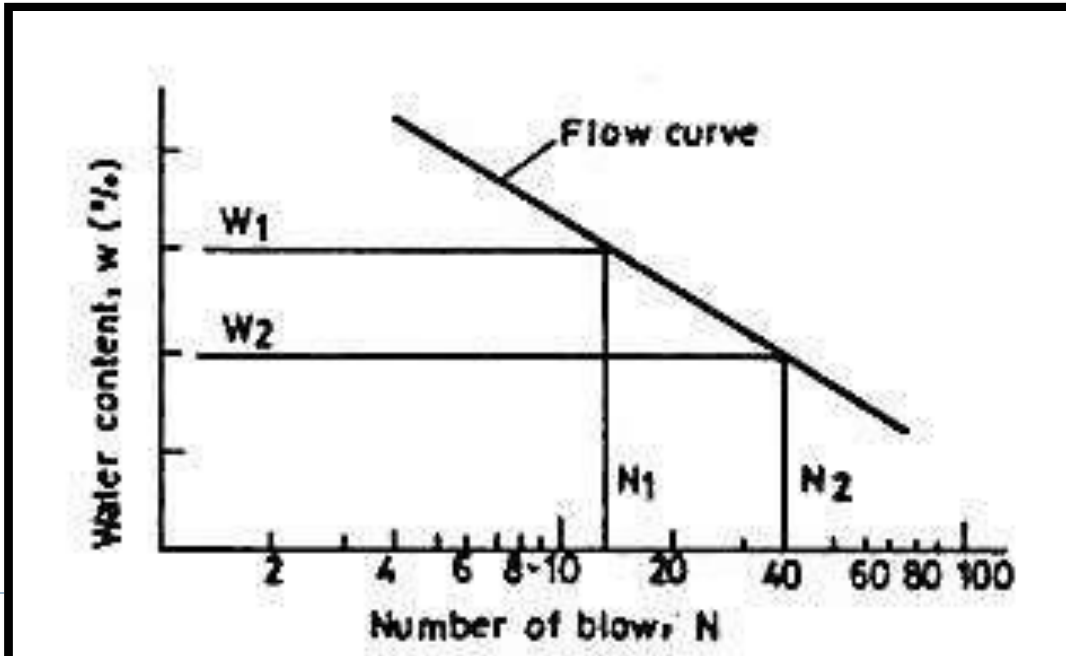
Plasticity index	Plasticity
0	Non-plastic
<7	Low plastic
7–17	Medium plastic
>17	Highly plastic

Flow Index (I_f)

- The flow index may be calculated from the following equation also:

$$I_f = (w_1 - w_2) / \log_{10} (N_2 / N_1)$$

- The flow index indicates the rate of loss in shearing strength upon increase in water content.
  - A soil with higher value of flow index (steeper flow curve) possesses lower shear strength when compared to soil with lower value of flow index (flatter curve).



Toughness Index, I_T

- The shearing strength of a clay at the plastic limit is a measure of its toughness.
- Two clays having the same plasticity index possess toughness which is inversely proportional to the flow indices.
- It can be obtained as the **ratio of plasticity index and flow index.**
- The value of I_T generally falls between 0 and 3 for most clay soils. When I_t is less than 1, the soil is friable at the plastic limit.
- It is quite a useful index to distinguish soils of different physical properties.

$$\boxed{I_t = \frac{I_p}{I_f}}$$

Liquidity Index, I_L

- The Atterberg limits are found for remolded soil samples. These limits as such do not indicate the consistency of undisturbed soils.
- The index that is used to indicate the consistency of **undisturbed soils** is called the liquidity index. The liquidity index is expressed as:

$$I_L = \frac{(w_N - w_P)}{I_P}$$

where, w_N is the natural moisture content of the soil in the undisturbed state.

- The liquidity index of undisturbed soil can vary from less than zero to greater than 1.
- The liquidity index indicates the state of the soil in the field. If the natural moisture content of the soil is closer to the liquid limit the soil can be considered as soft, and the soil is stiff if the natural moisture content is closer to the plastic limit. It varies according to the consistency of the soil as in Table in next slide.

Consistency Index, I_C

- The consistency index may be defined as

$$I_C = \frac{(w_L - w_N)}{I_P}$$

- The index I_C reflects the **state of the clay soil condition in the field** in an undisturbed state just in the same way as I_L described earlier.
- The values of I_C for different states of consistency are given in above Table along with the values I_L
- It may be seen that values of I_L and I_C are opposite to each other for the same consistency of soil.
- Also, $I_L + I_C = 1$

Consistency	I_l	I_c
Semisolid or solid state	Negative	>1
Very stiff state ($w_n = w_p$)	0	1
Very soft state ($w_n = w_l$)	1	0
Liquid state (when disturbed)	>1	Negative

Shrinking and Swelling of Soils

- If a moist cohesive soil is subjected to drying, it loses moisture and shrinks. The degree of shrinkage, S_r is expressed as

$$S_r = \frac{V_o - V_d}{V_o} \times 100$$

- Where, V_o = original volume of a soil sample at saturated state

  V_d = final volume of the sample at shrinkage limit
- On the basis of the degree of shrinkage, Scheidig (1934) classified soils as in Table.

S_r%	Quality of soil
< 5	Good
5–10	Medium good
10–15	Poor
> 15	Very poor

Shrinkage Ratio *SR*

- Shrinkage ratio is defined as the ratio of a volume change expressed as a percentage of dry volume to the corresponding change in water content above the shrinkage limit.

$$SR = \frac{(V_o - V_d)/V_d}{w_o - w_s} \times 100$$

where V_o = initial volume of a saturated soil sample at water content w_o

V_d = the final volume of the soil sample at shrinkage limit w_s

$(w_o - w_s)$ = change in the water content = $(V_o - V_d) * \gamma_w / W_d$

W_d = mass of dry volume, V_d, of the sample

- Substituting for $(w_o - w_s)$ in above Equation and simplifying, we have

$$SR = \frac{W_d}{\gamma_w V_d} = \frac{\gamma_d}{\gamma_w} = G_m$$

- Thus the shrinkage ratio of a soil mass is equal to the mass specific gravity of the soil in its dry state.

Volumetric Shrinkage S_v

- The volumetric shrinkage or volumetric change is defined as the decrease in volume of a soil mass, expressed as a percentage of the dry volume of the soil mass when the water content is reduced from the initial w_o to the final w_s at the shrinkage limit.

$$S_v = \frac{V_o - V_d}{V_d} \times 100 = (w_o - w_s)\ SR$$

- The volumetric shrinkage S_v is used as a decimal quantity.
- This equation assumes that the reduction in volume is both linear and uniform in all directions.

Activity

- Skempton (1953) considers that the significant change in the volume of a clay soil during shrinking or swelling is a function of plasticity index and the quantity of colloidal clay particles present in soil.

$$\text{Plasticity Index} \propto \text{\% Clay Particles in soil}$$

- The clay soil can be classified inactive, normal or active (after Skempton, 1953). The activity of clay is expressed as:

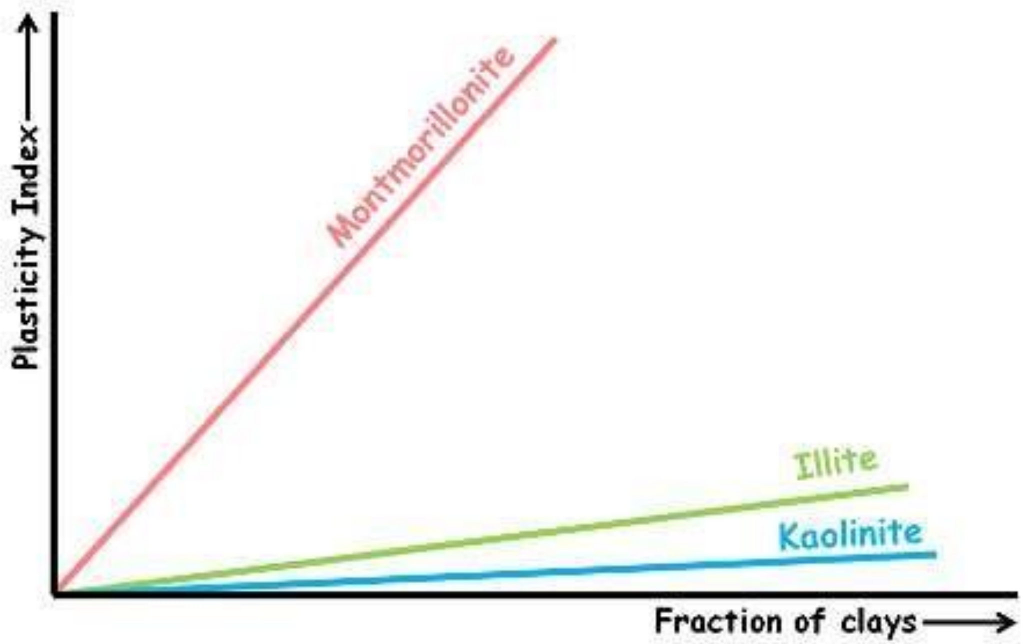
$$\text{Activity} = \frac{\text{Plasticity Index}}{\text{\% clay fraction in soil}}$$

$$A_C = \frac{I_P}{C} = \frac{W_L - W_P}{C}$$

- Table gives the type of soil according to the value of A. The clay soil which has an activity value greater than 1.25 can be considered as belonging to the swelling type.

Activity	Soil Classification
< 0.75	Inactive
0.75 - 1.25	Normal Active
> 1.25	Active

- The relationship between plasticity index and clay fraction is shown in figure:



Sensitivity Of Soil

- The consistency of a natural soil is different from that of a remolded soil at the same water content. Remolding destroys the structure of the soil and the particle orientation.
- The degree of disturbance of undisturbed clay sample due to remolding can be expressed as:

$$S_t = \frac{\text{Unconfined Compressive Strength of Undisturbed Soil}}{\text{Unconfined Compressive Strength of Remoulded Soil}}$$

- The unconfined compressive strength, q_u, is defined as the ultimate load per unit cross sectional area that a cylindrical specimen of soil (with height to diameter ratio of 2 to 2.5) can take under compression without any lateral pressure. Water content of the soil is assumed to remain constant during the duration of the test which generally takes only a few minutes.

- If soil's strength does not change after remoulding then compressive strength of undisturbed soil and remoulded soil being the same sensitivity of the soil will be equal to one and such soils are called insensitive soils.

$$S_t = \frac{(q_u)_{\text{Undisturbed Soil}}}{(q_u)_{\text{Remoulded Soil}}} = 1$$

- Then there are soils which lose up to half of their strength upon remoulding, their sensitivity value vary from one to two. These soils are called little sensitive.

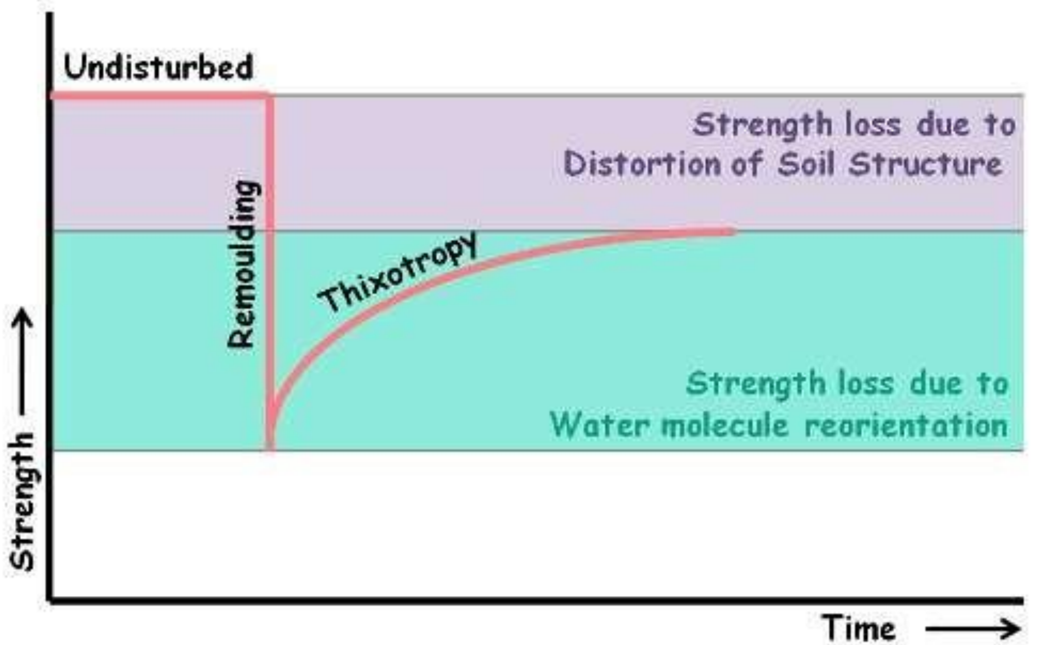
$$S_t = \frac{(q_u)_{\text{Undisturbed Soil}}}{(q_u)_{\text{Remoulded Soil}}} = \frac{(q_u)}{(q_u)/2} = 2$$

- Depending upon the sensitivity, soils may be divided into these following categories:

Sensitivity	Soil Type
0 - 1	Insensitive
1 - 2	Little Sensitive
2 - 4	Normal Sensitive
4 - 8	Sensitive
8 - 16	Extra Sensitive
> 16	Quick Clays

Thixotropy

- If a remolded clay sample with sensitivity greater than one is allowed to stand without further disturbance and change in water content, it may regain at least part of its original strength and stiffness.
- This increase in strength is due to the gradual reorientation of the absorbed molecules of water, and is known as **thixotropy.**
- The regaining of a part of the strength after remolding has important applications in connection with pile-driving operations, and other types of construction in which disturbance of natural clay formations is inevitable.



The laboratory tests on a sample of soil gave the following results:

$w_n = 24\%$, $w_l = 62\%$, $w_p = 28\%$, percentage of particles less than $2\ \mu = 23\%$

Determine: (a) The liquidity index, (b) activity (c) consistency and nature of soil.

(a) Plasticity index, $I_p = w_l - w_p = 62 - 28 = 34\%$

Liquidity index, $I_l = \dfrac{w_n - w_p}{I_p} = \dfrac{24 - 28}{34} = -0.12$.

(b) Activity, $A = \dfrac{I_p}{\%\text{ of particles } < 2\mu} = \dfrac{34}{23} = 1.48$.

(c) Comments:

(i) Since I_l is negative, the consistency of the soil is very stiff to extremely stiff (semisolid state).

(ii) Since I_p is greater than 17% the soil is highly plastic.

(iii) Since A is greater than 1.40, the soil is active and is subject to significant volume change (shrinkage and swelling).

Two soil samples tested in a soil mechanics laboratory gave the following results:

	Sample no. 1	Sample no. 2
Liquid limit	50%	40%
Plastic limit	30%	20%
Flow indices, I_f	27	17

(a) Determine the toughness indices and
(b) comment on the types of soils.

(a) $I_t = \dfrac{w_l - w_p}{I_f}$

Sample 1, $I_t = \dfrac{50-30}{27} = \dfrac{20}{27} = 0.74$; Sample 2, $I_t = \dfrac{40-20}{17} = \dfrac{20}{17} = 1.18$

(b)

(i) Both the soils are clay soils as their toughness indices lie between 0 and 3.

(ii) Soil one is friable at the plastic limit since its I_t value is less than one.

(iii) Soil two is stiffer than soil one at the plastic limit since the I_t value of the latter is higher.

The natural moisture content of an excavated soil is 32%. Its liquid limit is 60% and plastic limit is 27%. Determine the plasticity index of the soil and comment about the nature of the soil.

Plasticity index, $I_p = w_l - w_p = 60 - 27 = 33\%$

The nature of the soil can be judged by determining its liquidity index, I_l from Eq. (3.45)

$$I_l = \frac{w_n - w_p}{I_p} = \frac{32 - 27}{33} = +0.15$$

since the value of I_l is very close to 0, the nature of the soil as per Table 3.10 is very stiff.

Example 2.18 Two soils were tested for their consistency limits in the laboratory. The following data were obtained:

Soil A		Soil B	
No. of blows N	*w%*	*No. of blows N*	*w%*
8	43	5	65
20	39	15	61
30	37	30	59
45	35	40	58
Plastic limit = 25%		Plastic limit = 30%	

The natural moisture contents of soils A and B were measured in the field and were found to be 40% and 50 %, respectively.

(a) Which soil has greater plasticity?

(b) Which soil will be a better foundation material upon remoulding?

(c) Which soil is more compressible?

(d) Which soil shows a higher rate of loss in shear strength upon increase in water content?

(e) Which soil has a higher strength at plastic limit?

(f) Is there a likelihood of organic matter being present in these soils?

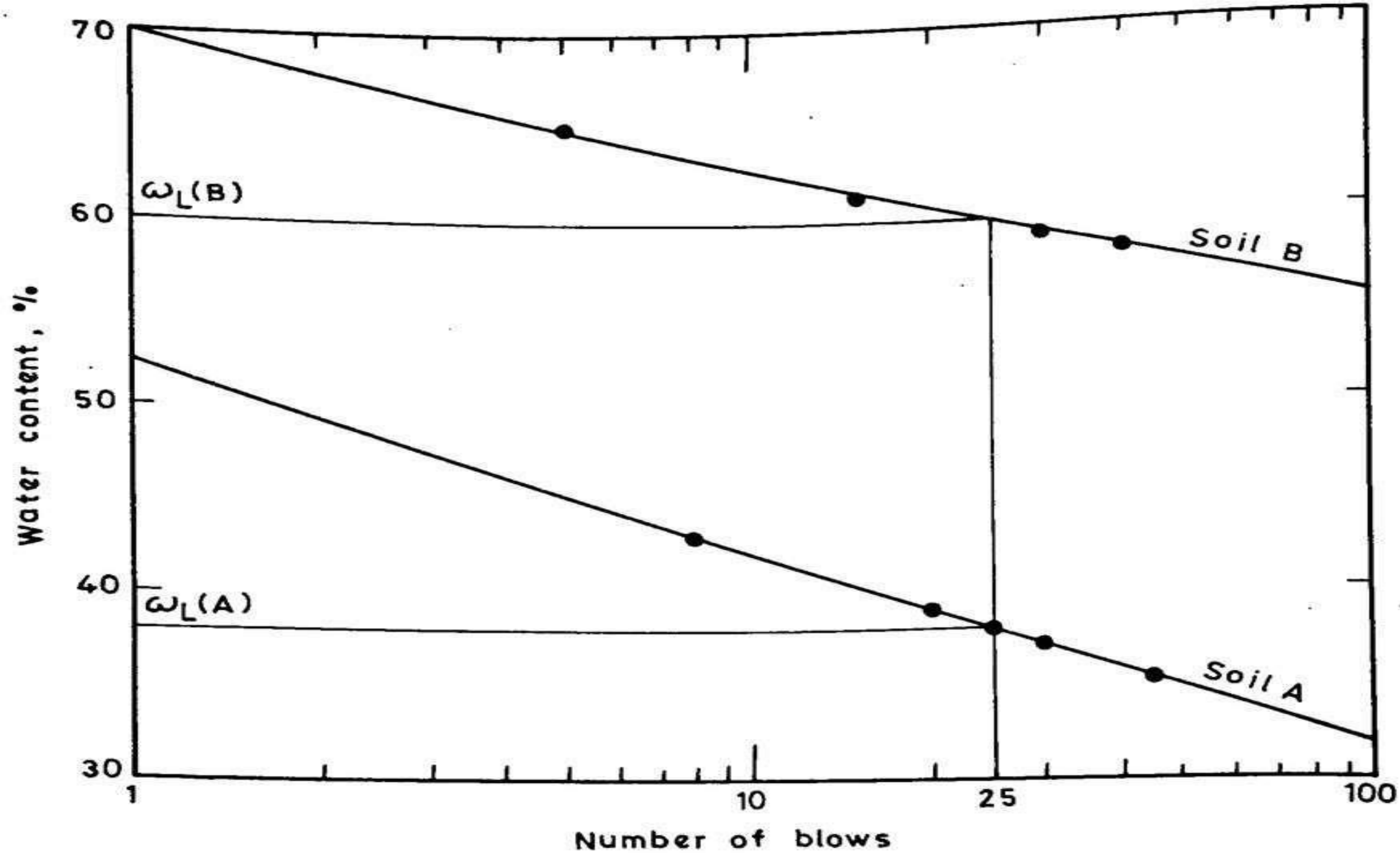


Fig. 2.31 Example 2.18

Solution:

Fig. 2.31 shows the flow curves for soils A and soils B.

From the figure, $(w_L)_A = 38\%$

$(w_L)_B = 60\%$

(a) $(I_P)_A = 38 - 25 = 13$

$(I_P)_B = 60 - 30 = 30$

Soil B has a higher degree of plasticity. Soils with $I_p > 17$ are highly plastic and soils with I_P between 7 and 17 are 'medium plastic', according to one empirical classification system.

(b) $$(I_L)_A = \frac{w_N - w_P}{I_P} = \frac{40 - 25}{13} = 1.15$$

$$(I_L)_B = \frac{50 - 30}{30} = 0.67$$

Soil A with $I_L > 1$ is in the liquid state of consistency and will, therefore, 'flow' like a viscous slurry *upon remoulding*. Soil B with $I_L = 0.67$ is in the plastic state and will be a better foundation material *upon remoulding*.

(c) Soil with $w_L = 60\ \%$ is more compressible than soil A with $w_L = 38\%$. Compressibility is a direct function of the liquid limit.

(d) From Fig. 2.31, Flow index, I_f of soil A = 42.0 – 32.0 = 10 (considering water contents at 10 and 100 blows)

I_f for soil B = 62.6 – 55.5 = 7.1

Since $(I_f)_A > (I_f)_B$, soil A shows greater loss of shear strength with increase in water content.

(e) Toughness index, I_t for soil $A = \frac{I_P}{I_f} = \frac{13}{10} = 1.3$

$$I_t \text{ for soil } B = \frac{I_P}{I_f} = \frac{30}{7.1} = 4.22$$

Soil B has a higher shear strength at plastic limit since a soil with higher toughness index possesses higher shear strength at plastic limit.

(f) Soils containing organic matter may have high liquid limit values but are also found to posses high plastic limit values and therefore low plasticity index values relative to their liquid limit values. Since both soil A and soil B have plastic limit values which are not very high, they are unlikely to contain any organic matter.

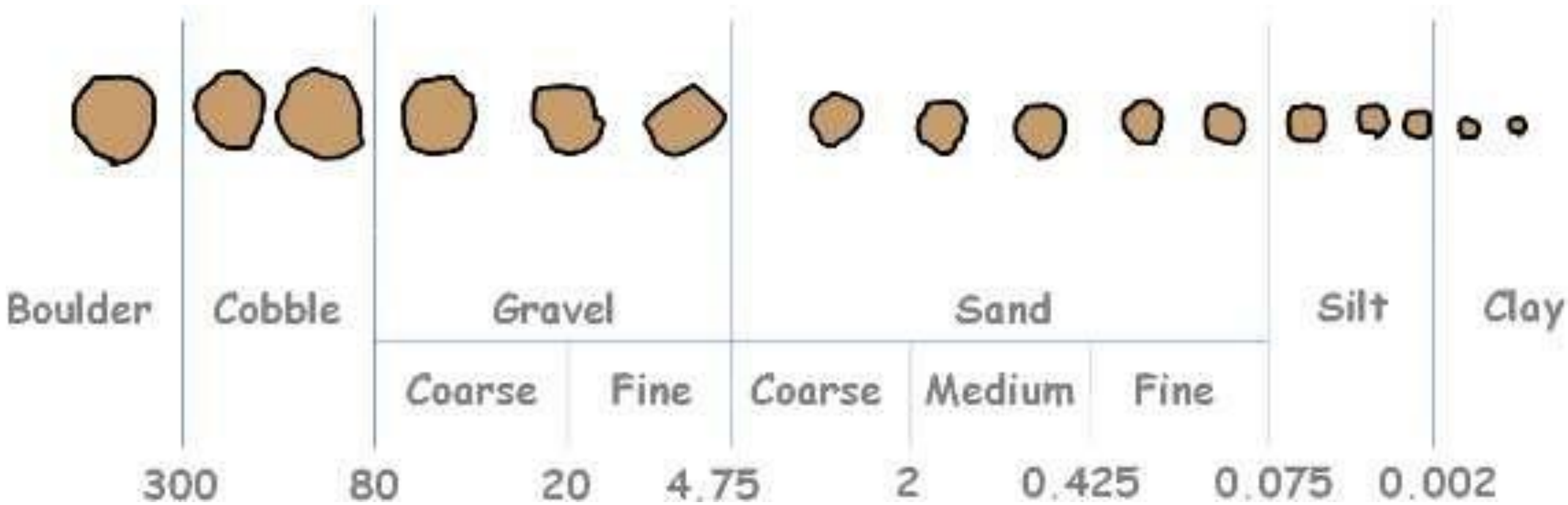
Soil Classification and its Significance

CLASSIFICATION OF SOILS

- Soils in nature rarely exist separately as gravel, sand, silt, clay or organic matter, but are usually found as mixtures with varying proportions of these components.
- Grouping of soils on the basis of certain definite principles would help the engineer to rate the performance of a given soil either as a sub-base material for roads and airfield pavements, foundations of structures, etc.
- The classification or grouping of soils is mainly based on one or two index properties of soil which are described in detail in earlier sections.
- The methods that are used for classifying soils are based on one or the other of the following two broad systems:
- 1. A textural system which is based only on grain size distribution.
- 2. The systems that are based on grain size distribution and Consistency limits of soil.

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.



Classification Based on Grain Size Continued..

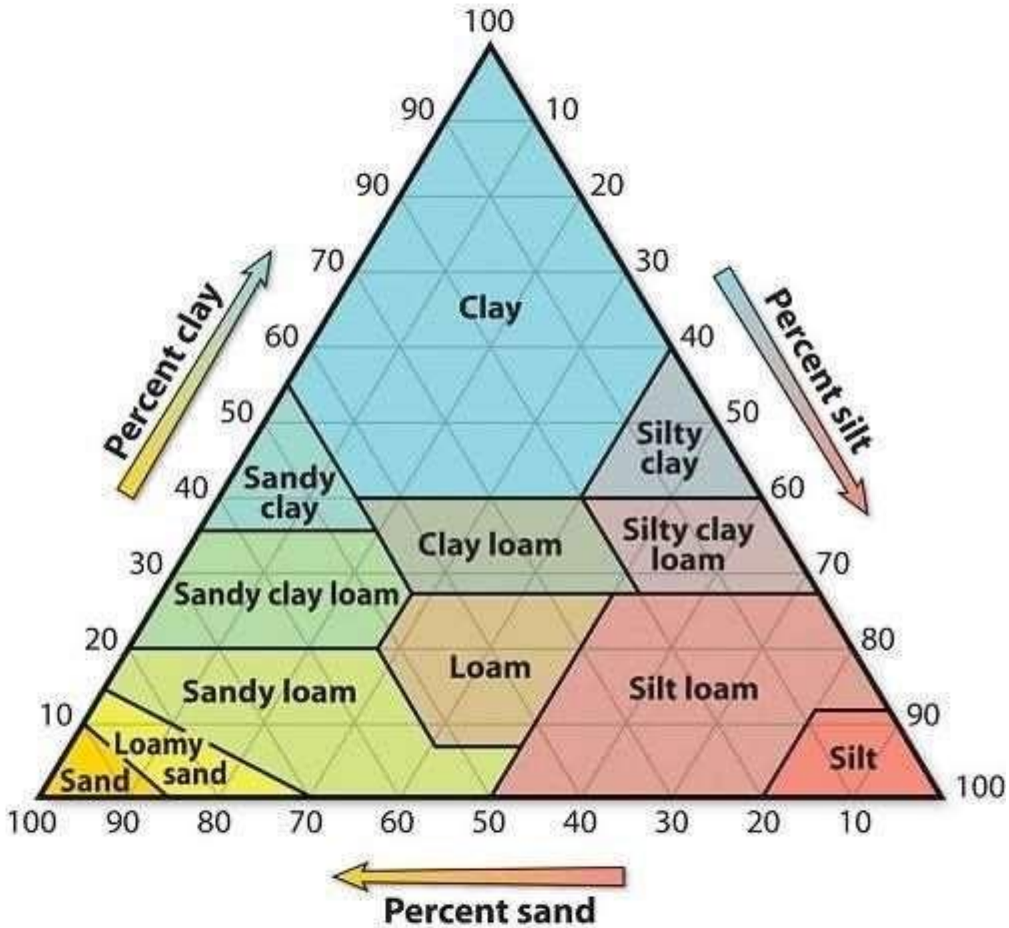
Very coarse soils	Boulder size		> 300 mm
	Cobble size		80 - 300 mm
Coarse soils	Gravel size (G)	*Coarse*	20 - 80 mm
		Fine	4.75 - 20 mm
	Sand size (S)	*Coarse*	2 - 4.75 mm
		Medium	0.425 - 2 mm
		Fine	0.075 - 0.425 mm
Fine soils	Silt size (M)		0.002 - 0.075 mm
	Clay size (C)		< 0.002 mm

Textural Classification

- Soils are also classified based on their texture.
- Texture of a soil means how a soil visually appears and feels.
- Texture is influenced by the size, shape and gradation of soil particles in a soil.
- A triangular representation of Textural Classification System was suggested by US Bureau of Public Roads.
- In this system the term texture is used to express the percentage of the three constituents of the soil, Sand, Silt and Clay on the three sides of an equilateral triangle.
- This system assumes that the soil does not contain the particles of size larger than sand.
- This equilateral triangle is divided into **12 zones**; each zone indicates a type of soil. If we know the percentages of sand, clay, and silt in our soil sample, this triangle can be used to know soil type out of these twelve soil types classified in the triangle.

Textural Classification Continued..

- But this system also does not takes into account the plasticity and consistency properties which are important when it comes to the fine-grained soils.



- Two classification systems **USCS and AASHTO** are adopted by US engineering agencies and the State Departments. Other countries including India, has also adopted the USCS with minor modifications.

AASHTO Classification System

- AASHTO stands for American Association of State Highway and Transportation Official (AASHTO) Classification System. It is particularly useful for classifying soils for **highways.**
- This system classifies both coarse-grained and fine-grained soils using both particles size analysis and plasticity characteristics of soil which makes it a complete classification system.
- In this system soils are divided into **7 types** designated as **A-1 to A-7** based on their relative expected quality for road embankments, sub-grades and bases.
- Some of the groups are divided into subgroups. Soils within each group are evaluated according to the **Group Index** calculated from an empirical formula.
- In general the greater the GI value the less desirable a soil is for highway construction within that subgroup. Likewise a soil with lower number, say A-1, is more suitable for the highway material than A-4.
- In AASHTO System initially there was no place for organic soil so additional group **A-8** was introduced for peat or muck.

AASHTO Classification System Continued..

Group Index (GI) = 0.2a + O.OO5ac + 0.01 bd

in which,

- *a* is that part of the percent passing through the No. 200 (0.075 mm) sieve greater than 35 and not exceeding 75, expressed as a positive whole number (range 1 to 40).
- *b* is that part of the percent passing through the No. 200 (0.075 mm) sieve greater than 15 and not exceeding 55, expressed as a positive whole number (range 1 to 40).
- *c* is that part of liquid limit greater than 40 and not exceeding 60, expressed as a positive whole number (range 1 to 20).
- *d* is that part of plasticity index greater than 10 and not exceeding 30, expressed as a positive whole number (range 1 to 20).

AASHTO Classification System Continued..

Table 5.1. AASHTO Classification System

General Classification	Granular materials (35% or less passing No. 200 Sieve (0.075 mm))							Silt-clay Materials More than 35% passing No. 200 Sieve (0.075 mm)			
Group Classification	A—1		A—3	A—2				A—4	A—5	A—6	A—7
	A—1—a	A—1—b		A—2—4	A—2—5	A—2—6	A—2—7				A—7—5 A—7—6
(a) Sieve Analysis: Percent Passing											
(i) 2.00 mm (No. 10)	50 max										
(ii) 0.425 mm (No. 40)	30 max	50 max	51 min								
(iii) 0.075 mm (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
(b) Characteristics of fraction passing 0.425 mm (No. 40)											
(i) Liquid limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
(ii) Plasticity index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min*
(c) Usual types of significant Constituent materials	Stone Fragments Gravel and sand		Fine Sand	Silty or Clayey Gravel Sand				Silty Soils		Clayey Soils	
(d) General rating as subgrade.	Excellent to Good							Fair to Poor			

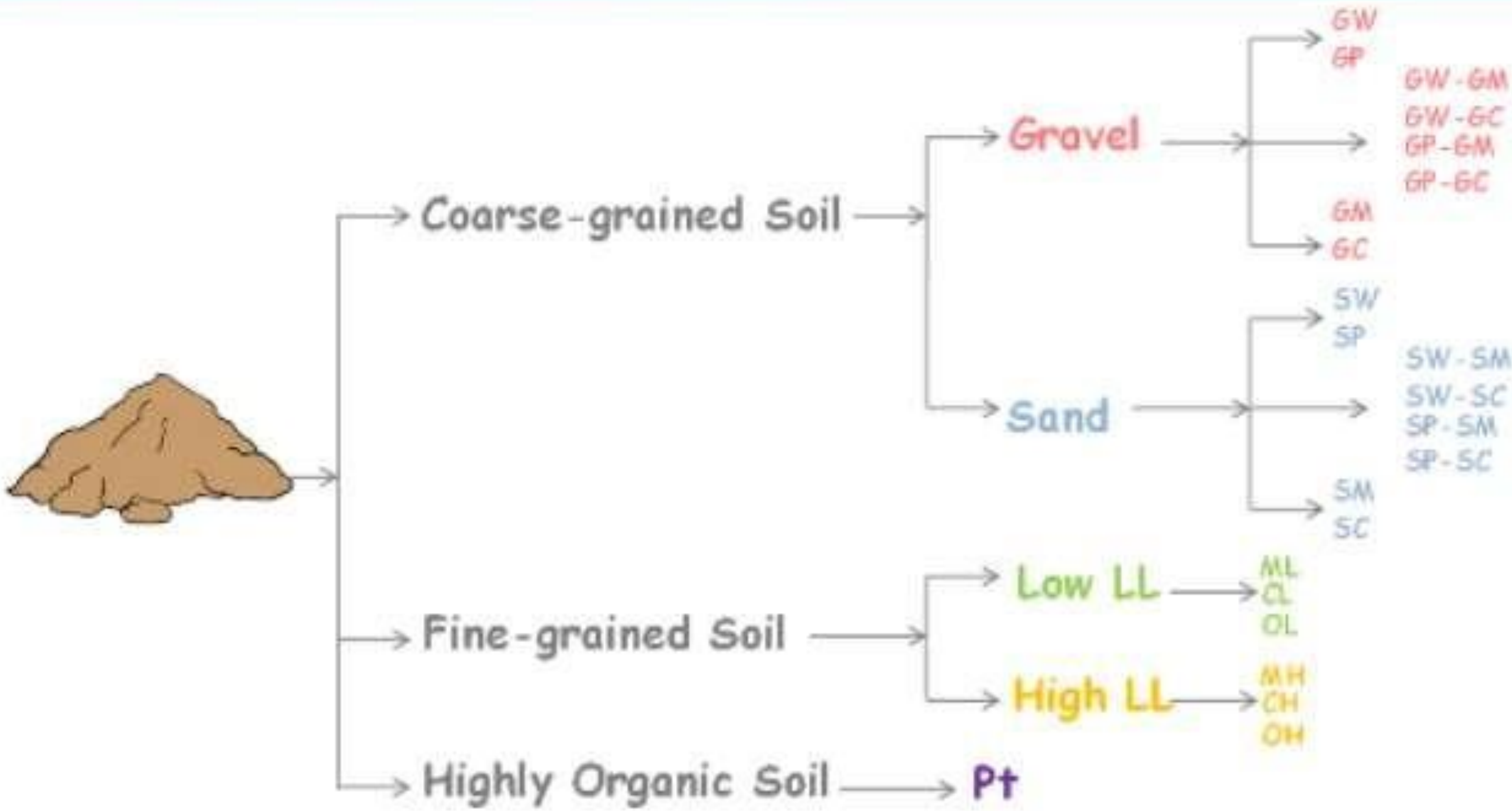
* If plasticity index is equal to or less than (liquid Limit—30), the soil is A—7—5 (*i.e.* PL > 30%)
If plasticity index is greater than (Liquid Limit—30), the soil is A—7—6 (*i.e.* PL < 30%)

Unified Soil Classification System

- It was first developed by Casagrande and later it was modified by Bureau of Reclamation and the Corps of Engineers of the USA. This system has also been adopted by American Society of Testing Materials, ASTM. It is the most popular system for use in all types of engineering problems involving soil.
- In the Unified System, the following symbols are used for identification:

Symbols :	
G = Gravel	W = Well Graded
S = Sand	P = Poorly Graded
M = Silt	L = Low Plasticity
C = Clay	H = High Plasticity
O = Organic	
Pt = Peat	

Unified Soil Classification System



Plasticity chart for fine-grained soils

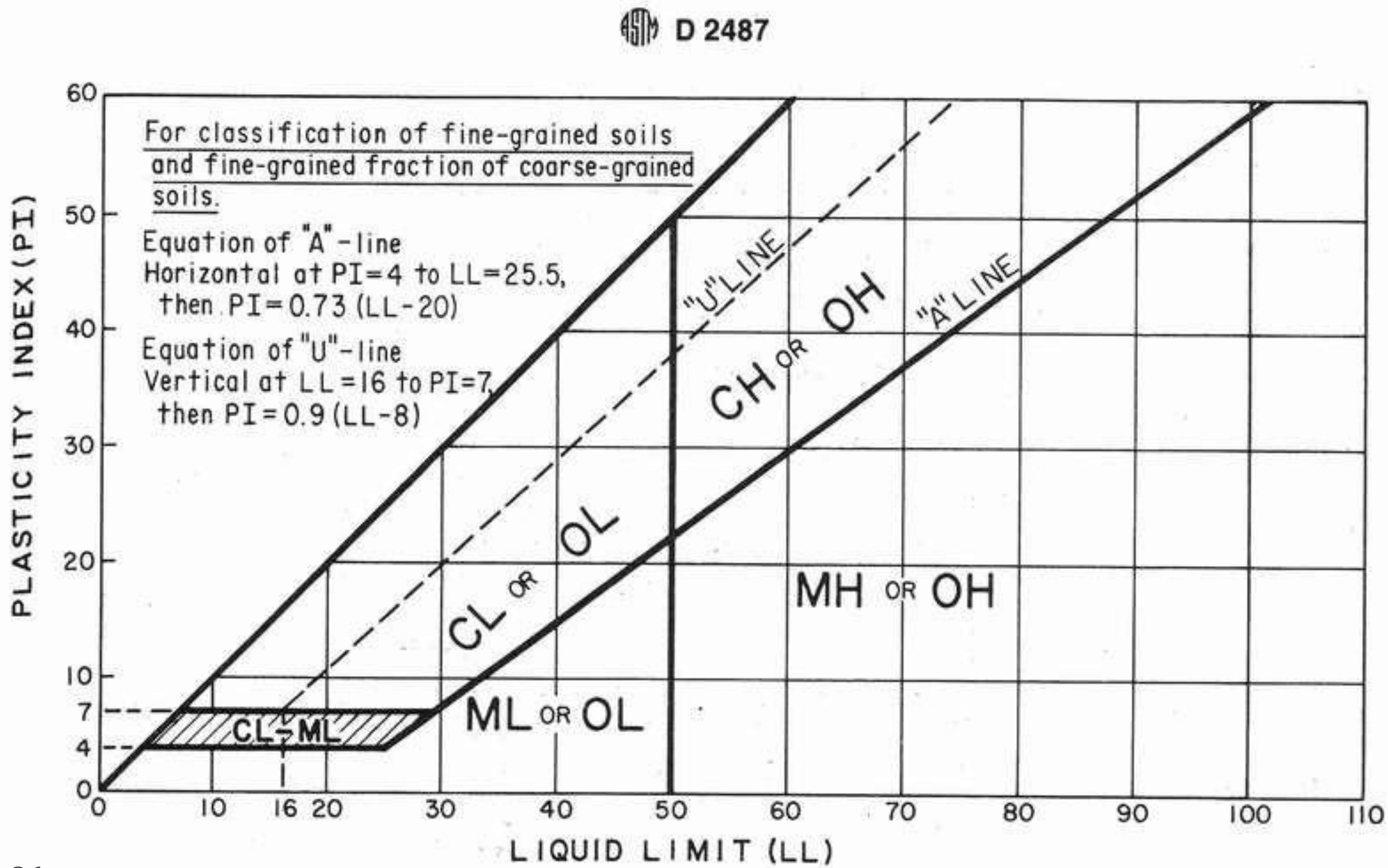


FIG. 3 Plasticity Chart

UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART

COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.)		
	Clean Gravels (Less than 5% fines)	
GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (More than 12% fines)	
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
	Clean Sands (Less than 5% fines)	
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly graded sands, gravelly sands, little or no fines
	Sands with fines (More than 12% fines)	
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS (50% or more of material is smaller than No. 200 sieve size.)		
SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fat clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

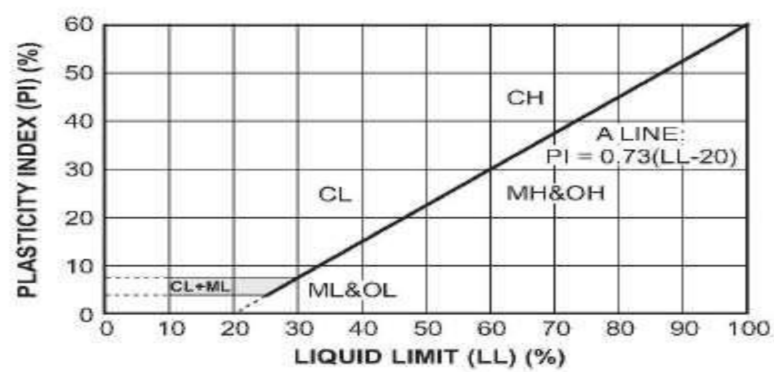
LABORATORY CLASSIFICATION CRITERIA

GW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
GP	Not meeting all gradation requirements for GW	
GM	Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
GC	Atterberg limits above "A" line with P.I. greater than 7	
SW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
SP	Not meeting all gradation requirements for GW	
SM	Atterberg limits below "A" line or P.I. less than 4	Limits plotting in shaded zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
SC	Atterberg limits above "A" line with P.I. greater than 7	

Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 percent .... GW, GP, SW, SP
More than 12 percent .... GM, GC, SM, SC
5 to 12 percent .... Borderline cases requiring dual symbols

PLASTICITY CHART



Subdivisions in the classification

The following subdivisions are considered in the classification:

1. Gravels and sands are **GW, GP, SW, or SP** if less than 5 percent of the material passes the No. 200 sieve; G = gravel; S = sand; W = well-graded; P = poorly-graded. The well- or poorly-graded designations depend on C_u and C_c
2. Gravels and sands are **GM, GC, SM, or SC** if more than 12 percent passes the No. 200 sieve; M = silt; C = clay. The silt or clay designation is determined by performing the liquid and plastic limit tests on the (-)No. 40 fraction and using the plasticity chart. This chart is also a Casagrande contribution to the USC system, and the A line shown on this chart is sometimes called Casagrande's A line.

- The chart has been slightly modified based on the Corps of Engineers findings that no soil has so far been found with coordinates that lie above the "upper limit" or U line shown. This chart and lines are part of the ASTM D 2487 standard.

3. Gravels and sands are (note using dual symbols)

   GW-GC,SW-SC, GP-GC, SP-SC, or GW-GM, SW-SM, GP-GM, SP-SM if between 5 and 12 percent of the material passes the No. 200 sieve. It may be noted that the M or C designation is derived from performing plastic and liquid limit tests and using Casagrande's plasticity chart.

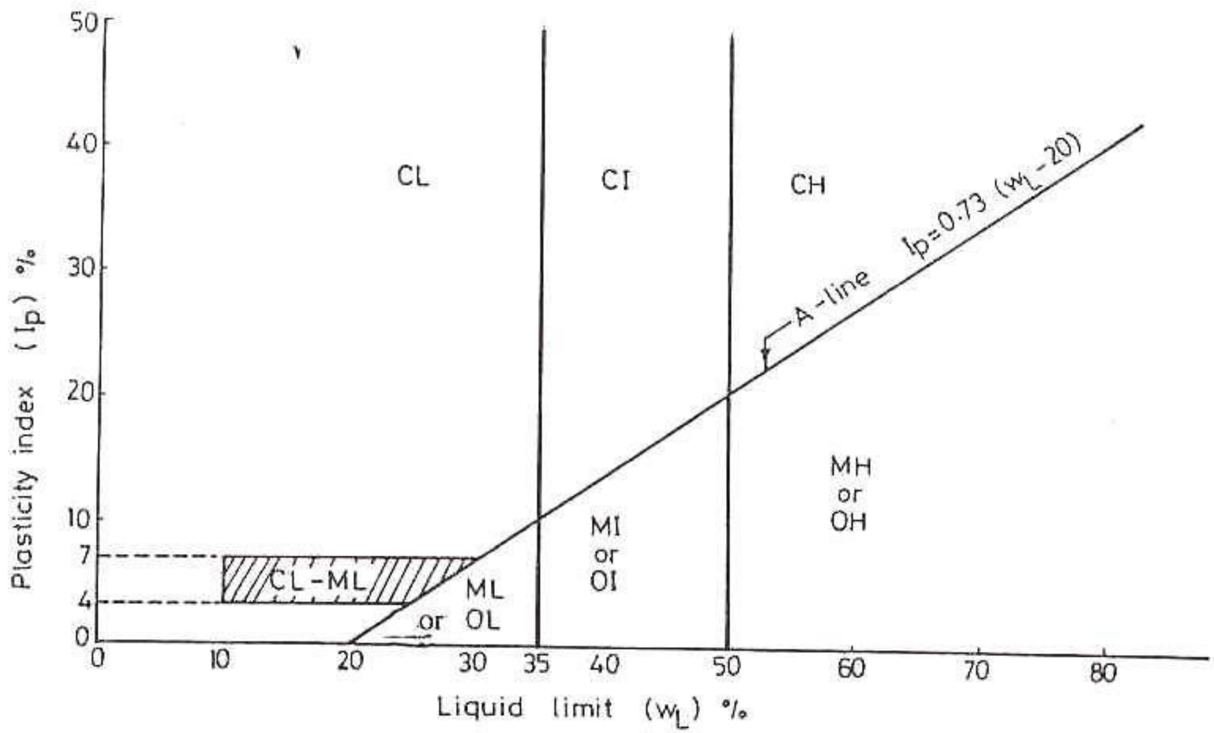
4. Fine-grained soils (more than 50 percent passes the No. 200 sieve) are: **ML, OL, or CL** if the liquid limits are < 50 percent; M = silt; O = organic soils; C = clay. L = Less than 50 percent for w_L

5. Fine grained soils are **MH, OH, or CH** if the liquid limits are > 50 percent; H = Higher than 50 percent. Whether a soil is a Clay (C), Silt (M), or Organic (O) depends on whether the soil coordinates plot above or below the A line.

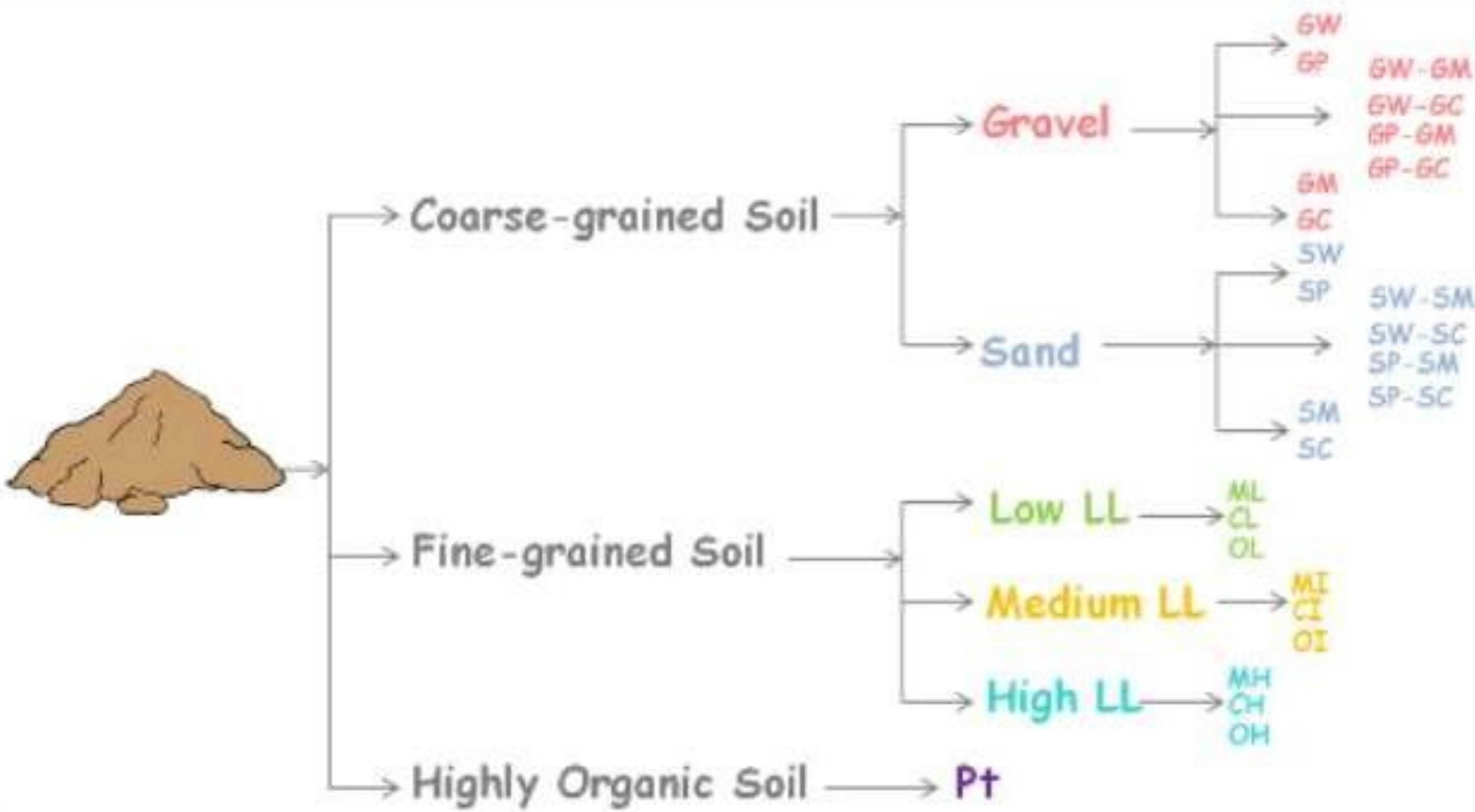
- The organic (O) designation also depends on visual appearance and odor in the USC method. In the ASTM method the O designation is more specifically defined by using a comparison of the air-dry liquid limit w_L and the oven-dried w'_L If the oven dried value is $w'_L < 0.75w_L$ and the appearance and odor indicates "organic" then classify the soil as O.

Indian Standard Soil Classification System

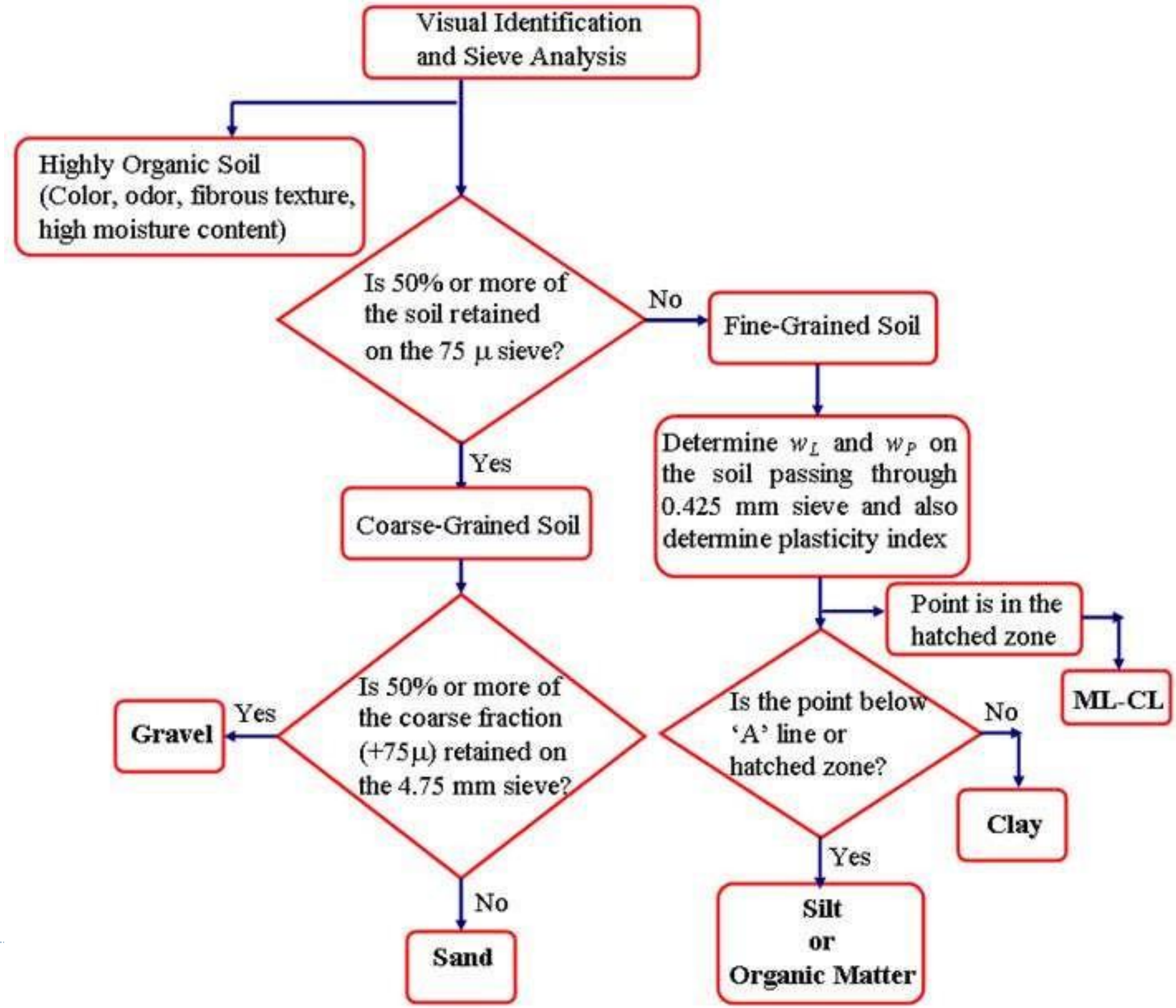
- ISSCS is in many respects similar to Unified Soil Classification System. There is one basic modification which is in the classification of fine-grained soils. **[*IS 1498 (1970): Classification and identification of soils for general engineering purposes]***
- In Indian classification system fine-grained soils are divided into three categories of low, medium and high liquid limit instead of only two categories of low and high liquid limit in USC System.

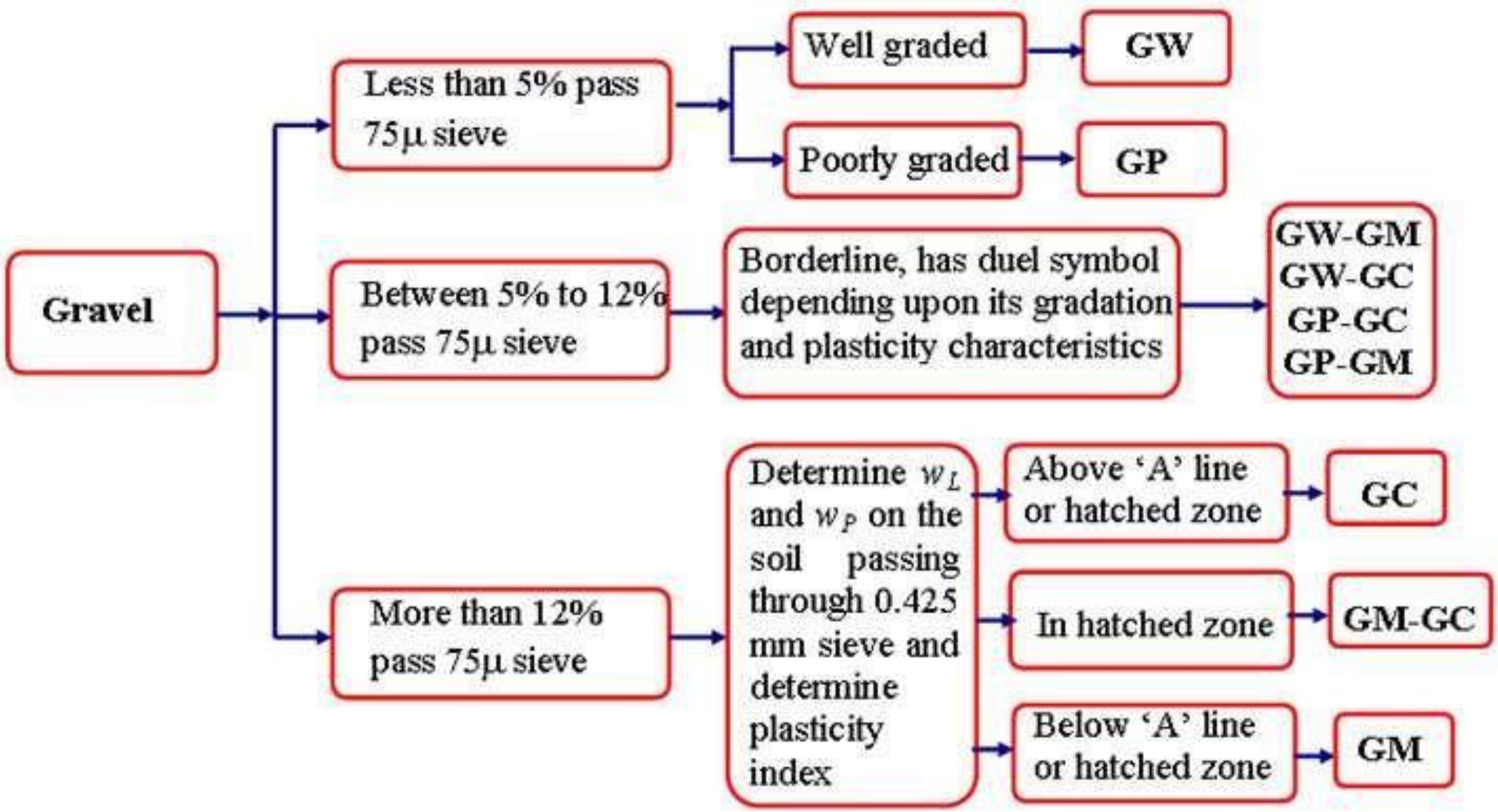


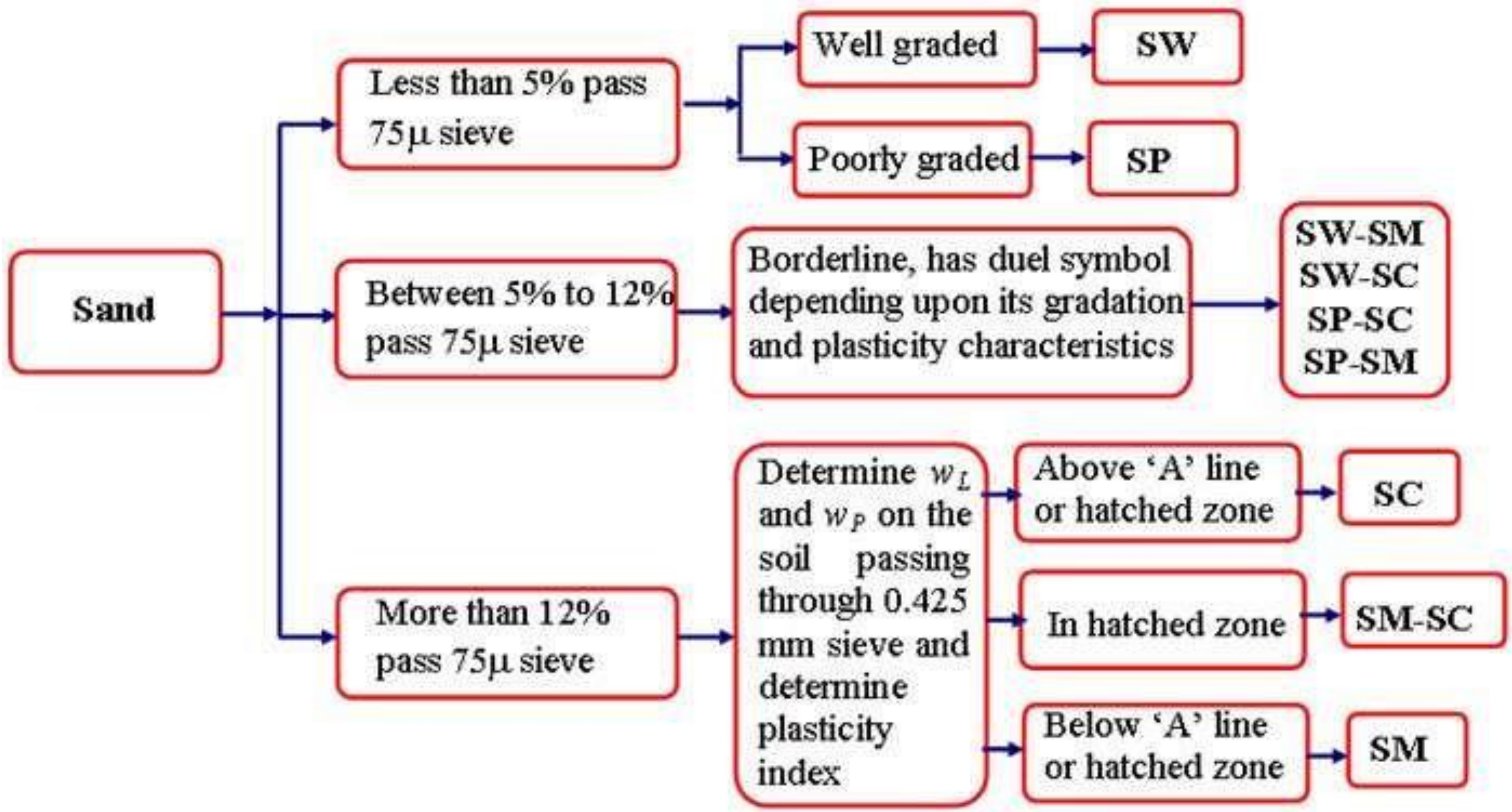
Indian Standard Soil Classification System

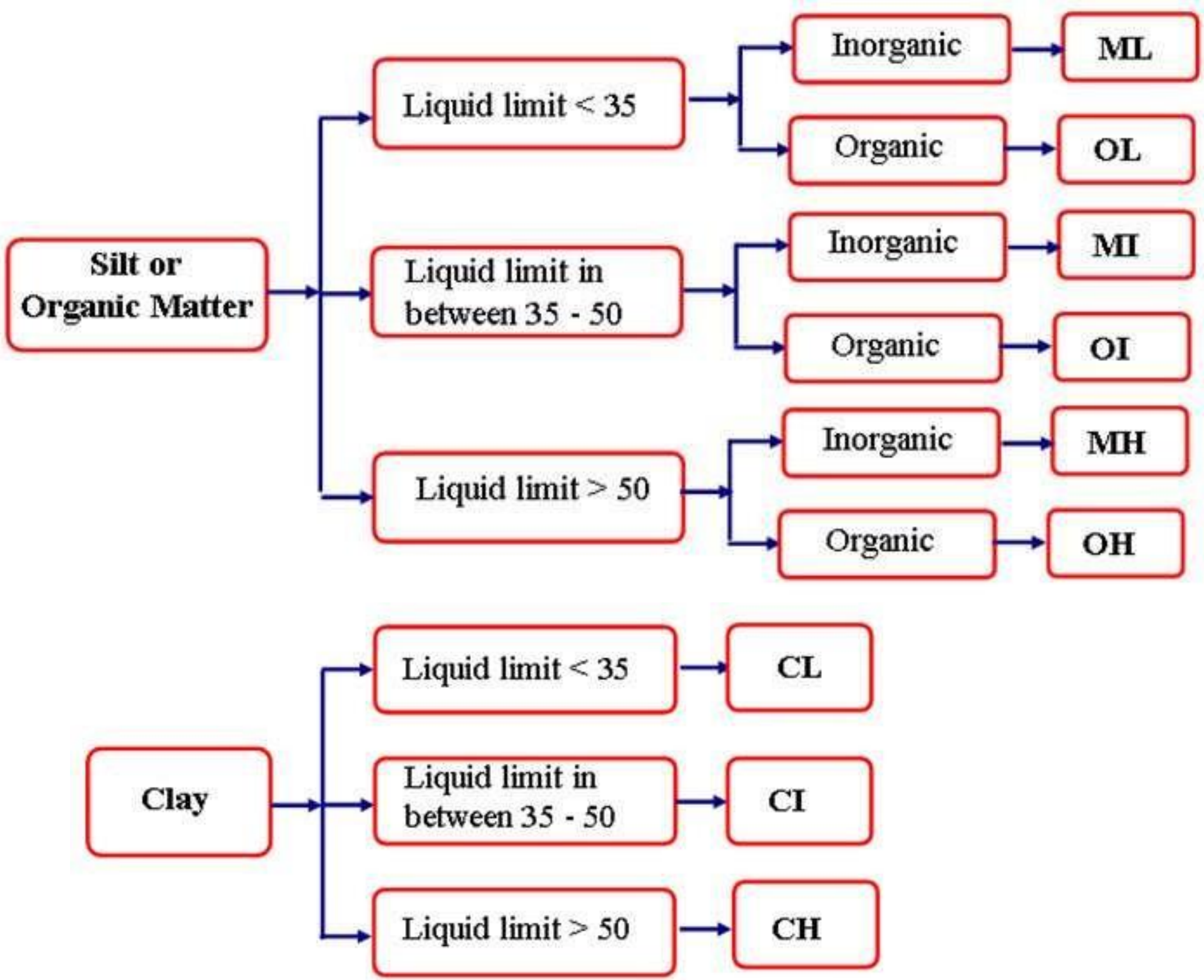


Flow chart to classify soil (as per ISSCS)




Gravel
Less than 5% pass 75μ sieve
Well graded
GW
Poorly graded
GP
Between 5% to 12% pass 75μ sieve
Borderline, has duel symbol depending upon its gradation and plasticity characteristics
GW-GM
GW-GC
GP-GC
GP-GM
More than 12% pass 75μ sieve
Determine w_L and w_P on the soil passing through 0.425 mm sieve and determine plasticity index
Above 'A' line or hatched zone
GC
In hatched zone
GM-GC
Below 'A' line or hatched zone
GM


Sand
Less than 5% pass 75μ sieve
Well graded
SW
Poorly graded
SP
Between 5% to 12% pass 75μ sieve
Borderline, has duel symbol depending upon its gradation and plasticity characteristics
SW-SM
SW-SC
SP-SC
SP-SM
More than 12% pass 75μ sieve
Determine w_L and w_P on the soil passing through 0.425 mm sieve and determine plasticity index
Above 'A' line or hatched zone
SC
In hatched zone
SM-SC
Below 'A' line or hatched zone
SM



Silt or Organic Matter
Liquid limit < 35
Liquid limit in between 35 - 50
Liquid limit > 50
Inorganic
Organic
Inorganic
Organic
Inorganic
Organic
ML
OL
MI
OI
MH
OH
Clay
Liquid limit < 35
Liquid limit in between 35 - 50
Liquid limit > 50
CL
CI
CH

(b)

Boundary Classification for Fine-Grained Soils :

Boundary classifications can occur within the fine-grained soil divisions, between low and medium or between medium and high liquid limits and between silty and clayey soils. First assume a coarse soil, when there is a choice, and then a finer soil and assign dual group symbols. Boundary classifications which are common arc as follows: 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.

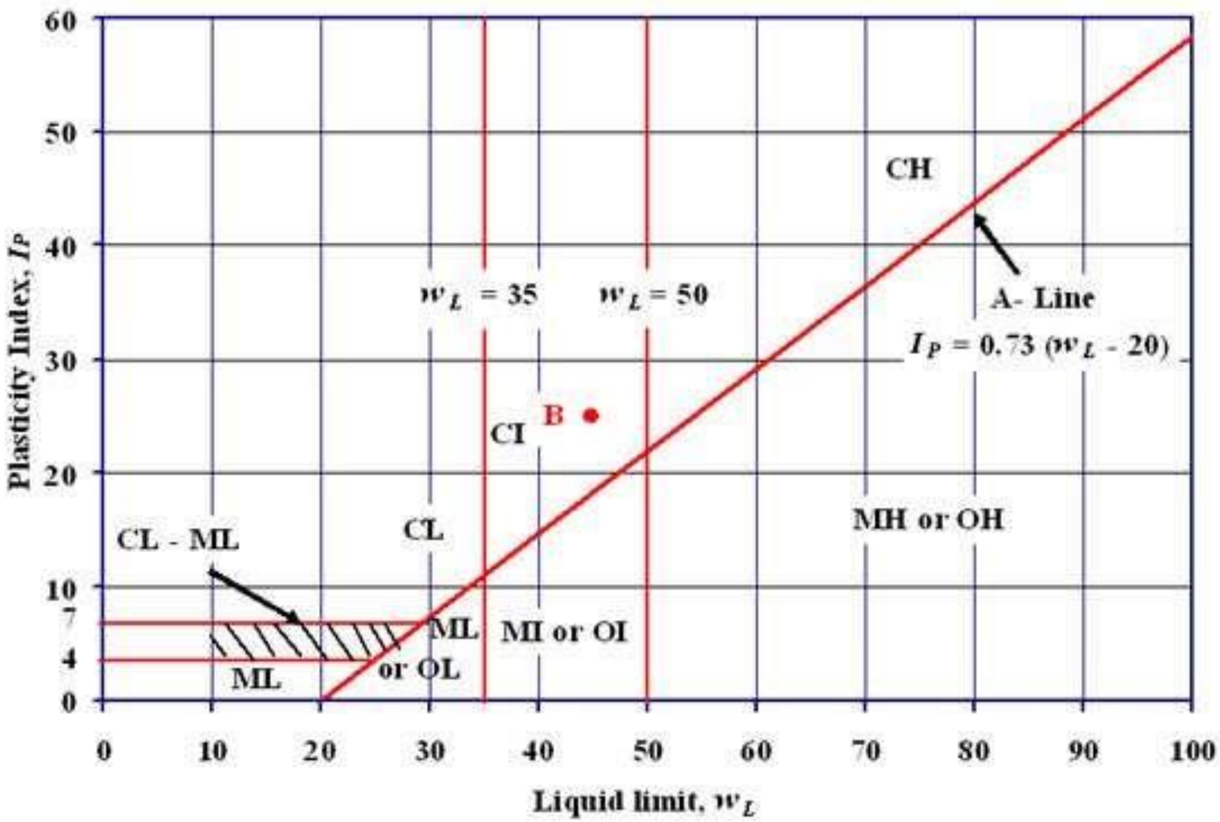


TABLE 3 CLASSIFICAITON OF COARSE-GRAINED SOILS (LABORATORY CLASSIFICATION CRITERIA)

(*Clause* 3.5.1)

Group Symbols	Laboratory Classification Criteria		
GW	C_u Greater than 4 C_c Between 1 and 3		Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than 75-micron IS Sieve) coarse-grained soils are classified as follows:
GP	Not meeting all gradation requirements for GW		
GM	Atterberg limits below 'A' line or I_p less than 4	Limits plotting above 'A' line with I_p between 4 and 7 are border-line cases requiring use of dual symbol	Less than 5% GW, GP,, SW, SP More than 12% GM, GC, SM, SC 5% to 12% Border-line cases requiring use of dual symbols
GC	Atterberg limits below 'A' line with I_p greater than 7		
SW	C_u greater than 6 C_c between 1 and 3		Uniformity coefficient, $C_u = \frac{D_{60}}{D_{10}}$ Coefficient of curvature $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ where D_{60} = 60 percent finer than size D_{30} = 30 percent finer than size D_{10} = 10 percent finer than size
SP	Not meeting all gradation requirements for SW		
SM	Atterberg limits below 'A' line or I_p less than 4	Limits plotting above 'A' line with I_p between 4 and 7 are border-line cases requiring use of dual symbol	
SC	Atterberg limits above 'A' line with I_p greater than 7		

I_p = plasticity index.

Table 5.7. Classification of Fine-grained Soils (ISC System)

Division	Subdivision	Group Symbols	Typical names	Laboratory Criteria (see Fig 5.6)		Remarks
2) Fine-grained soils (more than 50% pass 75μ, IS sieve)	Low-compressibility (*L*) (Liquid Limit less than 35%)	(1) ML	Inorganic silts with none to low plasticity	Atterberg limits plot below A-line or I_P less than 7	Atterberg limits ploting above A-line with I_P between 4 to 7 (hatched zone) ML-CL	(1) Organic and inorganic soils plotted in the same zone in plasticity chart are distinguished by odour and colour or liquid limit test after oven-drying. A reduction in liquid limit after oven- drying to a value less than three- fourth of the liquid limit before oven- drying is positive identification of organic soils.
		(2) CL	Inorganic clays of low plasticity	Atterberg limits plot above A-line and I_P greater than 7		
		(3) OL	Organic silts of low plasticity	Atterberg limits plot below A-line		
	Intermediate compressibility (I) (Liquid limit greater than 35% but less than 50%	(4) MI	Inorganic silts of medium plasticity	Atterberg limits plot below A-line		
		(5) CI	Inorganic clays of medium plasticity	Atterberg limits plot above A-line		(2) Black cotton soils of India lie along a band partly above the A-line and partly below tha A line
		(6) OI	Orgaic silts of medium plasticity	Atterberg limits plot below A-line		
	High compressibiliy (*H*) (Liquid limit greater than 50%)	(7) MH	Inorganic silts of high compressibility	Atterberg limits plot below A-line		
		(8) CH	Inorganic clays of high plasticity	Atterberg limits plot above A-line		See, plasticity chart (Fig. 5.6)
		(9) OH	Organic clays of medium to high plasticity	Atterberg limits plot below A-line		
(3) Highly organic soil		Pt	Peat and other highly organic soils	Readily identified by colour, odour, spongy feel and fibrous texture		

Example 1:

The laboratory test results of a soil sample are given below:

Percentage of particles finer than 4.75 mm = 80

Percentage of particles finer than 75 μm = 4

C_u= 1.5 and C_c= 2.1

Classify the soil as per IS soil Classification System.

Solution:

We are given that Soil finer than 75 μm = 4%, then Percentage of the sample retained on 75 μm sieve is 96%,

⇒ Coarse Fraction is 96% and Fine Fraction is 4%

Therefore, the soil is a coarse-grained material.

The percentage passing 4.75mm sieve is 80, so 20% is retained on 4.75mm sieve i.e. gravel fraction= 20%

The coarse fraction passing 4.75mm sieve and retained on 75 μm sieve (sand fraction) is 80-4=76% (which is more than 50% of the total coarse fraction).

Hence, the specimen is a **Sandy soil**.

As, finer fraction is 4% which is <5%, Sand is to be checked for grading.

Given that, C_u= 1.5 and C_c= 2.1. As $C_u < 4$, one of the conditions to be well graded is not satisfied.

Therefore, the soil is classified as **Poorly graded Sand (SP)**

Example 2:

The laboratory test results of a soil sample are given below:

Percentage of particles finer than 4.75 mm = 40

Percentage of particles finer than 75 μm = 3

C_u= 6.5 and C_c= 1.5

Classify the soil as per IS soil Classification System.

Solution:

We are given that Soil finer than 75 μm = 4%, then Percentage of the sample retained on 75 μm sieve is 96%,

⇒ Coarse Fraction is 96% and Fine Fraction is 4%

Therefore, the soil is a coarse-grained material.

The percentage passing 4.75mm sieve is 40, so 60% is retained on 4.75mm sieve i.e. gravel fraction= 60%

The coarse fraction passing 4.75mm sieve and retained on 75 μm sieve (sand fraction) is 40-3=37% (which is less than 50% of the total coarse fraction).

Hence, the specimen is a **Gravely soil**.

As, finer fraction is 3% which is <5%, Gravel is to be checked for grading.

Given that, C_u= 6.5 and C_c= 1.5. As both the conditions are satisfied, it is well graded.

Therefore, the soil is classified as **Well graded Gravel (GW)**

Example 3:

The laboratory test results of a soil sample are given below:

Percentage of particles finer than 4.75 mm = 60

Percentage of particles finer than 75 μm = 35

Liquid Limit = 40% and Plastic Limit = 15%

Classify the soil as per IS soil Classification System.

Solution:

We are given that Soil finer than 75 μm = 35%, then Percentage of the sample retained on 75 μm sieve is 100-35=65%,

⇒ Coarse Fraction is 65% and Fine Fraction is 35%

Therefore, the soil is a coarse-grained material.

The percentage passing 4.75mm sieve is 60, so 40% is retained on 4.75mm sieve i.e. gravel fraction= 40%

The coarse fraction passing 4.75mm sieve and retained on 75 μm sieve (sand fraction) is 60-35=25% (which is less than 50% of the total coarse fraction).

Hence, the specimen is a **Gravely soil**.

Now, as percentage of finer fraction is 35% which is >12%, so from the Liquid limit and plastic limit values, $I_p = w_L - w_P = 40 – 15 = 25$

From Plasticity chart,

On A-line, $I_p = 0.73 * (w_L - 20) = 0.73 * (40 – 20) = 14.6 <$ obtained $I_p = 25$.

Therefore, obtained soil lies above A line. So, it is **Clayey**.

The soil is classified as **Clayey Gravel (GC)**

Example 4:

The laboratory test results of a soil sample are given below:

Percentage of particles finer than 4.75 mm = 75

Percentage of particles finer than 75 μm = 18

Liquid Limit = 42% and Plastic Limit = 32%

Classify the soil as per IS soil Classification System.

Solution:

We are given that Soil finer than 75 μm = 18%, then Percentage of the sample retained on 75 μm sieve is 100-18=82%,

⇒ Coarse Fraction is 82% and Fine Fraction is 18%

Therefore, the soil is a coarse-grained material.

The percentage passing 4.75mm sieve is 75, so 25% is retained on 4.75mm sieve i.e. gravel fraction= 25%

The coarse fraction passing 4.75mm sieve and retained on 75 μm sieve (sand fraction) is 75-18=57% (which is more than 50% of the total coarse fraction).

Hence, the specimen is a **Sandy soil**.

Now, as percentage of finer fraction is 18% which is >12%, so from the Liquid limit and plastic limit values, $I_p = w_L - w_P = 42 – 32 = 10$
From Plasticity chart,
On A-line, $I_p = 0.73 * (w_L - 20) = 0.73 * (42 - 20) = 16.1 >$ obtained $I_p = 10$.
Therefore, obtained soil lies below A line. So, it is **Silty**.

The soil is classified as **Silty Sand (SM)**

Example 5:

The laboratory test results of a soil sample are given below:

Percentage of particles finer than 4.75 mm = 75

Percentage of particles finer than 75 μm = 10

C_u= 4.5 and C_c= 2.1

Liquid Limit = 38% and Plastic Limit = 15%

Classify the soil as per IS soil Classification System.

Solution:

We are given that Soil finer than 75 μm = 10%, then Percentage of the sample retained on 75 μm sieve is 100-10=90%,

⇒ Coarse Fraction is 90% and Fine Fraction is 10%

Therefore, the soil is a coarse-grained material.

The percentage passing 4.75mm sieve is 75, so 25% is retained on 4.75mm sieve i.e. gravel fraction= 25%

The coarse fraction passing 4.75mm sieve and retained on 75 μm sieve (sand fraction) is 75-10=65% (which is more than 50% of the total coarse fraction).

Hence, the specimen is a **Sandy soil**.

Now, as percentage of finer fraction is 10% which is lies 5-12%, Soil has to be given dual symbol.

For given C_u= 4.5 and C_c= 2.1, both conditions are satisfied for the sand to be **well graded**.

From the Liquid limit and plastic limit values, $I_p = w_L - w_P = 38 – 15 = 23$

From Plasticity chart,

On A-line, $I_p = 0.73 *(w_L-20) = 0.73 * (38–20) = 13.14 < \text{obtained } I_p = 23$.

Therefore, obtained soil lies above A line. So, it is **Clayey**.

The soil is classified as **Well graded Sand mixed with Clay (SW-SC)**

Example 5:

The laboratory test results of a soil sample are given below:

Percentage of particles finer than 4.75 mm = 20

Percentage of particles finer than 75 μm = 60

Liquid Limit = 38% and Plastic Limit = 15%

Classify the soil as per IS soil Classification System.

Solution:

We are given that Soil finer than 75 μm = 60%, then Percentage of the sample retained on 75 μm sieve is 100-60=40%,

⇒ Coarse Fraction is 40% and Fine Fraction is 60%

Therefore, the soil is a Fine-grained material.

From the Liquid limit and plastic limit values, $I_p = w_L - w_P = 38 - 15 = 23$

From Plasticity chart,

On A-line, $I_p = 0.73 * (w_L - 20) = 0.73 * (38-20) = 13.14 <$ obtained $I_p = 23$.

Therefore, obtained soil lies above A line. So, it is **Clayey**.

Also, w_L =38% which lies in between 35 and 50% , clay is sub classified as **intermediate compressible.**

The soil is classified as **Intermediate Compressible Clay (CI)**

Example 6:

The laboratory test results of a soil sample are given below:

Percentage of particles finer than 4.75 mm = 20

Percentage of particles finer than 75 μm = 60

Liquid Limit = 22% and Plastic Limit = 16%

Classify the soil as per IS soil Classification System.

Solution:

We are given that Soil finer than 75 μm = 60%, then Percentage of the sample retained on 75 μm sieve is 100-60=40%,

⇒ Coarse Fraction is 40% and Fine Fraction is 60%

Therefore, the soil is a Fine-grained material.

From the Liquid limit and plastic limit values, $I_p = w_L - w_P = 22 - 16 = 6$

From Plasticity chart,

The obtained $I_p = 6$ is in the range of 4 and 7 and Liquid limit is 22% . So, the point lie in hatched zone.

The soil is classified as **CI-MI**

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