ATTERBERG LIMITS

Atterberg Limits/Consistency State

- The consistency of a soil means its physical state with respect to the moisture content present that time.
- This term is related to fine grained soil
- In clay soil shape of the particles has great influence rather than size on engineering properties.
- These properties are very much influence by variation in moisture content.
- Strength of clay varies with change in moisture content
- Clay is very hard in dry state while it behaves as viscous fluid (almost zero shear strength at high moisture content
- There are four consistency states for clay (cohesive soil)
- Solid State
- Semi-Solid State
- Plastic State
- Liquid State

Atterberg Limits

- Atterberg a Swedish soil scientist defined the boundaries of the above four states in term of limits as follows
- **Shrinkage Limit:** It is the moisture content at which a soil changes from solid state to semi-solid state.
- **Plastic Limit:** It is the moisture content at which a soil changes from semi-solid state to plastic state.
- **Liquid Limit:** It is the moisture content at which a soil changes from plastic state to liquid state.
- The transition from one state to the next is gradual, and according to above definitions.
- It is very difficult to find the moisture content at which change of state occurs.
- The most important of these are Liquid limit and plastic limit, which indicate the state of plastic state. Plasticity enables a materials to undergo large irrecoverable deformations without cracking or crumbling. Plasticity is independent of soil size. For example Bentonite and kaolinite clay have same particle size but different plasticity values. It depends upon, shape, minerals of clay , nature of adsorbed layer

Shrinkage Limit

- It is that moisture content at which a reduction in moisture will not cause a decrease in the total volume of soil mass, but an increase in moisture will result in an increase in volume of soil mass.
- This happens due to the fact that at a certain point during drying, air begins to enter the soil mass and the volume decrease is appreciably less than the volume of water lost. As shown in Figure 1

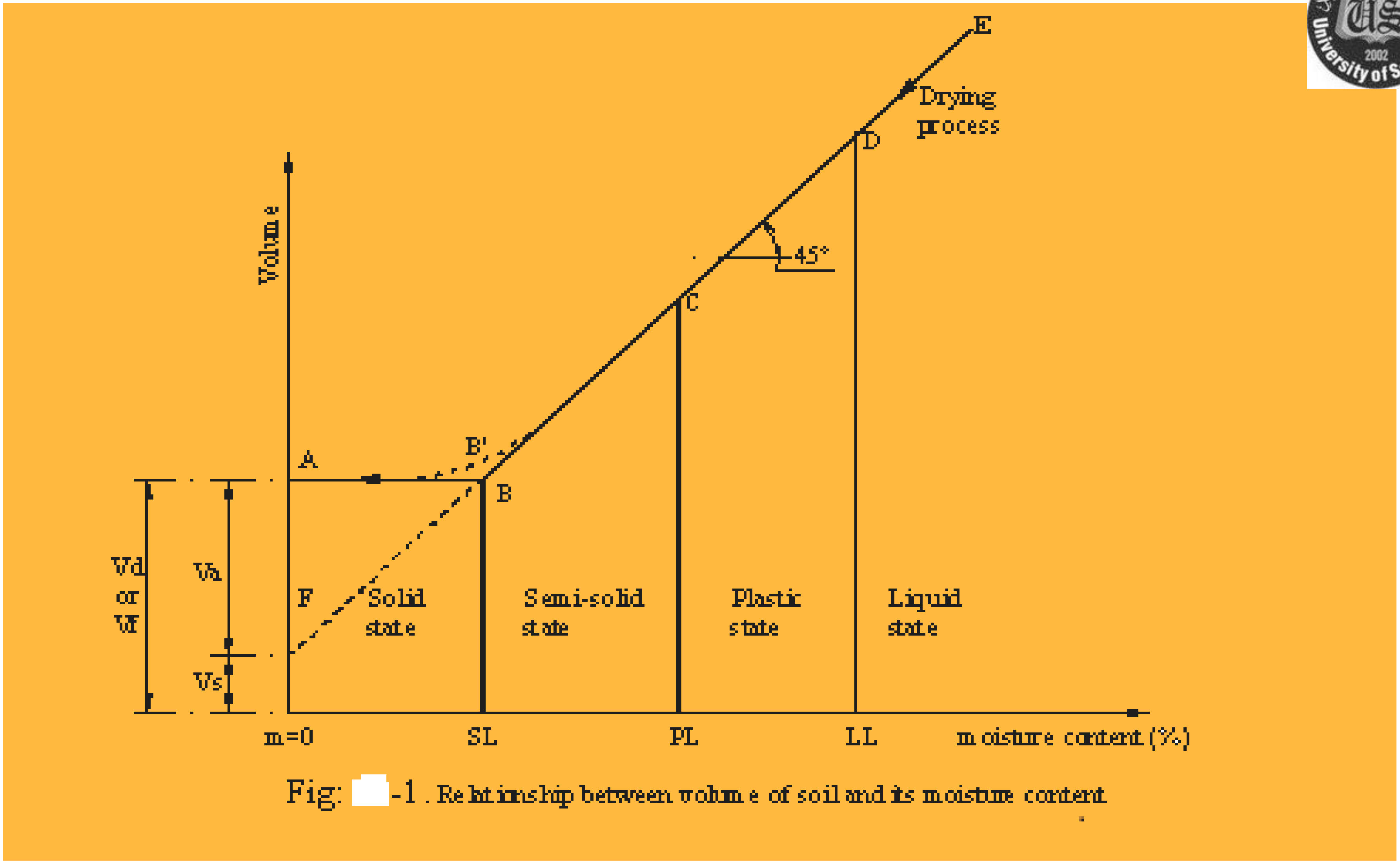


Figure 01:Relationship between volume and moisture content

Shrinkage Limit

- During the drying from point “E” to “B” the reduction in the total volume of the soil mass is equal to the volume of moisture lost and the soil shrink
- As the drying continue from Point “B” to point “A”i.e, up to zero % moisture content, no appreciable volume change is observed, and the soil ceases to shrink.
- At this point the soil changes it color from dark to light.
- It should be kept in mind that, at shrinkage limit the degree of saturation is 100 percent.
- The shrinkage limit however gives some idea about the soil structure e.g,, a dispersed structure will generally produce a low shrinkage limit while a flocculated structure show a high shrinkage limit

Shrinkage Limit

- It is also of much importance for certain soil types. which exhibit considerable volume change (i.e., shrinkage & swell) with changes in moisture content.
- It should be noted that smaller the shrinkage limit, the larger will be change in volume of soil due to moisture changes.
- The concept of shrinkage limit of cohesive soil is helpful in studying the behavior of slopes of dams, highway embankments and cuts, especially to check the possibility of development of shrinkage cracks.
- In rainy seasons these cracks get filled with water, which increase the weight of earth mass due to saturation and exert hydrostatic pressure and eventually, may cause a landslide.
- Higher the liquid limit of a soil, higher is the shrinkage potential.
-

Shrinkage limit

- With the increase of moisture in a soil mass, the thickness of moisture film around the clay particle increases, until at a certain state the cohesion is reduced to such a low level that soil behaves as a liquid.
- At this stage the soil particles are separated by water so widely that the shear strength of the soil mass is almost lost and the particles tend to flow under the influence of gravity.
- When this soil is subjected to drying, it looses its moisture and the particles which were separated by water get closer due to decrease in thickness of moisture film and the soil shrinks.
- During drying process the surface tension forces of the pore water, compress the particles together into a compact mass and the volume of soil decreases.

Shrinkage limit

- The loss of moisture accompanied by the decrease in volume continues down to the shrinkage limit moisture content.
- When this moisture Content is attained, no further decrease in volume or shrinkage takes place.
- At this stage the menisci of the moisture tear off (Fig: 2) and air begins to enter the voids and further drying causes no volume change.
- Due to fine particles of clay soil, the break of meniscus and air entry occurs at considerable low moisture content resulting in low shrinkage limit for clay soil.
- Since clay soils have high liquid limit the amount of moisture loss up to the shrinkage limit and the resulting volume is very high, and therefore very big cracks develop.

Concept of surface tension forces and induced compressive stresses (a) Particle separated due to thick moisture film
(b) Meniscus contracting due to drying process (c) Meniscus tending to tear off (d) Meniscus fully torn off allowing air entry

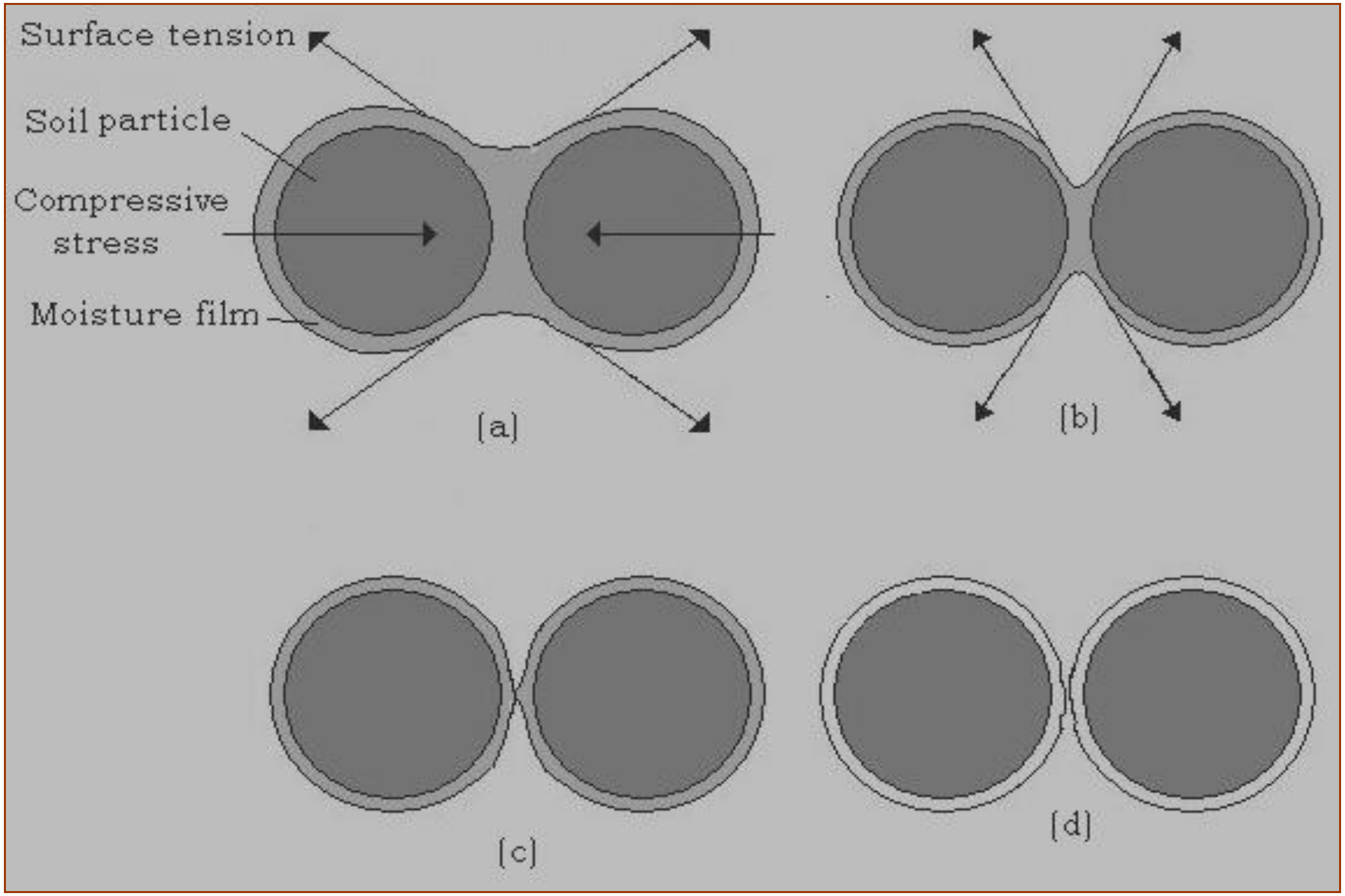


Fig 02

Shrinkage Limit

- The soil which show higher shrinkage upon drying , also swell more upon wetting are known as Expansive soil

Relationship between Atterberg's limits and volume change

Volume change potential	Plasticity index (%)		Shrinkage limit (%)
	Arid area	Humid area	
Little	0-15	0-30	>12
Moderate	15-30	30-50	10-12
High	>30	>50	<10

Determination Shrinkage Limit

- Take paste of saturated soil (passing no.40 sieve) in the shrinkage mould.
- **OBSERVATIONS**
- Initial weight of saturated sample (paste) = W_i
- Initial volume of saturated sample = Volume of mould = V_i
- Final volume of sample after drying = V_f or V_d
- Dry weight of sample = W_d
- Initial (Total) weight of water in the sample = $W_i - W_d$
- Weight of water lost due to drying of the original sample up to the shrinkage limit = $(V_i - V_f)\,\gamma_w$
- As the drying starts, there is a loss of moisture and the volume decreases, which continues to decrease up to the shrinkage limit and sample still remains saturated .
- Further drying reduces the moisture but keeping the volume constant equal to V_d , since air begins to enter the voids.

Determination Shrinkage Limit

- **CALULATIONS**

Weight water at shrinkage limit = $(W_i - W_d) - [(V_i - V_f)\,\gamma_w]$

Moisture content at shrinkage limit = $\dfrac{(W_i - W_d) - (V_i - V_f)\,\gamma_w}{W_d}$

$$SL = \left[m - \left(\frac{V_i - V_f}{W_d}\right)\gamma_w \right] \times 100$$

Alternate Method for determination of Shrinkage Limit

- Volume of soil in dry state *(V_d)* = Volume in saturated state at shrinkage limit

- Volume of void in dry state *(V_v)* = Volume of water *(V_w)* at shrinkage limit (saturated soil)

- Volume of voids in dry state *(V_v)* = V_d - V_s

- Hence,
- Volume of water *(V_w)* at shrinkage limit = $V_d - \frac{W_d}{\gamma_s}$

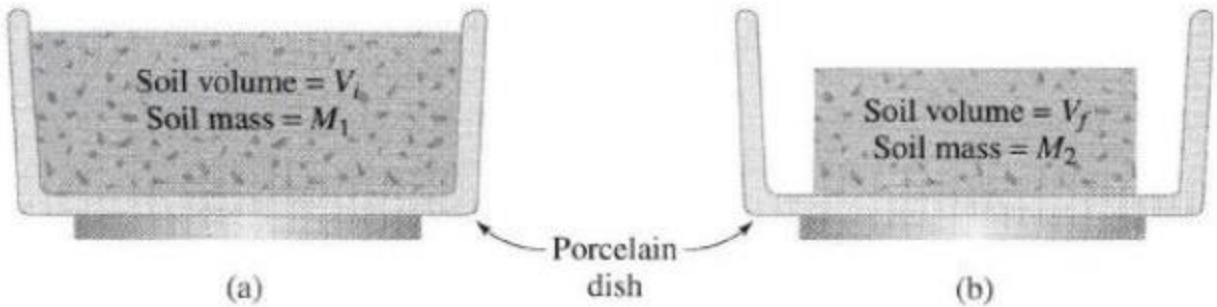
Weight of water at shrinkage limit = $(V_d - \frac{W_d}{\gamma_s})\gamma_W$

Moisture content at shrinkage limit (S.L.) = $$\frac{(V_d - \frac{W_d}{\gamma_s})\ \gamma_w}{W_d}$$

S.L.= $$\frac{V_d\ \gamma_W}{W_d} - \frac{W_d\ \gamma_W}{W_d\ \gamma_s}$$

S.L. = $$\frac{\gamma_w}{\gamma_d} - \frac{1}{G}$$

Determination Shrinkage Limit



$$SL = w_i(\%) - \Delta w(\%)$$

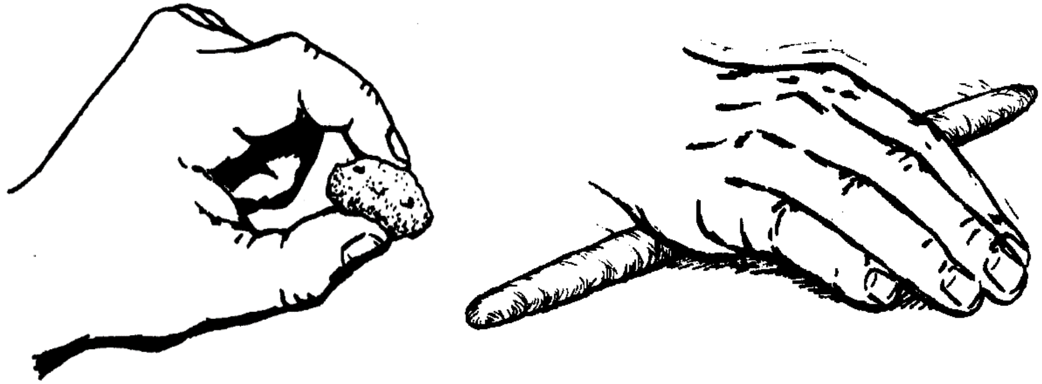
$$w_i(\%) = \frac{M_1 - M_2}{M_2} \times 100$$

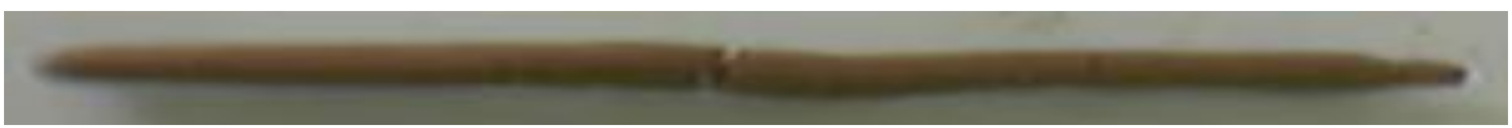
$$\Delta w(\%) = \frac{(V_i - V_f)\rho_w}{M_2} \times 100$$

Plastic Limit

- The moisture content at which a soil can be rolled into threads of 1/8 ″ (3.2mm) diameter without cracking and crumbling.
- Threads thinner than 1/8 ″ (3.2 mm) diameter are possible, if the moisture is higher than the plastic limit.
- And if the moisture is less than plastic limit the thread will crumble before reaching the required diameter of 1/8 ″ (3.2 mm).
- Sandy soil does not have plastic limit and known as non plastic soil.
- Fine grained soil (Clay and Silts) has plastic limits, and known as plastic or cohesive soil
- The plastic limit depends upon amount and nature of clay minerals present in soil mass
- Higher clay contents usually give higher plastic limits
- Plastic limit increases as the decrease in grain size

Plastic Limit





Application of Plastic Limit

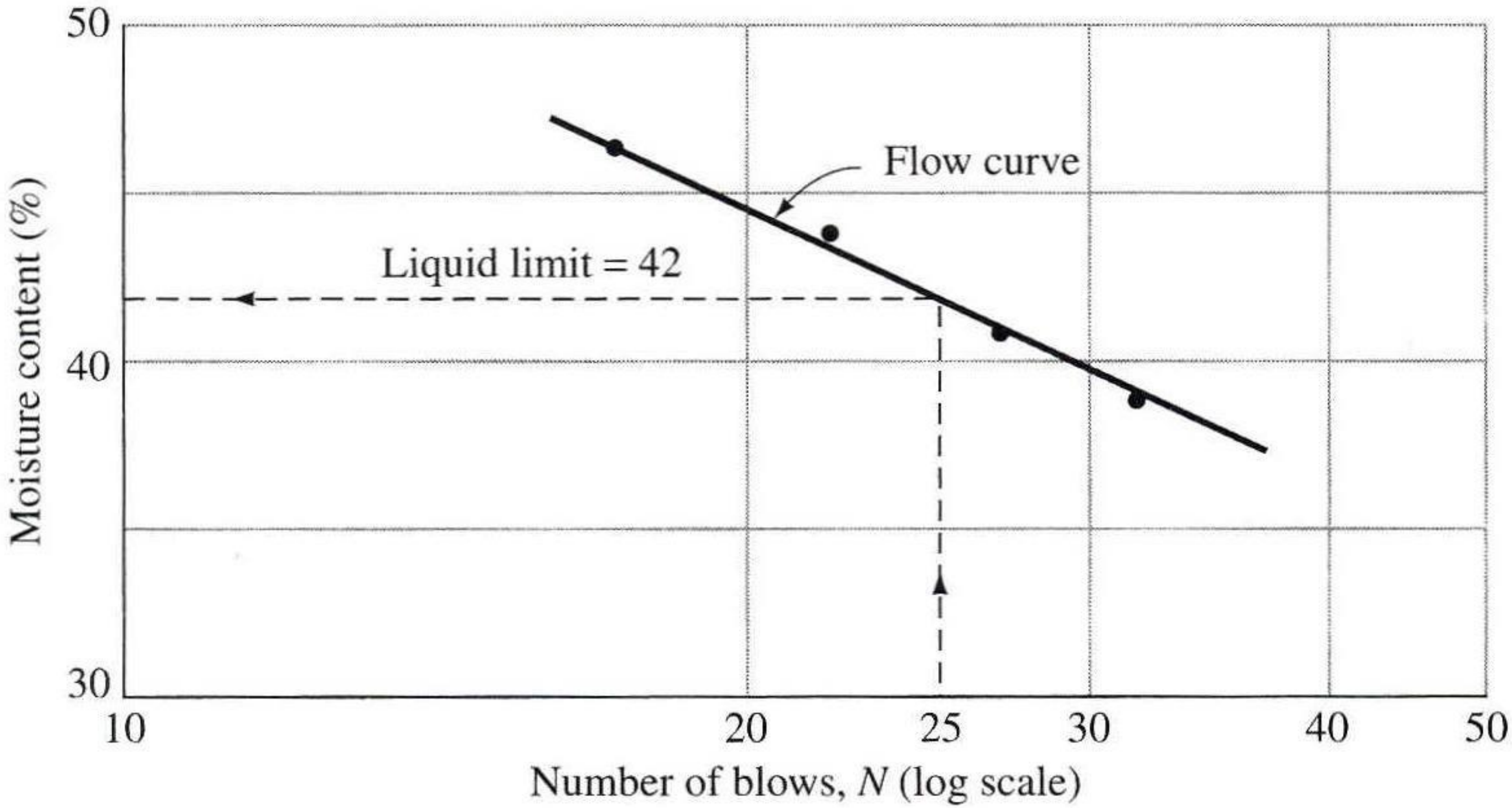
- Plastic limit is used to find the :
  - Plasticity index
  - Liquidity index
  - Optimum Moisture Content
  - Classification of soil

Liquid Limit

- That moisture content at which 25 blows of Cassagrande apparatus closes a standard groove cut in the soil paste along a distance of 12.7 mm (0.5 in).
- The moisture content which gives a penetration depth of 20mm of the standard cone (fall cone test) into the soil, when the cone is released for 5 seconds.
- It is the cohesion which retards the flow of soil to close the groove
- Therefore liquid limit give idea about cohesion
- Liquid limit increases as the grain size decreases.
- Higher value of liquid limit indicates high cohesion, and higher percentage of clay.
- Each blow indicate 1 g/cm^2 shear strength. In other words shear strength of soil at liquid limit is 25.0 g/cm^2.

Liquid Limit

- **Three Point Method**



Liquid Limit

- **One Point Method**

$$LL = w_n \left(\frac{N}{25}\right)^{\tan\beta}$$

$$\tan\beta = 0.121$$

- W_n = Moisture Content N Blows
- Assumes a constant slope of the flow curve.
- The slope is a statistical result of 767 liquid limit tests.
- **Limitations:**
- Good results can be obtained only for the blow number between 20 to 30.

Liquid Limit

Plasticity Index

- Plasticity Index indicates the range of moisture through which a cohesive soil behaves as a plastic material
- It is the numerical difference between liquid and plastic limits. It is expressed as

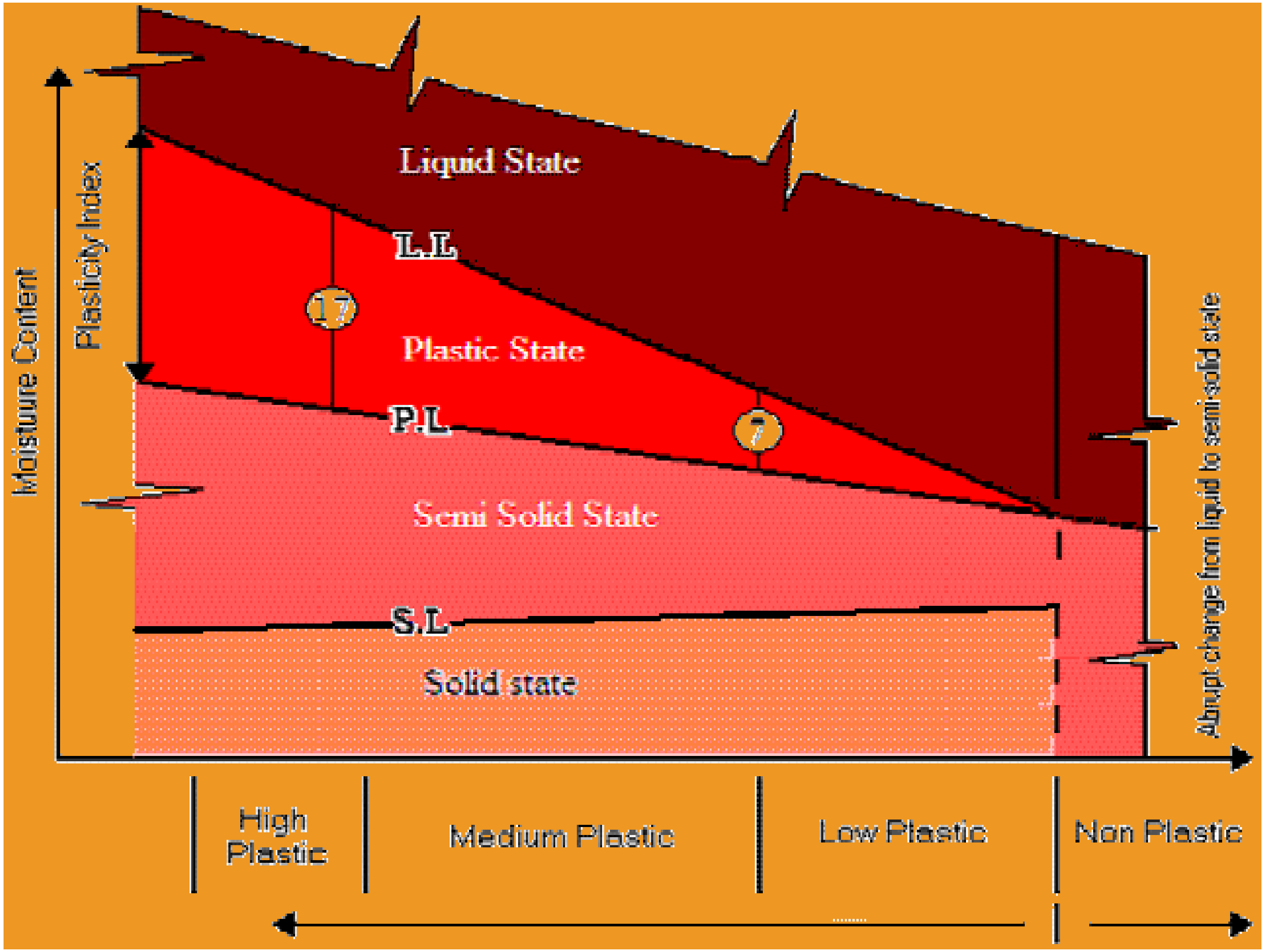
$$P.I = L.L. - P.L \qquad (\%)$$

- It can never be negative
- When P.I is zero, (i.e. Plastic limit = Liquid Limit), the soil is termed as Non-cohesive, Non-plastic

Atterberg defined the range of plasticity index as under

- P.I. = 0 The soil is non-plastic and non-cohesive.
- P.I. < 7 The soil is low plastic and partly cohesive.
- P.I. 7 - 17 The soil is medium plastic and cohesive.
- P.I. > 17 The soil is highly plastic and very cohesive.

Change of liquid, plastic and shrinkage limits with plastic properties (not to scale, just to show comparison)



Liquidity Index

- The ratio of difference between the moisture content and plastic Limit to the plasticity index

$$L.I = \frac{m - P.L}{L.L - P.L} = \frac{m - P.L}{P.I}$$

- L.I < 0, (i.e. negative value) the field moisture content is less than the plastic limit, and hence the soil is in a semi-solid state.

- When $0 \le$ L.I. ≤ 1, The soil is in a plastic state
- When L.I. > 1, The soil is in a liquid state.

Consistency of a Soil at its Natural Moisture Content

- $L.I < 0$, The soil is in a semi-solid or solid state (hard)
- $0.00 < L.I \leq 0.25$, The consistency is stiff or hard
- $0.25 < L.I \leq 0.50$, The consistency is medium
- $0.5 < L.I \leq 0.75$, The consistency is soft
- $0.75 < L.I \leq 1$, The consistency is very soft
- $L.I > 1$, The soil is in a liquid state

Flow Index

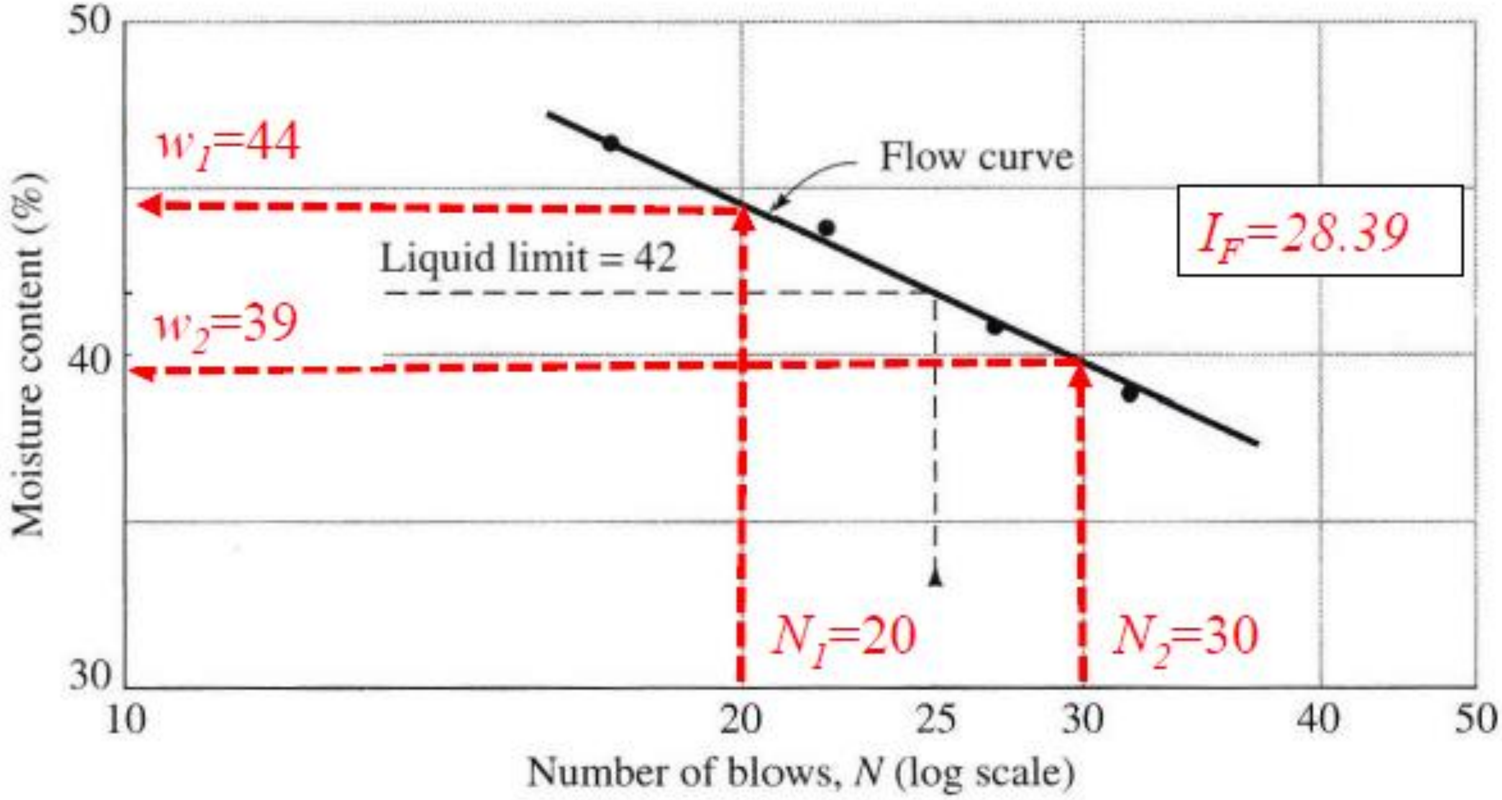
- The slope of the flow curve (graph between log N and moisture content drawn for the determination of liquid limit) is known as the flow index and is equal to

- F.I $$\frac{m.c.}{Log\ N} = \frac{m_1 - m_2}{\log N_2 / N_1}$$

- F.I $$\frac{m_1 - m_2}{\log N_2 - \log N_1}$$

- Steep curve means higher flow index, and lesser shear strength
- Any two soil having the same plasticity index and/or liquidity index may have different value of flow index

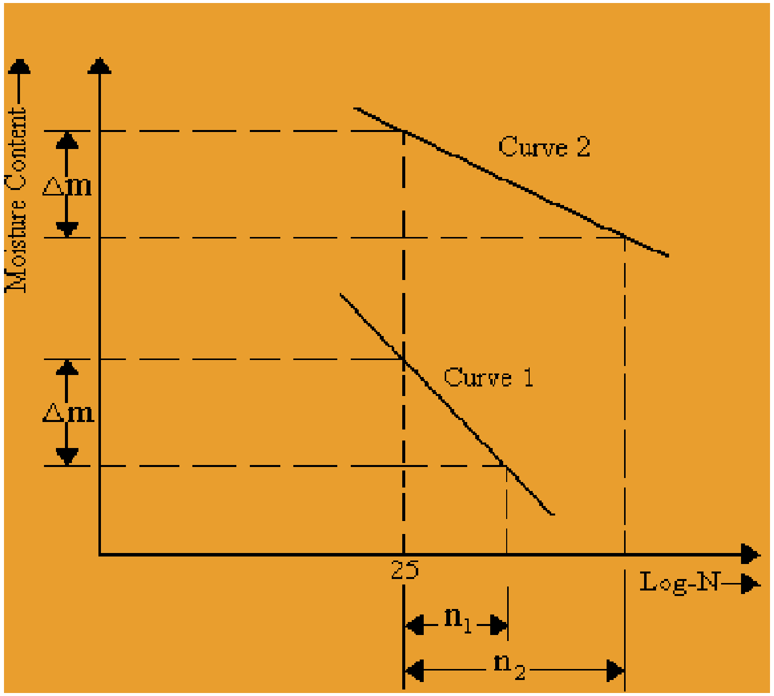
Flow Index



50
40
30
10
20
25
30
40
50
Moisture content (%)
Number of blows, N (log scale)
Flow curve
Liquid limit = 42
w1=44
w2=39
N1=20
N2=30
IF=28.39

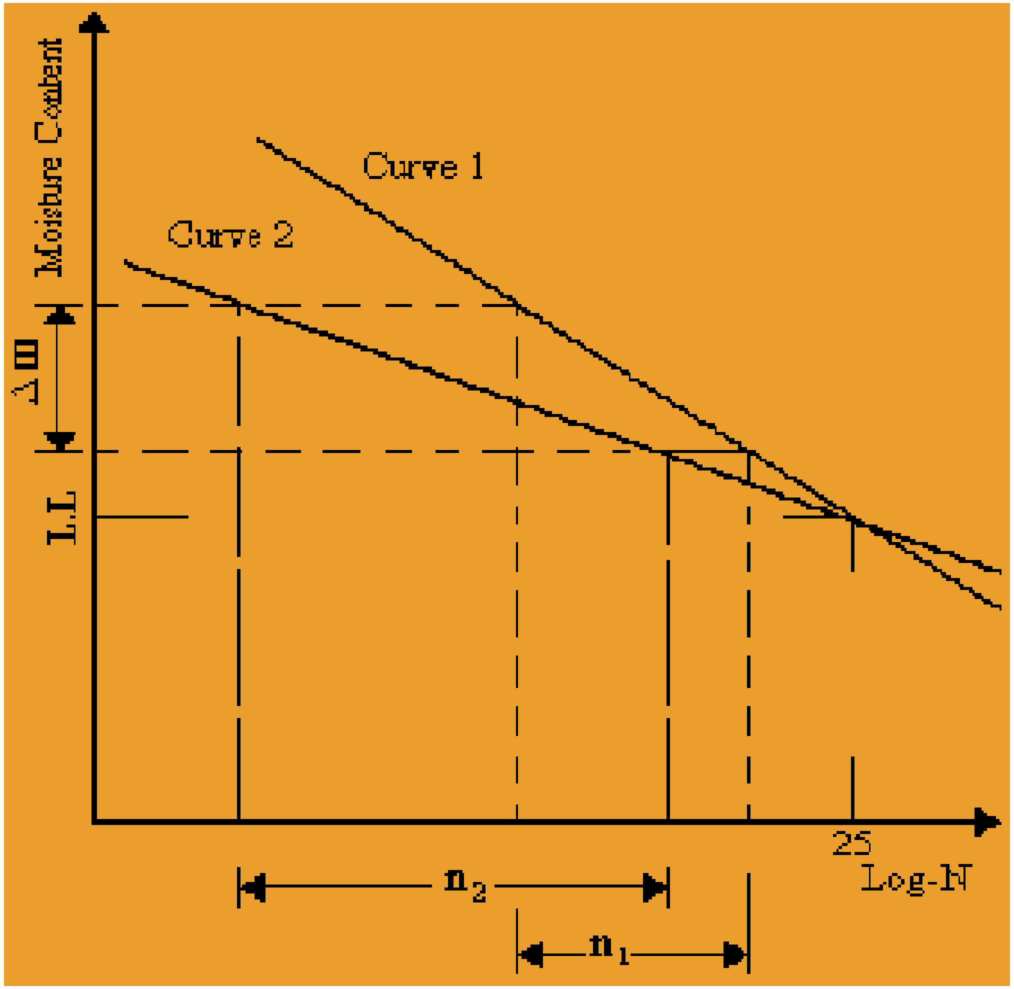
Case-I: Two soils having the same values of plasticity index

The Flow Curves of two soil having same plasticity index indicated by curve-1 and curve-2. The curve-1 is steep and gives higher flow index as compared to curve-2 which is less steep. No. of blows are indicative of the resistance to deformation or shear strength. For the same drop of moisture Δm, the No. of blows for flat curve increase very much, indicating higher shear strength (Curve-2). Therefore, the soils with same plasticity index may posses different shear strength.



Case-II: Two soils having the same value of liquid limit

This also conclude same that the curve-2 which has greater number of blows has higher shear strength



Toughness Index

- Soils having same values of plasticity indices may vary in toughness. This property of a soil is expressed by the toughness Index

$$T..I. = \frac{P.I.}{F.I.}$$

- Toughness and dry strength increases with increases with increase in toughness index

Particle Size Distribution

- The percentage of various particle sizes present in a soil is known as particle size distribution or gradation.
- Particle size analysis is made by sieving or by sedimentation.
- The particle size distribution is better explained in the form of particle size distribution curve or gradation curve.
- A gradation curve is drawn by plotting the percentage finer than various equivalent particle sizes (%age passing) and sizes of sieve.
- Particle size analysis is performed by sieving or by sedimentation
- Sieving method – when particle size $\geq$ 0.074 mm
- Sedimentation method (Stokes Law)– when particle size < 0s.074mm

Significance of Particle Size Distribution:

- Engineering classification of soils.
- Selection of the most suitable soil for construction of roads, airfields, levees, dams and other embankments.
- To predict the seepage through soil (although permeability tests are more generally used)
- To predict the susceptibility to frost action.
- Selection of most suitable filter material.

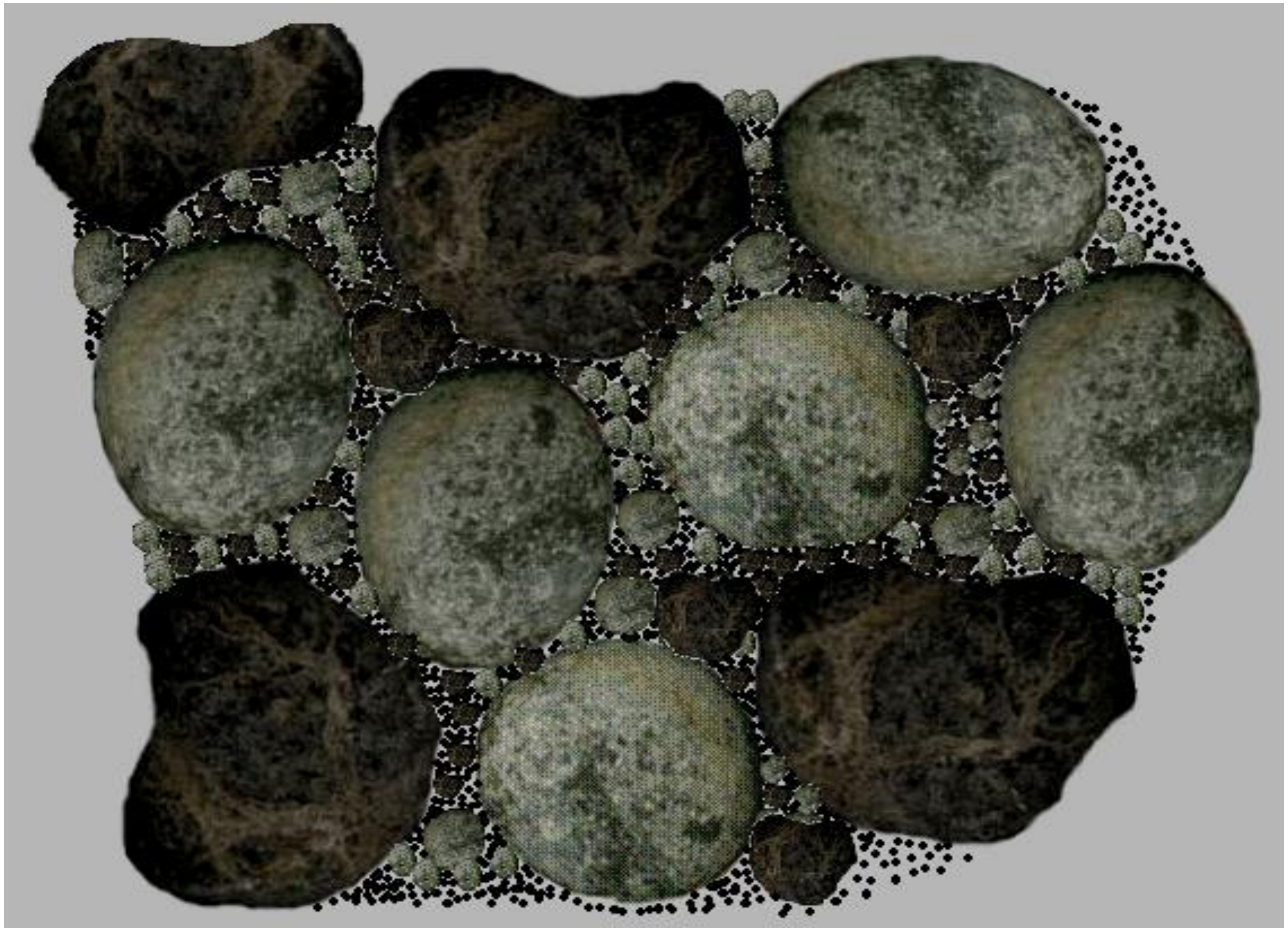
Gradation Curve

- A gradation curve is drawn by plotting the percentage finer (%age passing) as ordinate against the sizes as abscissa
- The gradation curves indicate the type of soil, and provide very important information related to the properties and behavior of soil

Gradation of Soil

- There are following three types of Gradation
  - Well Graded
  - Uniformly Graded
  - Poorly Graded
- **Well Graded**
- Soil containing an assortment of particles with a wide range of sizes.
- The gradation curve cover a wide range of particle sizes.
- This gradation produces an ideal particle size distribution for optimum packing, because smaller particle always available to fill the voids between bigger particles
- **Merits**
- High shear strength, because there is more particle contact
- High density, since voids are almost eliminated
- Reduced compressibility, because there are no or less voids are available to allow volume changes
- Low permeability
- High bearing capacity, because particles being densely packed

Gradation of Soil

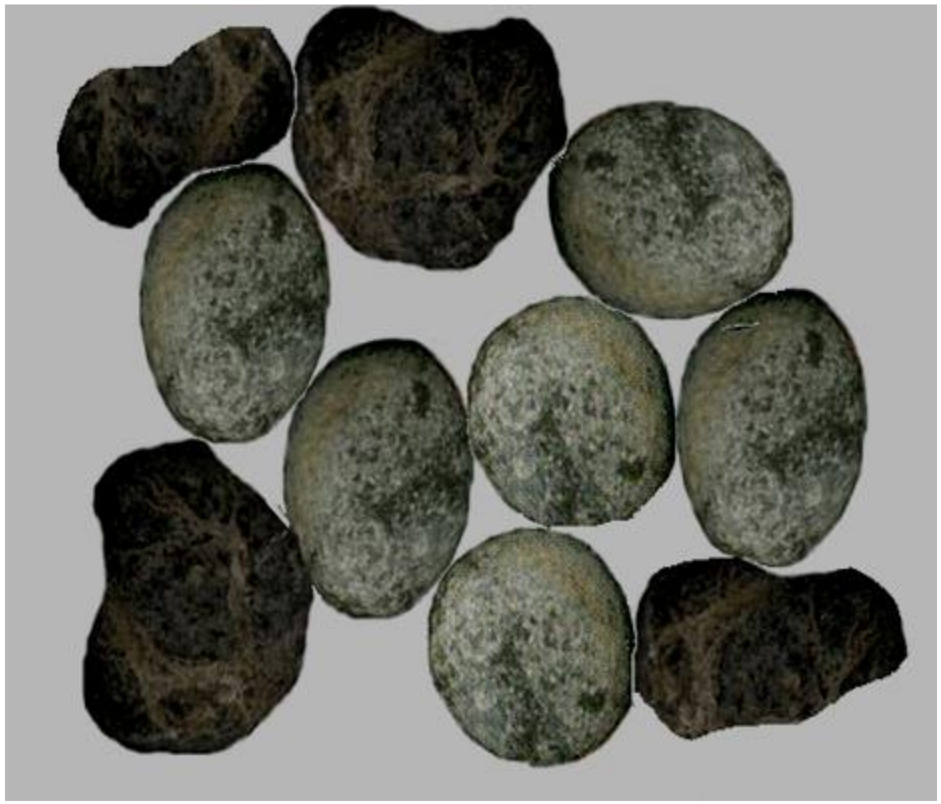


Well graded

Ideal packing, due to particles ranging from large to small sizes

Gradation of Soil

- **Uniformly Graded**
- A uniformly graded soil is defined as a soil containing particles having a limited range of sizes (Almost the same sizes)



Uniformly graded

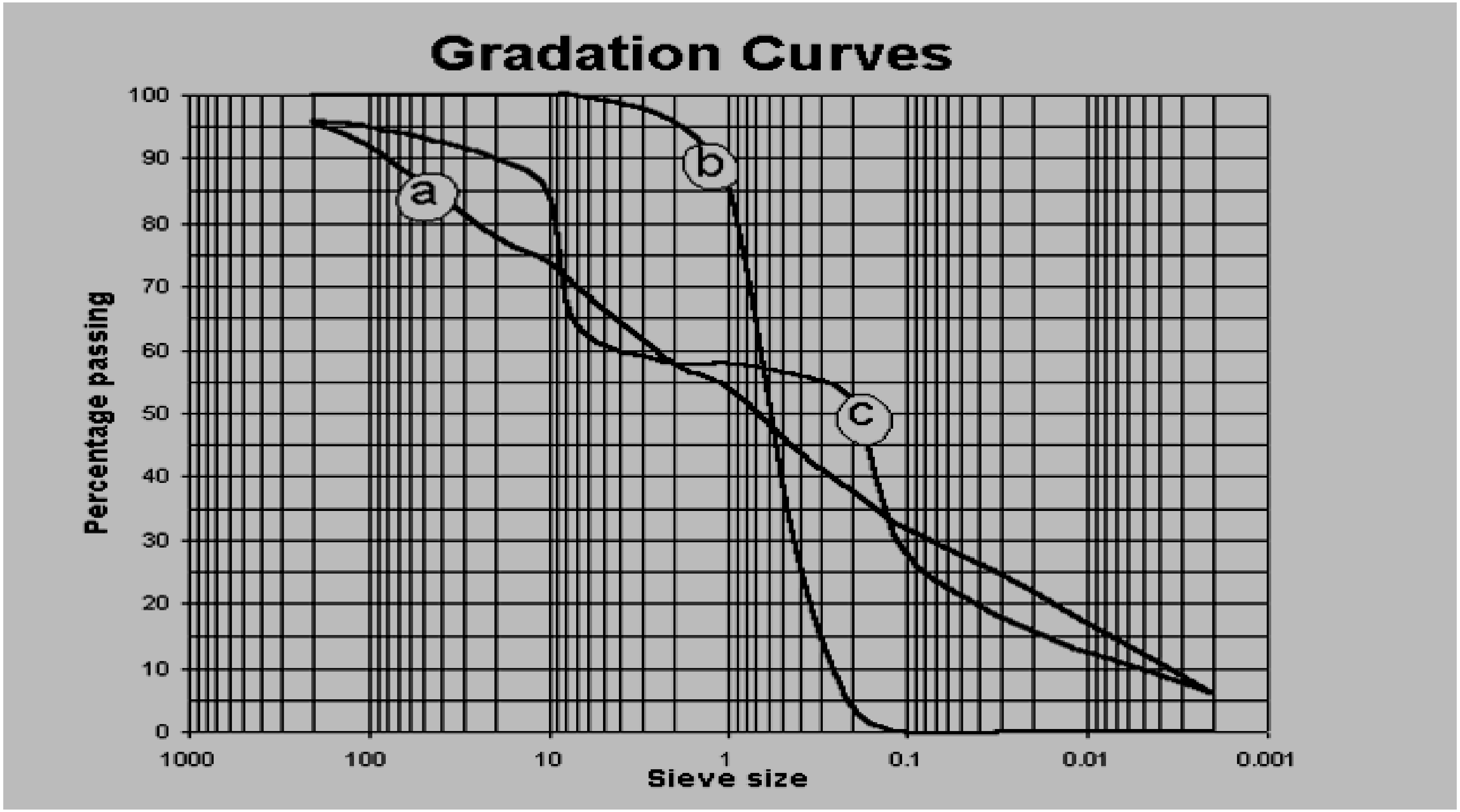
Loose packing, as smaller particles to fill voids missing

Gradation of Soil

- **Poorly Graded**
- A poorly graded soil is defined as a soil containing particles of varying sizes with intermediate particle sizes missing.
- The gradation curve of a poorly graded soil show steps indicating an excess of certain particle sizes, and a deficiency of others

Gradation of Soil

- (a) well graded soil
- (b) uniformly graded soil
- (c) poorly graded soil.



Application of Gradation Curve

- Determination of Effective Grain (Particle) Size.
- Determination of Uniformity co-efficient.
- Determination of co-efficient of Curvature.
- Determination of percentage of different soil types in a soil sample e.g., sand, silt, clay.
- Determination of percentage larger or finer than a given size.
- Classification of soil.
- Design of filters.
- Concrete mix design.

Effective Grain Size

- **Effective Grain Size**
- It is the size of the sieve through which only 10% of the soil grains pass.
- It is denoted by D_{10}
- **Coefficient of Uniformity**
- The uniformity coefficient C_u is defined as the ratio of D_{60} by D_{10}.

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

- Where D_{60} is the grain diameter at 60% passing, and D_{10} is the grain diameter at 10% passing
- So when C_u is greater than 4 to 6, it is understood as a well graded soil and
- When the C_u is less than 4, they are considered to be poorly graded or uniformly graded. Uniformly graded in the sense, the soils have got identical size of the particles.
- For single grained soil (having same size) C_u is Unity

Co-efficient of curvature or Co-efficient of Concavity

- It is given by following formula

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

- It is also known as coefficient of gradation (C_g).
- C_c = 1, represents that all the soil particles have the same size, and the soil is uniformly graded.
- $1 < C_c < 3$ Soil is Well Graded

Relative Density (D_r) or Density Index (I_D)

- The term relative density is used to express the state of compactness of a granular soil.
- The following relationship between the void ratio values is termed as the relative density

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

$$Dr = I_D = \frac{\gamma_{d\,max}}{\gamma_d}\left(\frac{\gamma_d - \gamma_{d\,min}}{\gamma_{d\,max} - \gamma_{d\,min}}\right)$$

- e = Void ratio of soil Deposit (In-situ state)

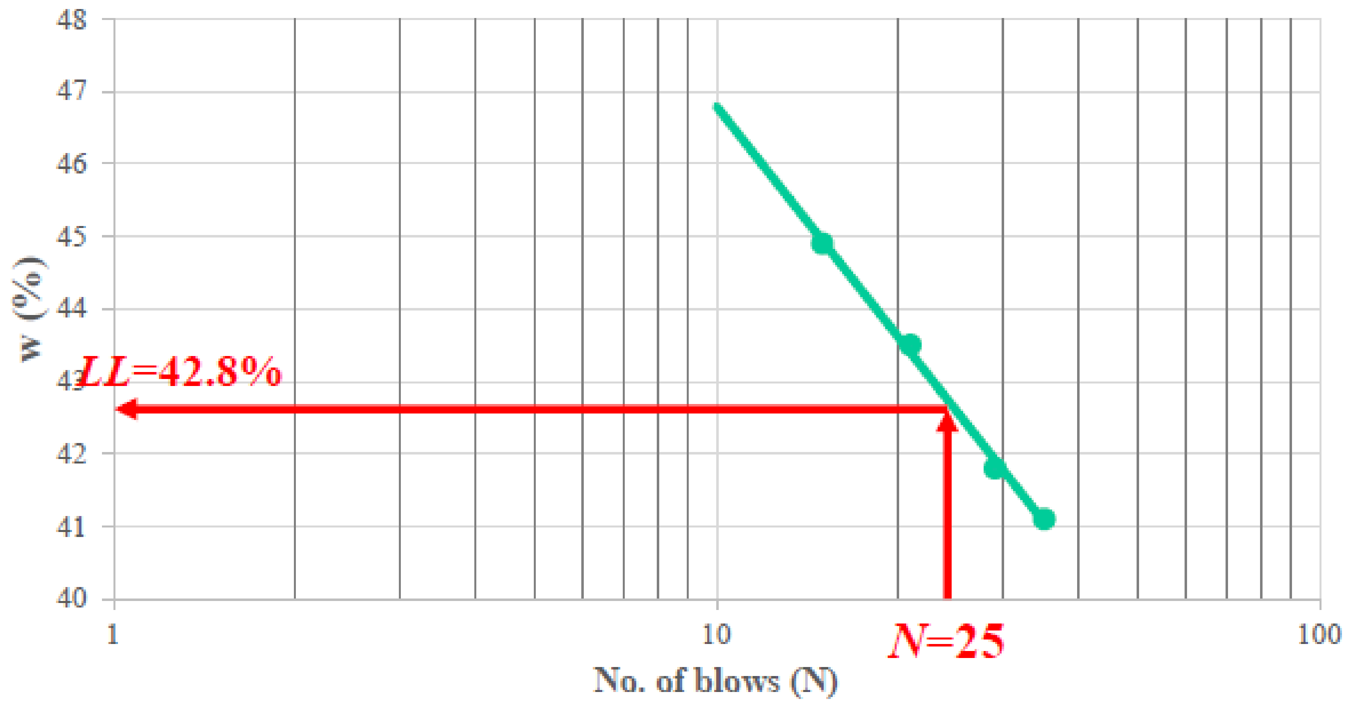
Practice Problem

The following data were recorded from a *LL* test on a silty clay;

No. of blows	Water content (%)
35	41.1
29	41.8
21	43.5
15	44.9

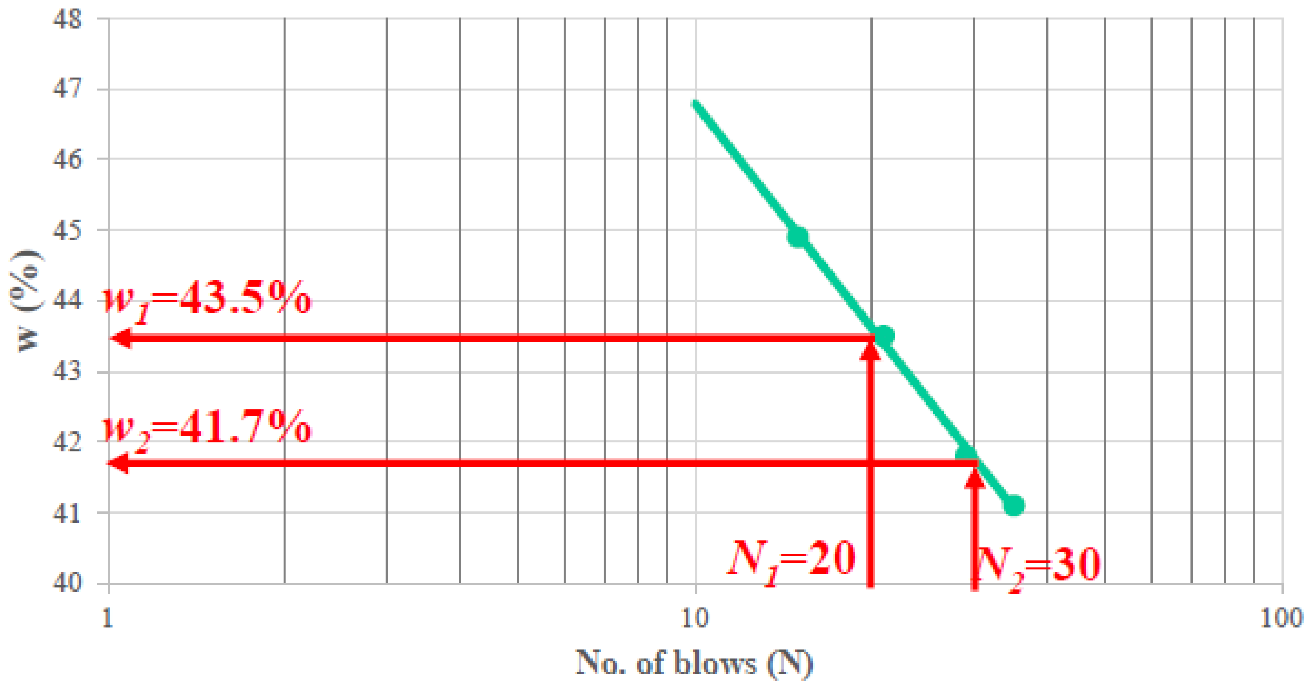
If *PL*=23.4%, determine *LL*, *flow index*, and the *toughness index*.

Practice Problem



$$LL = 42.8\%$$
$$PL = 23.4\%$$
$$PI = 42.8 - 23.4$$
$$PI = 19.4\%$$

Practice Problem



$$I_F = \frac{w_1 - w_2}{\log\left(\frac{N_2}{N_1}\right)} = \frac{43.5 - 41.7}{\log\left(\frac{30}{20}\right)}$$

$I_F = 10.22$

$I_t = I_P / I_F$

$I_t = 19.4/10.22$

$I_t = 1.898$

Problem 01

Four different types of soil were encountered in a big project. Their LL, PL, and natural moisture content (NMC) are given below;

Type of Soil	Liquid Limit (%)	Plastic Limit (%)	NMC (%)
1	120	40	150
2	64	32	34
3	60	30	30
4	65	32	25

Determine liquidity index and comment on the state of soil in the field.

$$I_L = \frac{w_n - PL}{LL - PL}$$

- **Problem 02:**
- A soil specimen has liquidity index of 0.2, liquid limit of 56% and plasticity index of 20%. Determine the natural moisture content of this soil specimen.

Problem 3

Liquid limit test carried out on two samples of clay resulted in the following information.

	Test #	1	2	3	4
Sample #1	w (%)	120	114	98	96
	No. of blows	7	10	30	40
Sample #2	w (%)	96	74	45	30
	No. of blows	9	15	32	46

PL for sample #1 is 40% and PL for sample is 32%. Determine the flow index and toughness index for two samples.

THANK YOU!