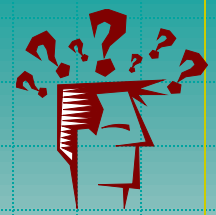
Chapter 03: Soil Deposit, Type, Structure and Classification



Main Soil Type/ Classification Schemes

- Classification based on Origin/ Deposition
- Classification based on Grain Size
- Classification based on Cohesive Properties
- Classification based on Use

Chapter 03: Soil Deposit, Type, Structure and Classification



Soil Deposit

- Organic Soil Deposit
  - OC: ≤ 5%; Inorganic soil
  - OC: 6 – 20% Organic silt or Organic clay
  - OC: 21 – 74% Silty or Clayey Organic soil
  - OC: ≥ 75%; Peat soil;
    - High natural moisture content (up to 1500%).
    - High compressibility .
    - Low strength in natural conditions.
- Inorganic or Mineral Soil Deposit

Organic Soil Deposit



Typical Organic Soil Deposit →

MZA

Inorganic or Mineral Soil Deposit



- Inorganic Soil Deposit
  - Residual Soil
    - Laterite
    - Lateritic
    - Black Cotton
  - Sedimentary/ Transported Soil
    - Water Transported
    - Glacier Transported
    - Wind Transported
    - Gravity Transported

Inorganic or Mineral Soil Deposit



Residual Soil

- Lateritic: Yellowish or Reddish; Fine grained
- Laterite: More than 90% Coarse Grained
- Black Cotton: Black, Swelling Properties; Montmorillonite

Residual Soil Deposits



Typical Residual Soil Deposit ↑

MZA

Transported/ Sedimentary Soil Deposits



Typical Transported/ Sedimentary Soil Deposit

↑

MZA

Water Transported Soil Deposits



Alluvial Soil

- Deposited in running water; River Bed Soil
- Sorted material

Lacustrine Soil

- Deposited in quiet water; Lake deposit
- Verved secondary structure; Verved clay
- Thin alternate layers of coarse and fine soils

Marine Soil

- Deposited in saline water
- Fine grained

Marl

- Calcium carbonate or Lime rich soil
- Also known as Mudstone ot Marlstone

Alluvial Soil Deposits



Typical Alluvial Soil Deposit ↑

Lacustrine Soil Deposits



Typical Lacustrine Soil Deposit ↑

Marine Soil Deposits



Typical Marine Soil Deposit ↑

Marl Soil Deposits



Typical Marl Soil Deposit ↑

MZA

Water Transported Soil Deposits



Alluvial Soil

- Deposited in running water; River Bed Soil
- Sorted material

Lacustrine Soil

- Deposited in quiet water; Lake or Haor deposit
- Verved secondary structure; Known as Verved clay
- Thin alternate layers of coarse and fine soils

Marine Soil

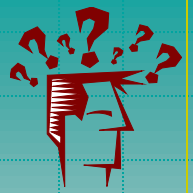
- Deposited in saline water
- Fine grained

Marl

- Calcium carbonate or Lime rich soil
- Also known as Mudstone ot Marlstone

MZA

Glacier Transported Soil Deposits



Glacier Transported Soil Deposits

The general term to describe glacier transported soil deposit is Glacial Drift: There may be presence of both sorted and unsorted materials.

MZA

Glacier Transported Soil Deposits



Glacial Till

- **Heterogeneous combination of unstratified sediments**

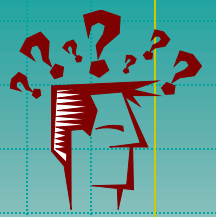
Boulder Clay

- Composed of clay, boulders of intermediate size, or both

Moraine

- Land form or topographic surface after the recession of the glacier

Glacier Transported Soil Deposits





Eskers

Form of long winding ridges



Erratics

Deposits of large size particles (boulders)



Drumlin

Asymmetrical, canoe shaped hills with aerodynamic profiles

Glacier Transported Soil Deposits



Unsorted materials known as Glacial Till ↑

Glacier Transported Soil Deposits



Sorted materials are Stratified ↑

Glacier Transported Soil Deposits



↑ Boulder clay: Glacial till composed of clay, boulders of intermediate size, or both.

Glacier Transported Soil Deposits



↑ Moraine: Formation of irregular hills or mounds is called moraine.

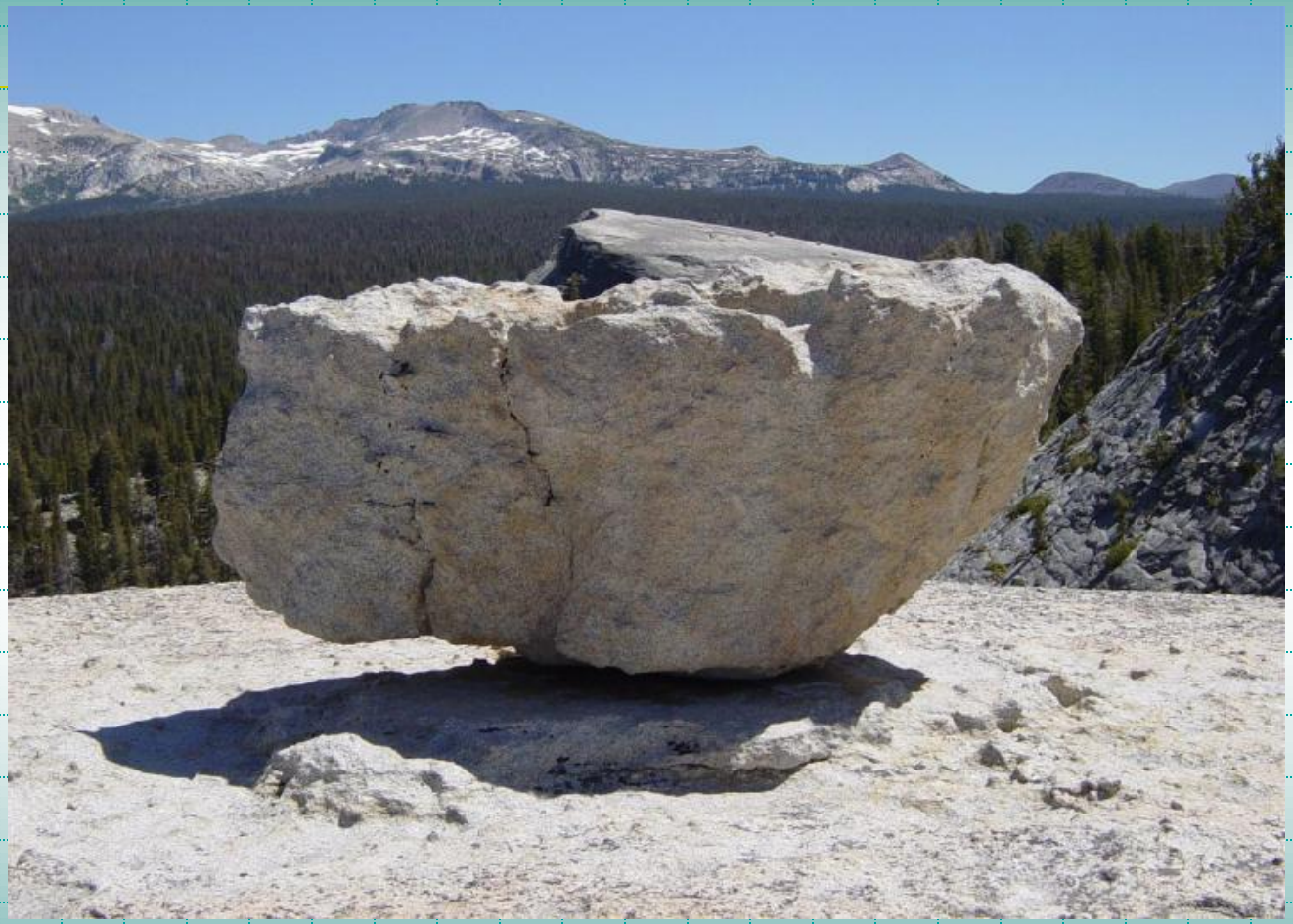
MZA

Glacier Transported Soil Deposits



↑ Eskers: Glacial deposit in the form of long winding ridges is called eskers.

Glacier Transported Soil Deposits



↑ Erratics are deposits of large size particles picked up by glacier to a new location.

Glacier Transported Soil Deposits



↑ Drumlins are asymmetrical, canoe shaped hills with aerodynamic profiles made mainly of till.

Wind Transported Soil Deposits



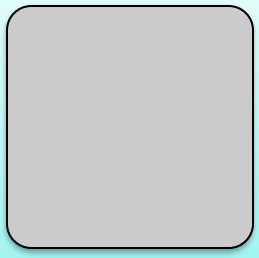
Wind Transported Soil Deposits

Common name of wind transported soil is
Aeolian soil

MZA

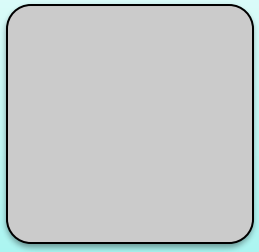
Wind Transported Soil Deposits





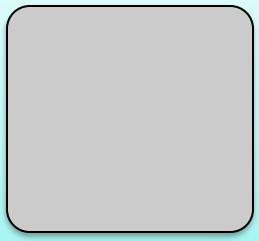
Dunes

Formed due to accumulation of sand particles carried and deposited by wind



Loess

Wind blown finer particles (silt) deposited with some clay and cementing materials. Also known as Collapsible Soil



Tuff

Wind blown volcanic ashes

Wind Transported Soil Deposits



↑ Dunes: Formed due to accumulation of sand particles carried and deposited by wind

Wind Transported Soil Deposits



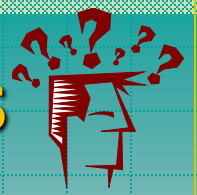
↑ Loess: Wind blown finer particles (silt) deposited with some clay and cementing materials.

Wind Transported Soil Deposits



↑ Tuff is wind blown volcanic ashes. Sometimes called Tufa.

Gravity Transported Soil Deposits



Gravity Transported Soil Deposits

Common **Name:** **Colluvial Soil or Talus**

Gravity Transported Soil Deposits



↑ Colluvial soils are usually silt size particles.

Soil Classification Based on Particle Size

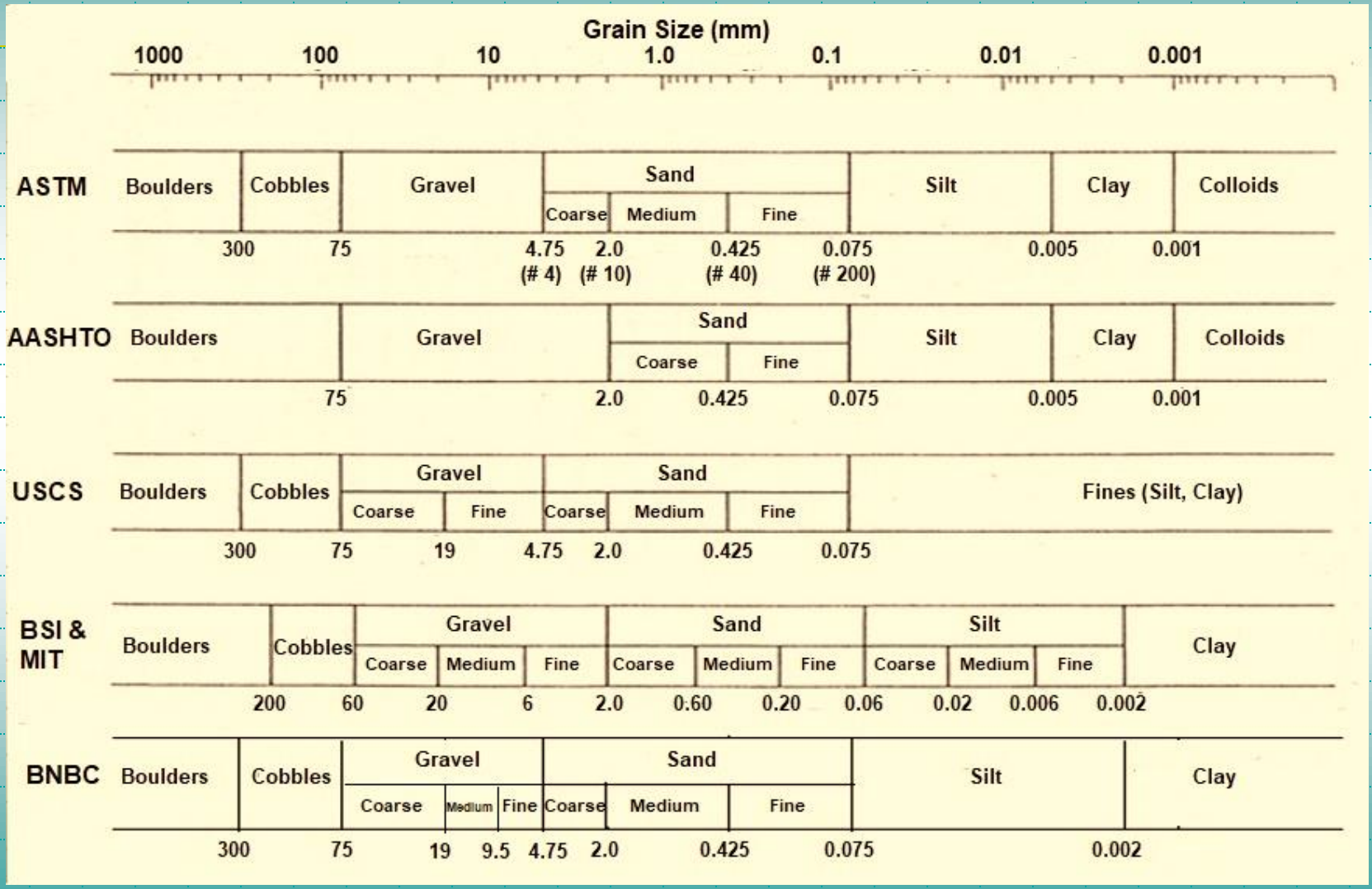


- Soil
  - Coarse grained
    - Gravel size
    - Sand size
  - Fine grained
    - Silt size
    - Clay size

Various Classification Agencies

- ASTM
- AASHTO
- USCS
- MIT/ BSI
- BNBC 2020

Soil Classification Based on Particle Size



MZA

Soil Classification Based on Particle Size



Name	Size Limits		Familiar Example
	(in)/ sieve	(mm)	
Boulder	> 12	> 300	Larger than a Basketball
Cobbles	12 – 3	300 – 75	Grapefruit
Coarse gravel	3 – ¾	75 – 19	or Lemon
Fine gravel	¾ – # 4	19 – 4.75	Grape or Pea
Coarse sand	#4 – #10	4.75 – 2.00	Rocksalt
Medium sand	#10 – #40	2.00 – 0.425	Sugar or Table Salt
Fine sand*	#40 – #200	0.425 – 0.075	Powdered Sugar
Fines	< #200	< 0.075	-

* Particles finer than fine sand cannot be discerned with the naked eye at a distance of 8 in (20 cm).

MZA

Field Identification Tests of Soil



Purposes of field Identification tests

In the field coarse grained soils are identifiable by naked eye. Fine grained soils usually form lumps because of their inherent bonding properties; these lumps may also include some fine sands. Field identification tests are meant to perform some simple tests using simple tools available in the field to diffentiate the fine grained soils (silt, clay and fine sand) as they are not discernable by naked eye.

MZA

Field Identification Tests of Soil





Colour

Highly organic soils havedark brown to black colour. Inorganic soil is usually grey colour.



Odour

Bad smell or odour of organic soil.



Appearance

Coarse grained soil particles are large enough to be visible to the naked eye.



Feel

May be tested for feel by placing it in between the teeth. Gritty feelings for sandy soil.

MZA

Field Identification Tests of Soil



Dry Strength

The reaction of this test may be described as very low, low, medium, high and very high.

Plasticity or Toughness

The conditions may be described as weak and friable, medium and tough.

Dilatancy or Shaking

The reaction is rapid, slow or none.

Dispersion

Sands settle in 30-60 sec., materials of silt size settle in 15-60 min, clay $\geq$ 60 mins.

Field Identification Tests of Soil



Typical Reactions from Field Identification Tests				
Soil Type	Dry Strength	Dilatancy	Plasticity	Dispersion
Sandy Silt	None to very low	Rapid	Weak to friable	30 sec to 60 min
Silt	Very low to low	Rapid	Weak to friable	15 min to 60 min
Clayey silt	Low to medium	Rapid to slow	Medium	15 min to several hours
Sandy clay	Low to high	Slow to none	Medium	30 sec to several hours
Silty clay	Medium to high	Slow to none	Medium	15 min to several hours
Clay	High to very high	None	Tough	Several hours to days
Organic silt	Low to medium	Slow	Weak to friable	15 min to several hours
Organic clay	Medium to very high	None	Tough	Several hours to days

Soil Classification Based on Cohesive Properties



Soil

Cohesionless soil: Gravel, Sand, Non-plastic silt.

Cohesionless means the soil has no shear strength if no frictional properties exists

Cohesive soil: Clay, Plastic silt.

Cohesive soil contains clay minerals and posses plasticity.

MZA

Soil Structure and Fabric



Soil structure may be defined as the geometric and skeletal arrangement of the particles and inter-particle forces that may act on them. Soil structure includes gradation, arrangement of particles, void ratio, bonding agents, and associated electrical forces.

Soil fabric is a term used to describe the structure of clays and denotes the geometric arrangement of the mineral particles in a clay mass as observed by optical and electron microscope.

MZA

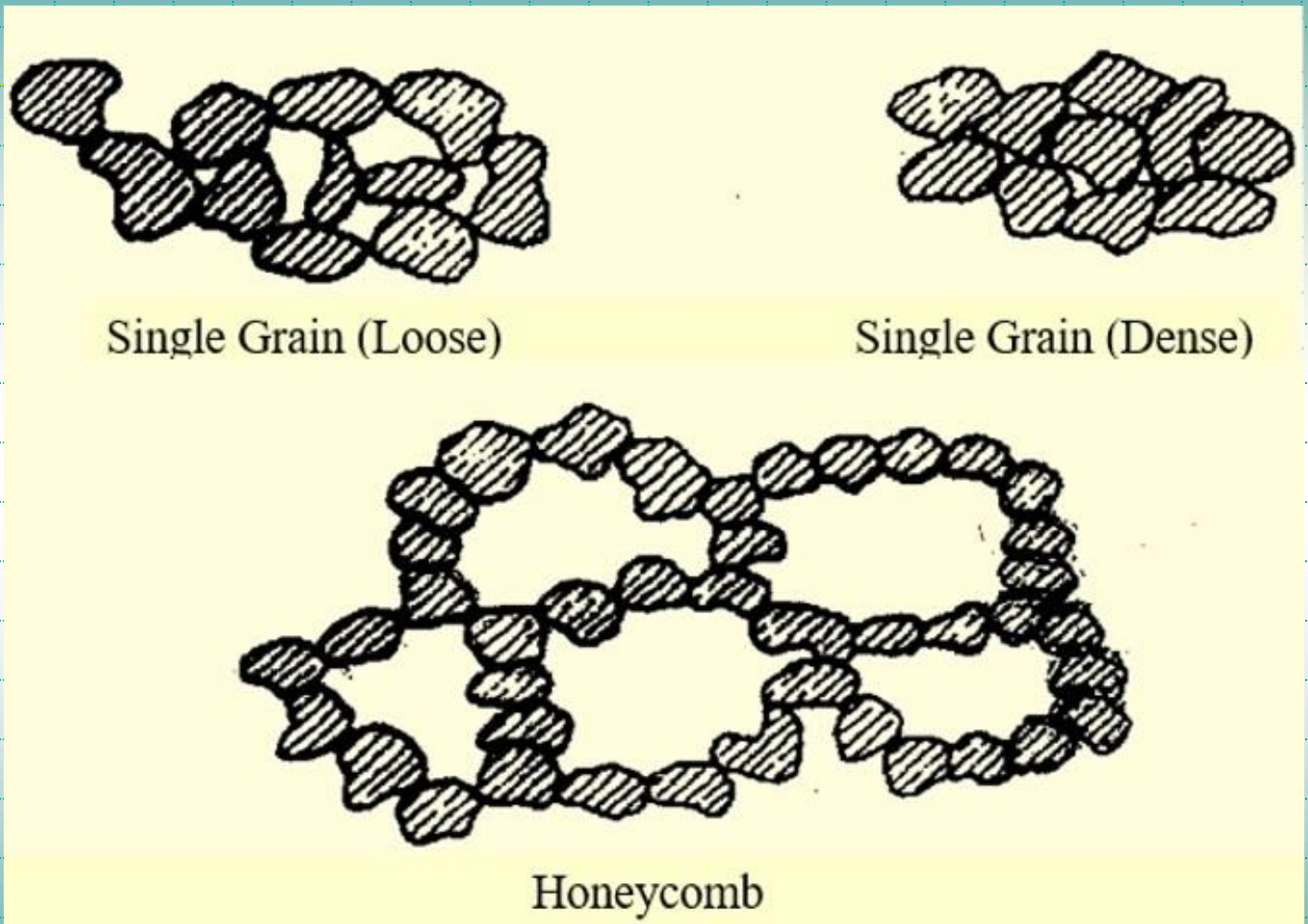
Soil Structure and Fabric



Soil Structure and Fabric

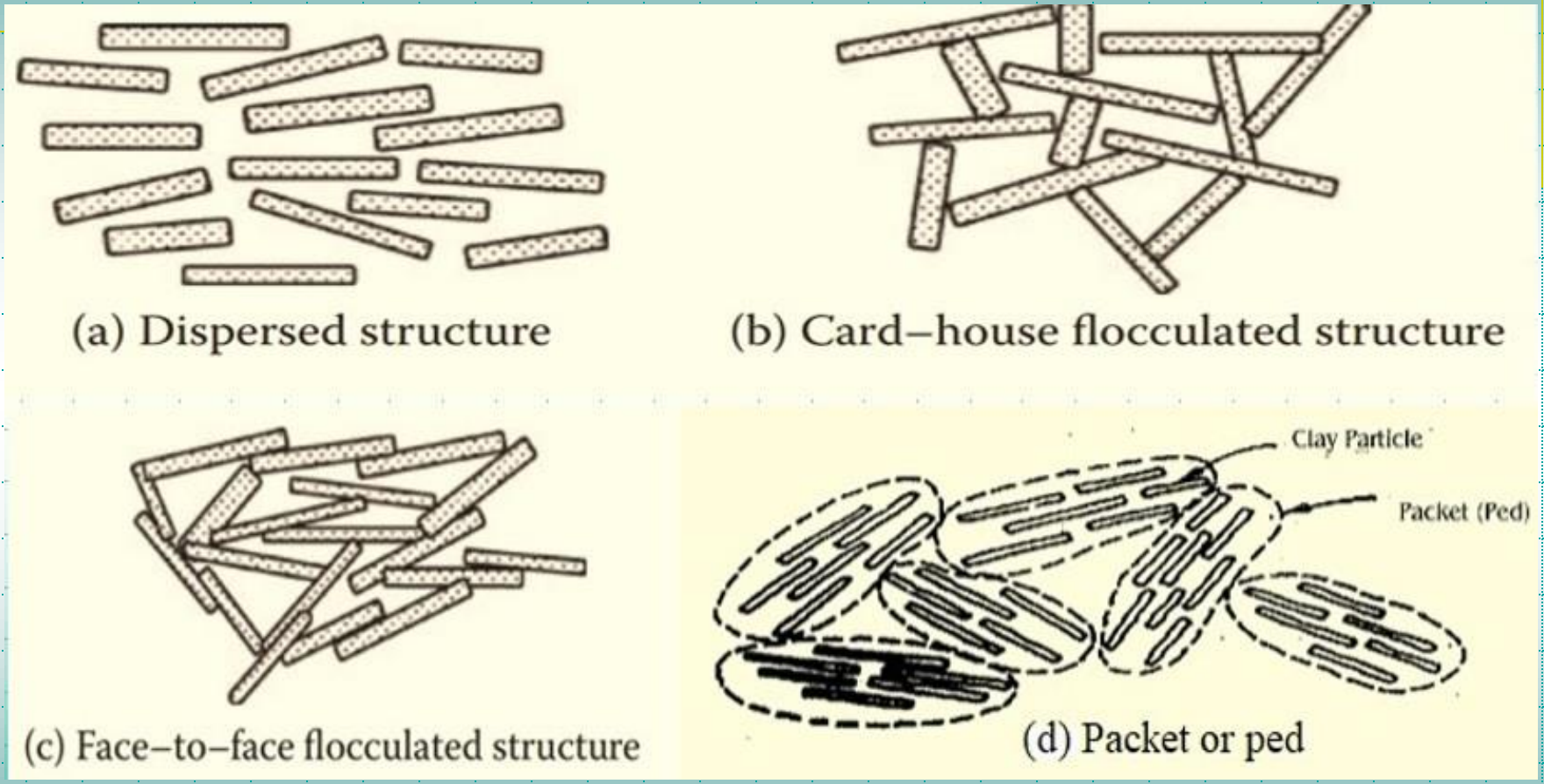
- Single grain structure
- Honeycomb structure
- Flocculated structure
- Dispersed structure
- Packet or ped

Soil Structure and Fabric



↑ Soil structures for cohesionless soils.

Soil Structure and Fabric



↑ Soil structures for cohesive soils.

Soil Structure and Fabric



Fabric of Soil

The term fabric is used to define the arrangement of the particles



Soil Structure and Fabric

Micro-fabric

The term micro fabric refers to those particle arrangements that require an optical microscope for their study.

Macro-fabric

Macro fabric refers to features such as stratification, fissures and voids that can be observed by naked eye.

Particle Shapes of Soil



Particle Shape of Soil

The shape of soil particles can generally be classified into three major categories.



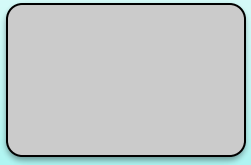
Particle Shapes of Soil





Bulky

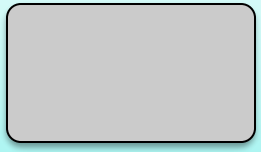
Bulky particles are mostly formed by mechanical weathering. The shapes of the particles are angular, subangular, subrounded and rounded.



Flaky

sphericity: a measure of how closely the shape of an object resembles a perfect sphere

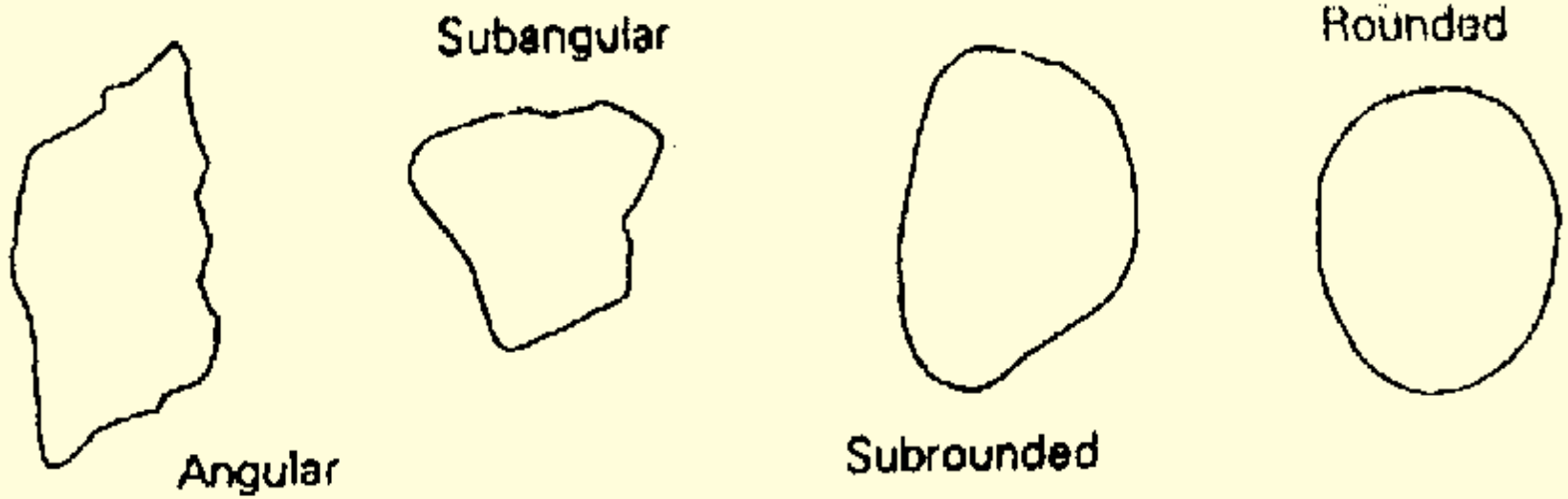
Flaky particles have very low sphericity, usually 0.01 or less. These particles are predominantly clay minerals.



Needle Shape

Needle shaped particles are much less common. Coral deposits and attapulgate clays are the examples.

Particle Shapes of Soil



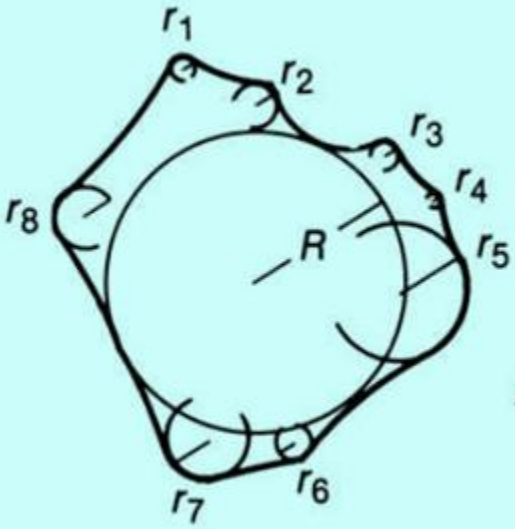
↑ The coarse grained soil is usually bulky in shape and its behaviour is greatly influenced by the shape of the particles.

Particle Shapes of Soil

Bulky Shape of Soil

The angularity of a bulky particle, A is defined as:

$$A = \frac{Average\ radius\ of\ corners\ and\ edges}{Radius\ of\ the\ maximum\ inscribed\ sphere}$$



Particle Shapes of Soil



Bulky Shape of Soil

The roundness or shericity of a particle is defined as the ratio of minimum radius of the particle edges to the inscribed radius:

$$S = \frac{D_e}{L_p}$$

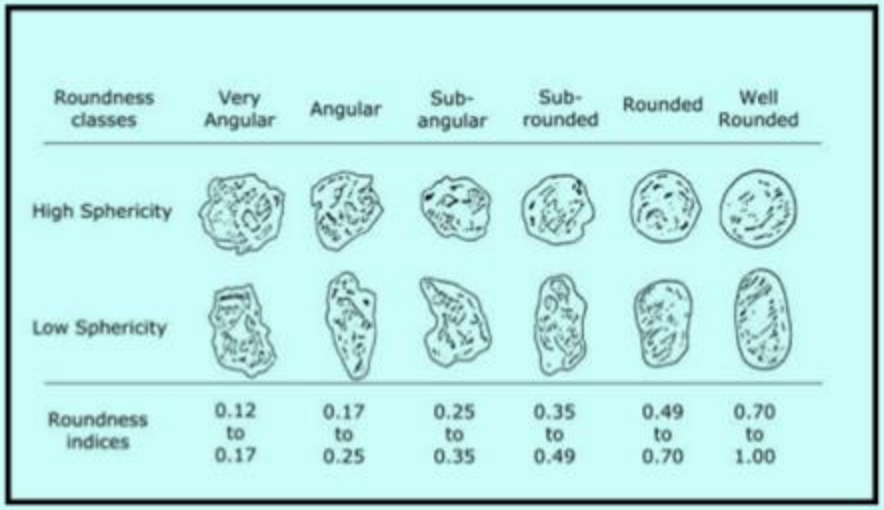
Equivalent diameter of the particle, $D_e = \sqrt[3]{\frac{6V}{\pi}}$

V = volume of the particle

L_p = length of the particle

Particle Shapes of Soil

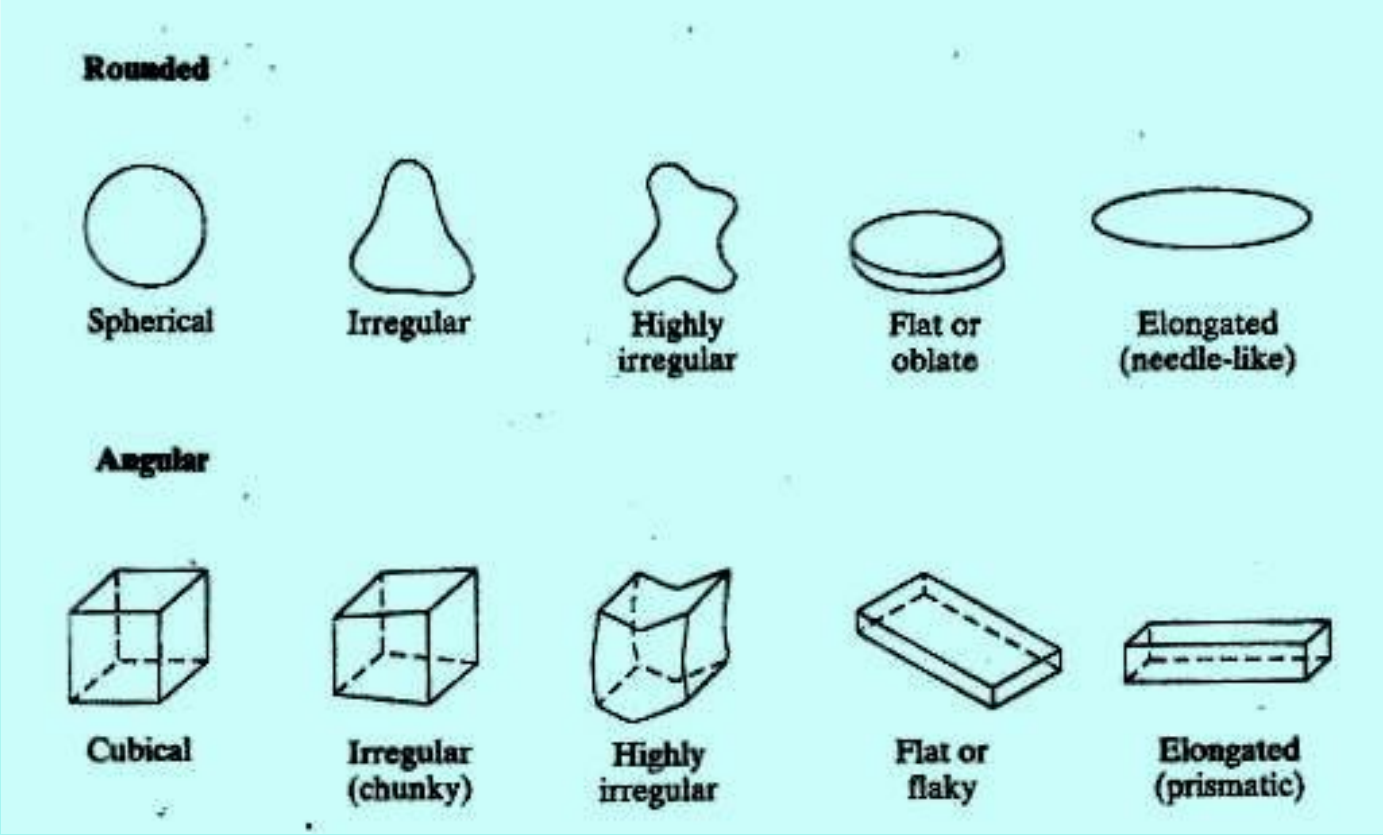
Roundness and Sphericity



The degree of roundness and sphericity for grains in sediment or a sedimentary rock are usually determined by comparing grain shapes to published charts that are based on statistical studies. The degree of rounding and sphericity both tend to increase with transport distance and with time. They are also impacted by grain composition.

Particle Shapes of Soil

Roundness and Sphericity



MZA

Engineering Classification of Soils



The purpose of engineering classification of soil is to arrange various types of soils into groups according to their engineering use. Soil possessing similar characteristics can be placed in the same group. From engineering point of view, the classification may be done based on some index properties or classification test results with the objective of finding the suitability of the soil for construction of dams, highways or foundations, etc. The other important purpose of engineering classification of soil is to develop a common language of soil classes among the engineers.

Engineering Classification of Soils

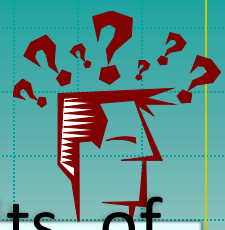


- For general engineering purposes, soils may be classified by the following systems:
  - Unified Soil Classification System (USCS)
  - AASHTO Soil Classification System

Both the classification scheme uses the results of some physical properties of soil called as index properties.

MZA

Engineering Classification of Soil



Both the classification systems uses the results of some basic tests of soil materials. These tests are known as the classification tests. The numerical results of these tests are often termed as index properties of soil.

Two most common classification tests are:

- Grain size analysis for coarse grained soil
- Consistency tests for fine grained soil



Classification Tests: Coarse Grained Soil



Grain Size Analysis

Sieve Analysis: A set of sieves is used

Sedimentation Analysis

Hydrometer Analysis: A hydrometer is used

Pipette Analysis: uses by the agriculturists

Sieve Analysis: Coarse Grained Soil



↑ A set of sieves is used.

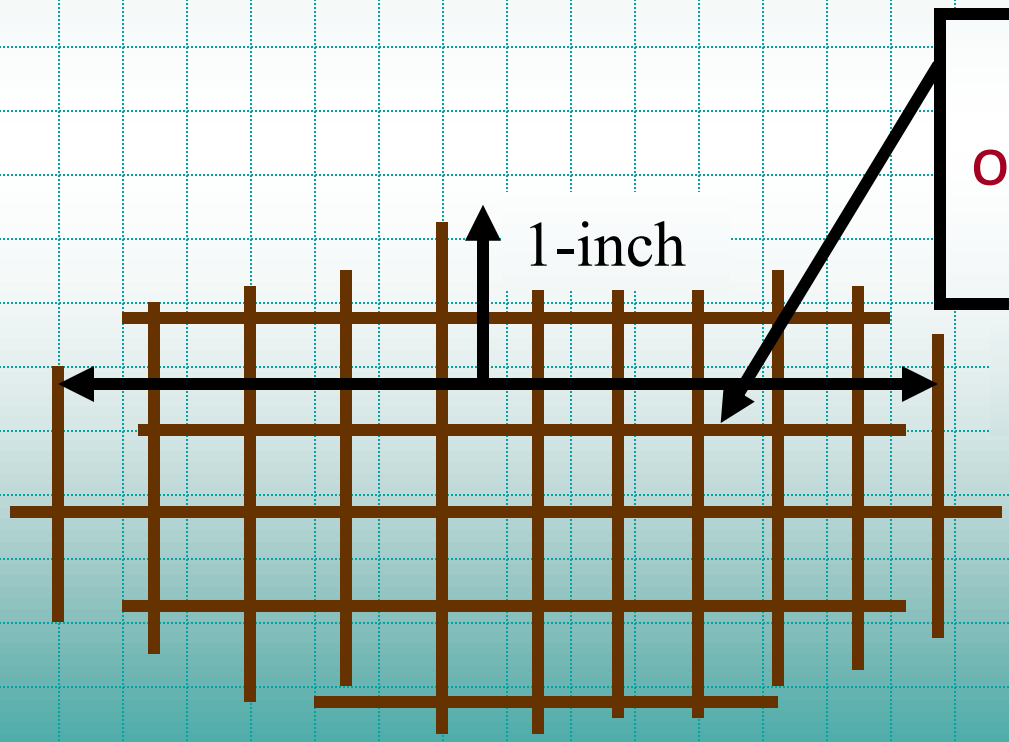
Sieve Designations: Larger Sieves



↑ Sieves larger than the #4 are designated by the size of the openings in the sieve.

Sieve Designations: Smaller Sieves

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



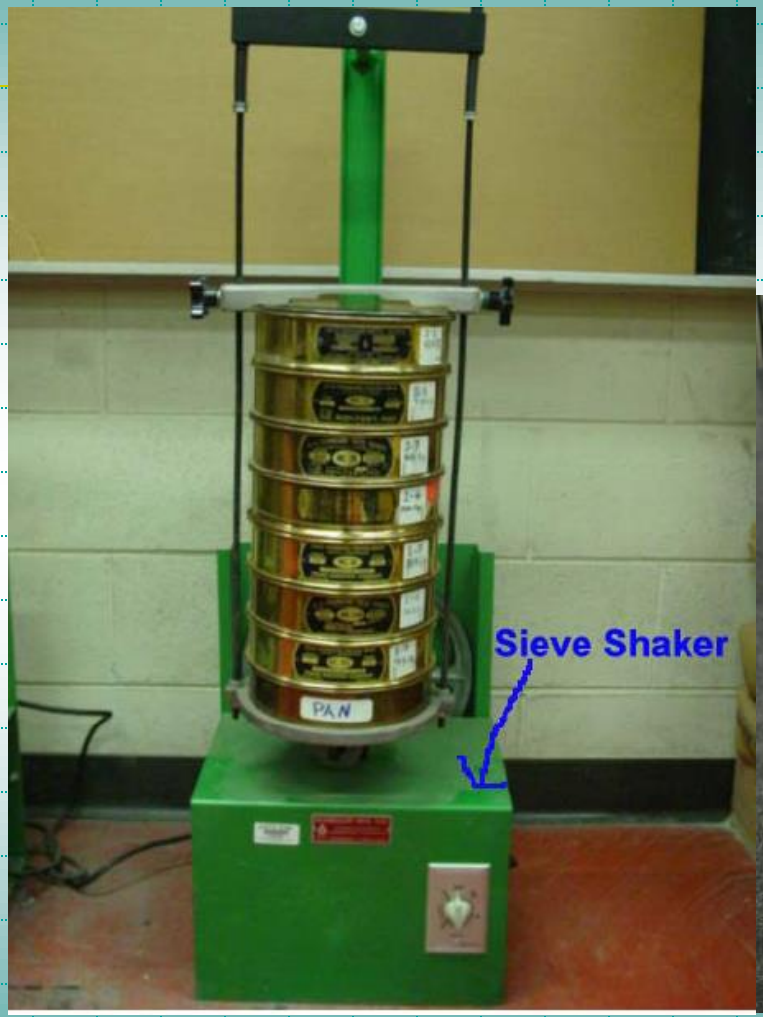
Sieve Analysis: Test Procedures





MZA

Sieve Analysis: Test Procedures



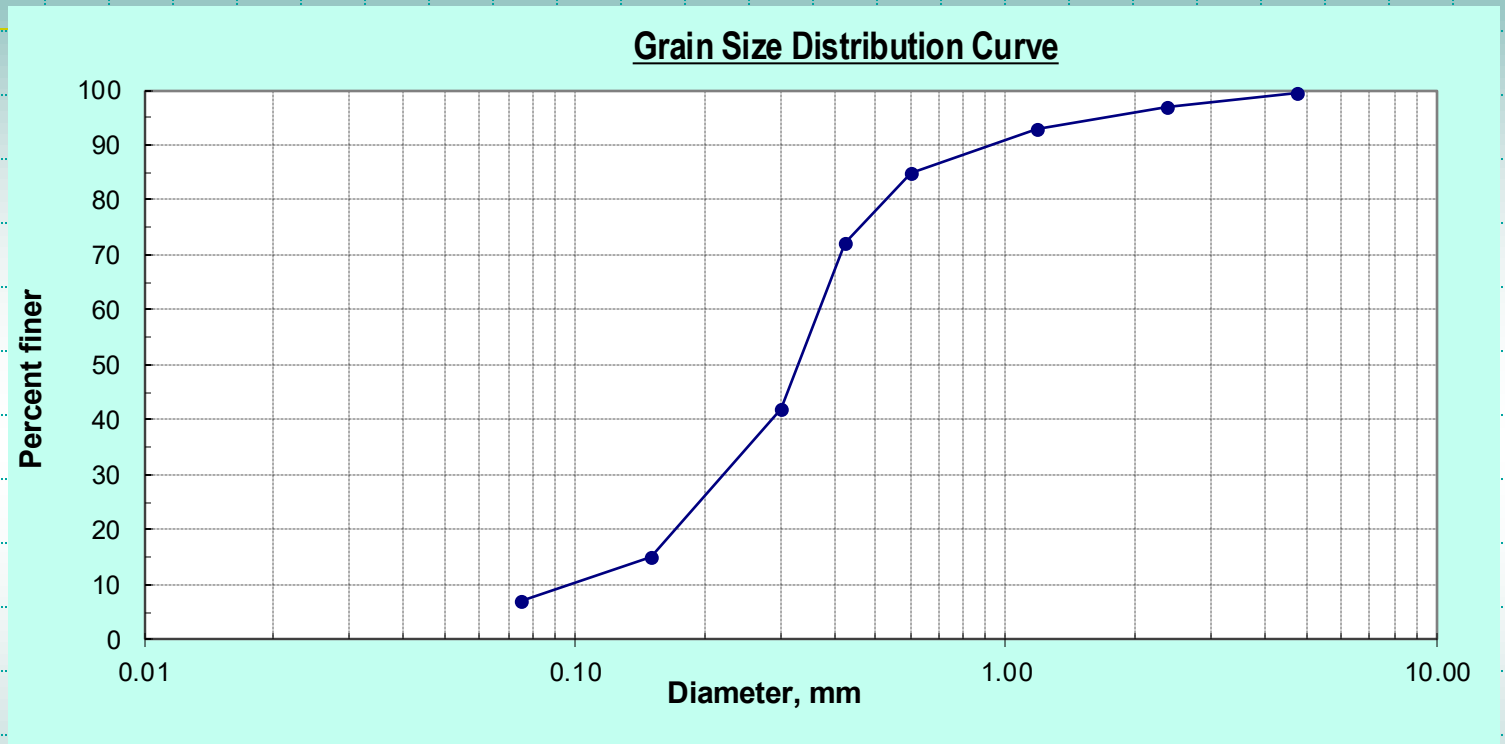


Sieve Analysis: Calculations



Sieve Size/ No	Sieve opening (mm)	Wt. of soil retained (gm)	**Percent soil retained**	**Cumulative percent retained**	**Percent finer**
4	4.750	0.6	**1**	**1**	**99**
8	2.360	1.5	**2**	**3**	**97**
16	1.180	4.3	**4**	**7**	**93**
30	0.600	8.4	**8**	**15**	**85**
40	0.425	13.0	**13**	**28**	**72**
50	0.300	30.4	**30**	**58**	**42**
100	0.150	26.8	**27**	**85**	**15**
200	0.075	7.7	**8**	**93**	**7**
Pan	-	7.3	**7.3**		

Sieve Analysis: Grain Size Distribution Curve



Grain Size Parameters :

D_{60} = 0.37 mm D_{50} = 0.33 mm D_{30} = 0.22 mm D_{10} = 0.097

C_u = 3.77 C_z = 1.36

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil

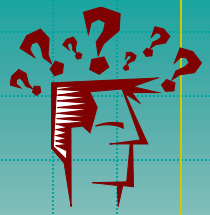


A hydrometer analysis determines the size distribution of fine-grained soils. It is based on the principle of sedimentation of soil particles settling in water. Hydrometer analyses are typically performed on particles passing the No. 200 sieve (0.075 mm). The data from a hydrometer analysis allow for the determination of the suspension density.



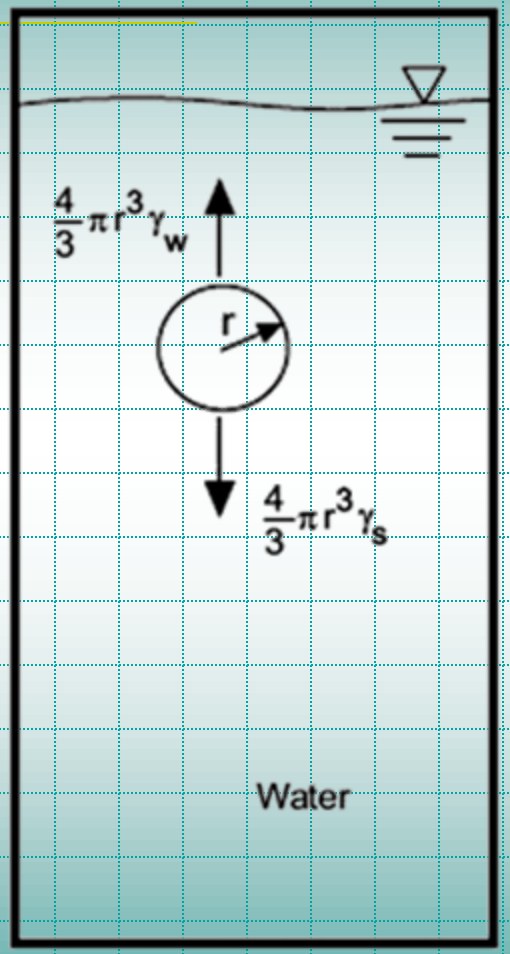
MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



In determining the distribution of particle sizes, a deflocculating agent (usually sodium hexa-metaphosphate) is first applied to the soil, which has been mixed with water. On mixing, the particles are separated out and form a solution. When a soil sample is dispersed in water, the particles will settle at different velocities, depending on their size, shape, weight, and on the viscosity of water. All particles are assumed to be spherical as shown in Figure below.

Hydrometer (Wet) Analysis: Fine Grained Soil



← Schematic illustration of a single particle in suspension.

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



For a spherical particle of radius r, the upward buoyancy force is equal to the volume of fluid displaced multiplied by the unit weight of water; i.e.,

$$F_b = \frac{4}{3}\pi r^3 \gamma_w$$

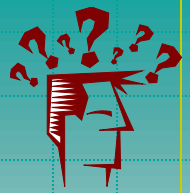
The downward force is due to the weight of the particle; i.e.,

$$F_d = \frac{4}{3}\pi r^3 \gamma_s$$

Where, γ_w is the unit weight of water and $\gamma_s$the unit weight of the solid phase.

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



Stokes found that the net vertical force was related to the velocity of the particle according to the following relation:

$$F_d - F_b = \frac{4}{3}\pi r^3 \gamma_s - \frac{4}{3}\pi r^3 \gamma_w = 6\pi\eta r v$$

Where, η is the viscosity of water and v is the velocity of the sphere as it settles in the water.

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



- Solving for the velocity and relating this to the particle diameter D gives

$$v = \frac{2}{9}\frac{r^2}{\eta}(r_s - r_w) = \frac{2}{9}\frac{(D/2)^2}{\eta}(r_s - r_w)$$

$$= \frac{(r_s - r_w)D^2}{18\eta}$$

Solving for this diameter gives

$$D = \sqrt{\frac{18\eta v}{(r_s - r_w)}} = \sqrt{\frac{18\eta}{(r_s - r_w)}}\sqrt{\frac{L}{t}}$$

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



Since, $G_s = \gamma_s/\gamma_w \Rightarrow \gamma_s = G_s\gamma_w$, the above expression can also be written as

$$D = \sqrt{\frac{18\eta}{(G_s - 1)\gamma_w}}\sqrt{\frac{L}{t}}$$

At a depth L (commonly called the effective length) at time t, all particles have a diameter smaller than D, that is, all larger particles would have settled beyond the zone of measurement. Hydrometers are thus designed to allow the amount of soil that is still in suspension to be determined.

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



In typical calculations of a hydrometer analysis, L is measured in centimeters (cm), the units of η are $(g\ s)/cm^2$, $\gamma_w = 1\ g/cm^3$, t is measured in minutes, and it is advantageous to represent D in units of millimeters. The above expression for D is thus modified so as to account for the afore mentioned units, giving

$$D = \sqrt{\frac{18\eta}{(G_s - 1)\gamma_w}}\sqrt{\frac{L}{t}\left(\frac{min}{60\ s}\right)}\left(\frac{10\ mm}{cm}\right)$$

$$= \sqrt{\frac{30\eta}{(G_s - 1)\gamma_w}}\sqrt{\frac{L}{t}}$$

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



The above expression is often written as

$$D = K\sqrt{\frac{L}{t}}$$

Where, D has units of millimeters, L has units of centimeters, t is expressed in minutes, and

$$K = \sqrt{\frac{30\eta}{(G_s - 1)}}$$

Since the viscosity η is a function of temperature, it follows that K will likewise be a function of temperature.

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



Corrections of Hydrometer Reading

The ASTM 152-H type of hydrometer is calibrated up to a reading of 60 at a temperature of 20^oC for soil particles having a $G_s = 2.65$. A hydrometer reading of, say, 30 at a given time of a test means that there are 30 g of soil solids ($G_s = 2.65$) in suspension per 1000 cc of soil-water mixture at a temperature of 20^oC at a depth where the specific gravity of the soil-water suspension is measured (i.e., L) and where no dispersing agent is added.

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



Corrections of Hydrometer Reading

If the hydrometer analysis is performed under conditions that differ from these calibration conditions, corrections need to be made. The four commonly made corrections are thus

(1) Temperature correction (FT) : when the temperature differs from 20^oC, the following correction must be made:

$$F_T = -4.85 + 0.257T$$

Where, the test temperature T is between 15^oC and 28^oC. The F_T value can be positive or negative.

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



(2) Specific gravity correction (a): when the specific gravity of the solids is not 2.65, the following correction must be made:

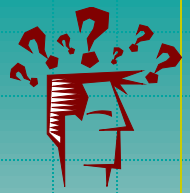
$$a = \frac{1.65G_s}{2.65(G_s - 1)}$$

(3) Zero correction (F_z): A deflocculating agent is added to the soil-distilled water suspension for performing experiments. This will change the zero reading (F_z can be either positive or negative).

(4) Meniscus correction (F_m): Generally, the upper level of the meniscus is taken as the reading during laboratory work (F_m is always positive).

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



Effective Length of Hydrometer

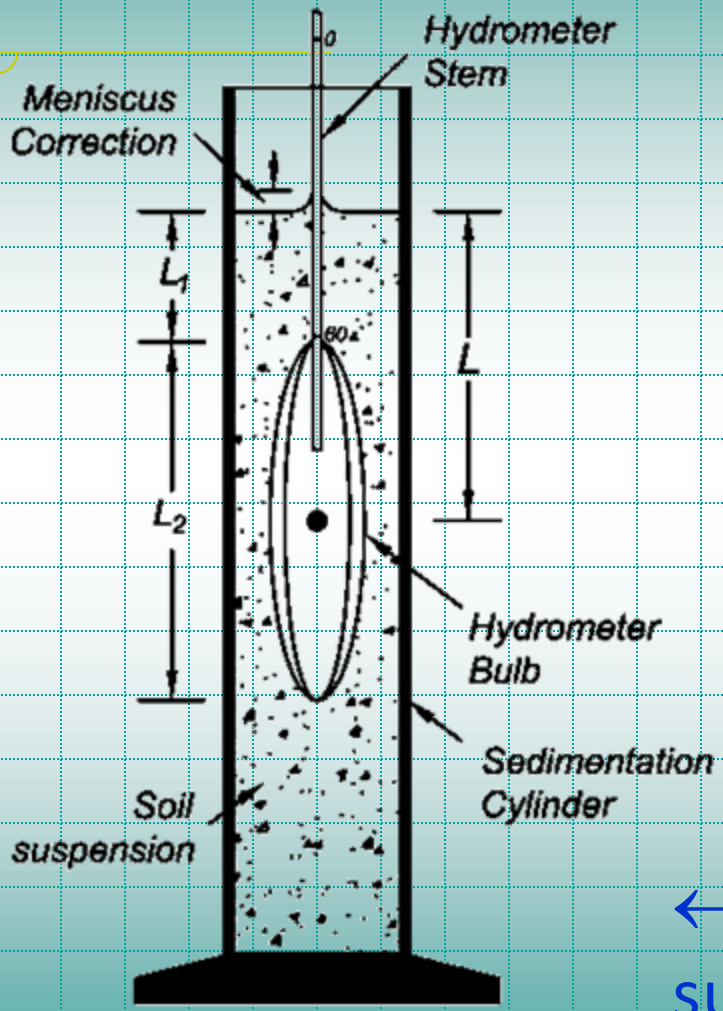
The effective length (L) must be related to the hydrometer reading (R), which ranges between 0 and $60\ g/L$. The magnitude of L is often computed from the following expression:

$$L = L_1 + \frac{1}{2}\left(L_2 - \frac{V_b}{A_c}\right)$$

Where, L_1 is the distance along the stem of the hydrometer from the top of its bulb to the mark for a specific hydrometer reading, R.

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



← Hydrometer in a soil suspension.

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



Effective Length of Hydrometer

L_2 is the length of the hydrometer bulb (typically 14 cm), V_b is the volume of the hydrometer bulb, and A_c is the cross-sectional area of the sedimentation cylinder (typically 27.8 cm^2).

Typically, L_1 is equal to $10.5\ cm$ for a reading of $R = 0$, and $2.3\ cm$ for a value of $R = 50$. Assuming a linear relationship between L_1 and R, it follows that for any value of R,

$$L_1 = 10.5 - \frac{(10.5 - 2.3)}{50} R$$

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil



Effective Length of Hydrometer

Where L_1 and R will have the same units, and the hydrometer reading R is corrected for the meniscus. In this case, the general expression for L becomes

$$L = 10.5 - 0.164R + \frac{1}{2}\left(14.0 - \frac{V_b}{A_c}\right)$$

Where, L and R will have units of cm, A_c will have units of cm^2, and V_b will have units of cm^3.

Hydrometer (Wet) Analysis: Fine Grained Soil

Particle Size, D (mm)

$$= \mathrm{K}\sqrt{\frac{L(cm)}{t(min)}}$$

% Finer, N

$$= \frac{G_s \gamma_w V R}{10(G_s - 1)W}$$

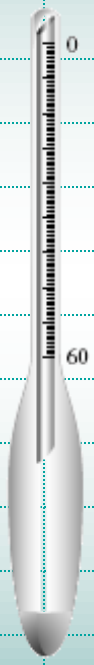


Figure 2.23 ASTM 152H hydrometer (Courtesy of ELE International)

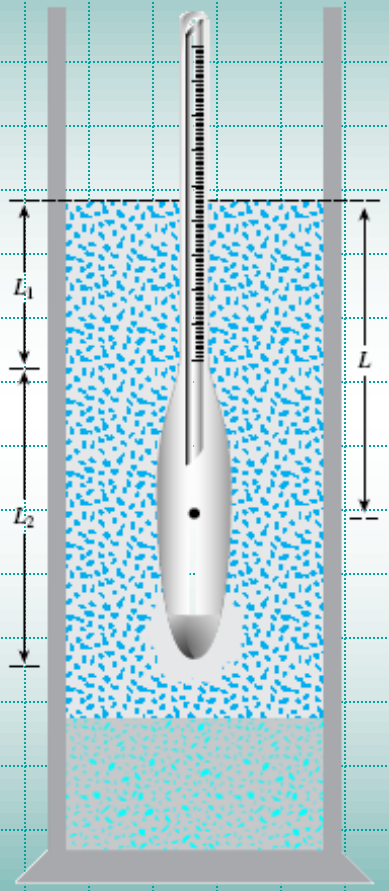
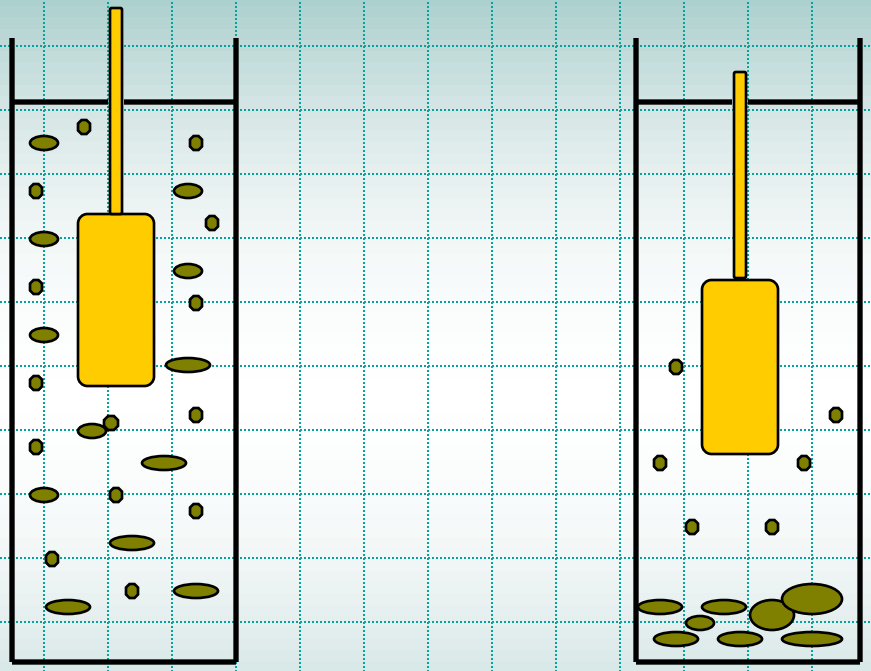


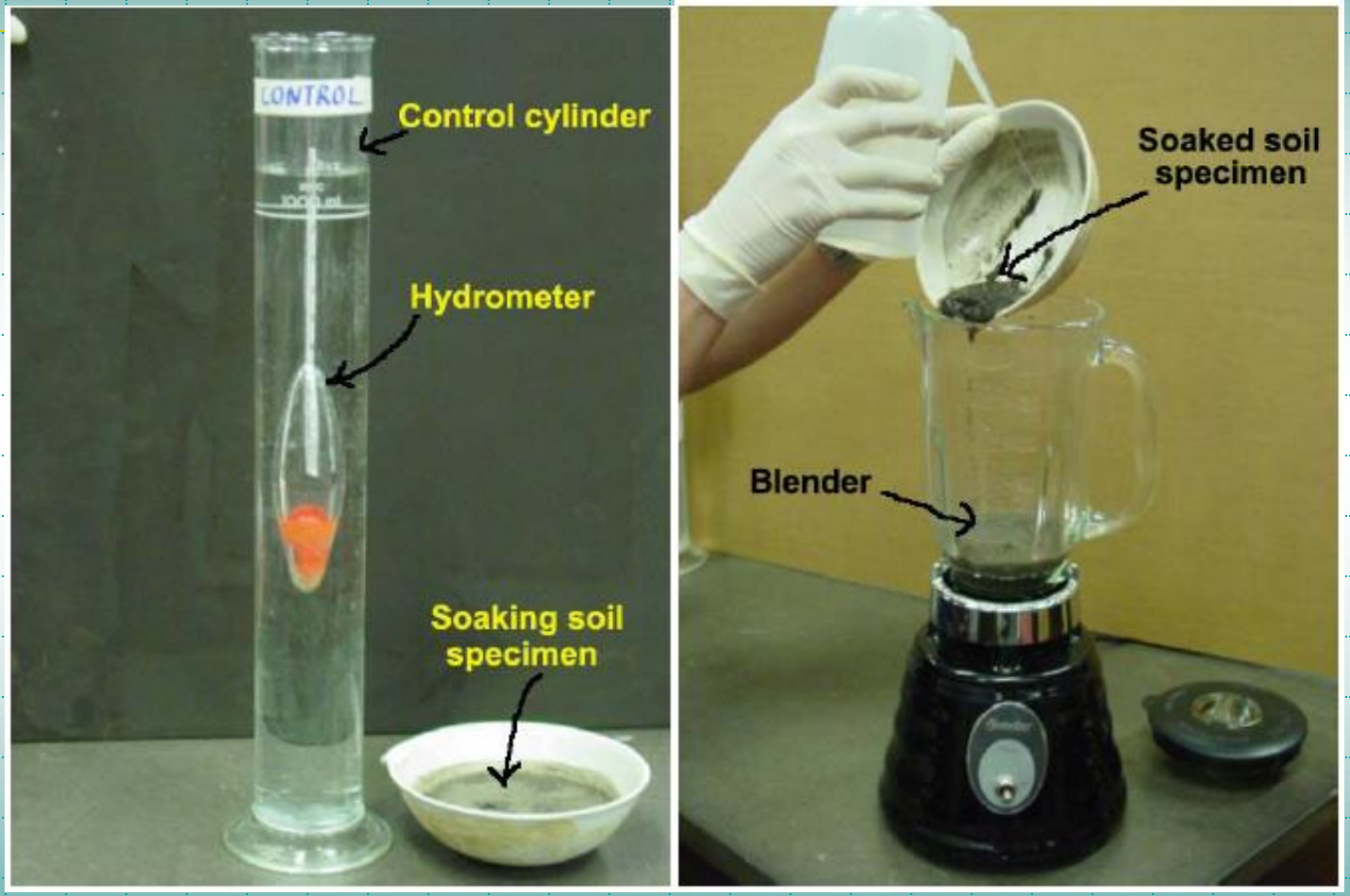
Figure 2.24 Definition of L in hydrometer test

Hydrometer (Wet) Analysis: Fine Grained Soil



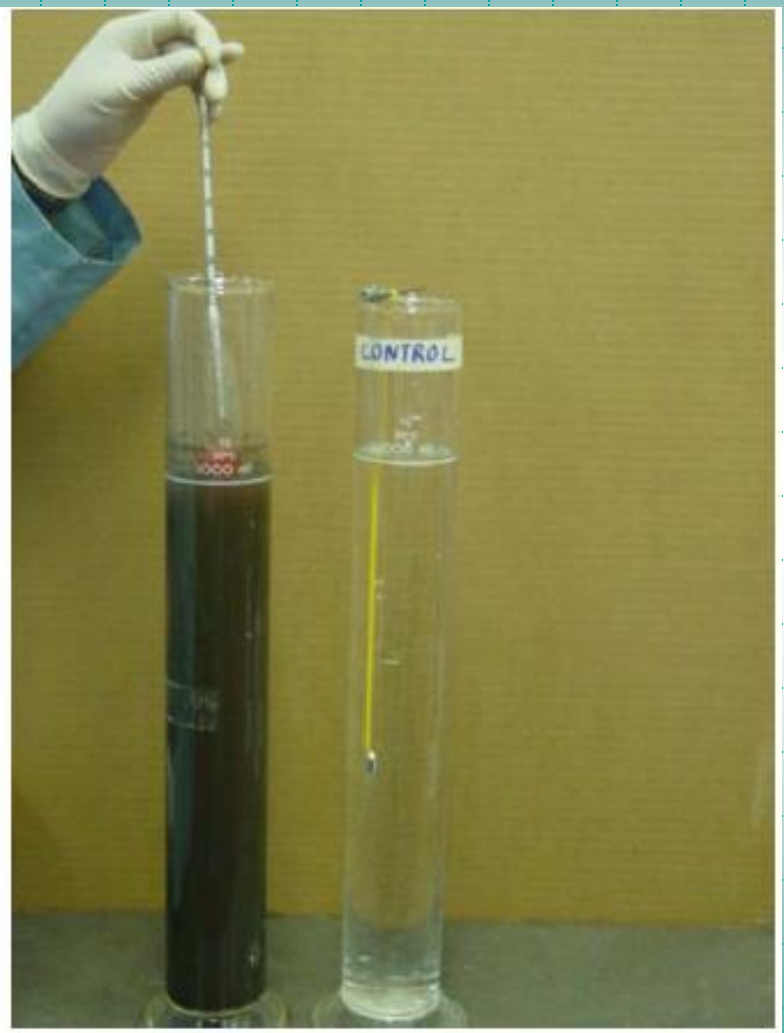
↑ Schematic diagram of hydrometer test.

Hydrometer (Wet) Analysis: Fine Grained Soil

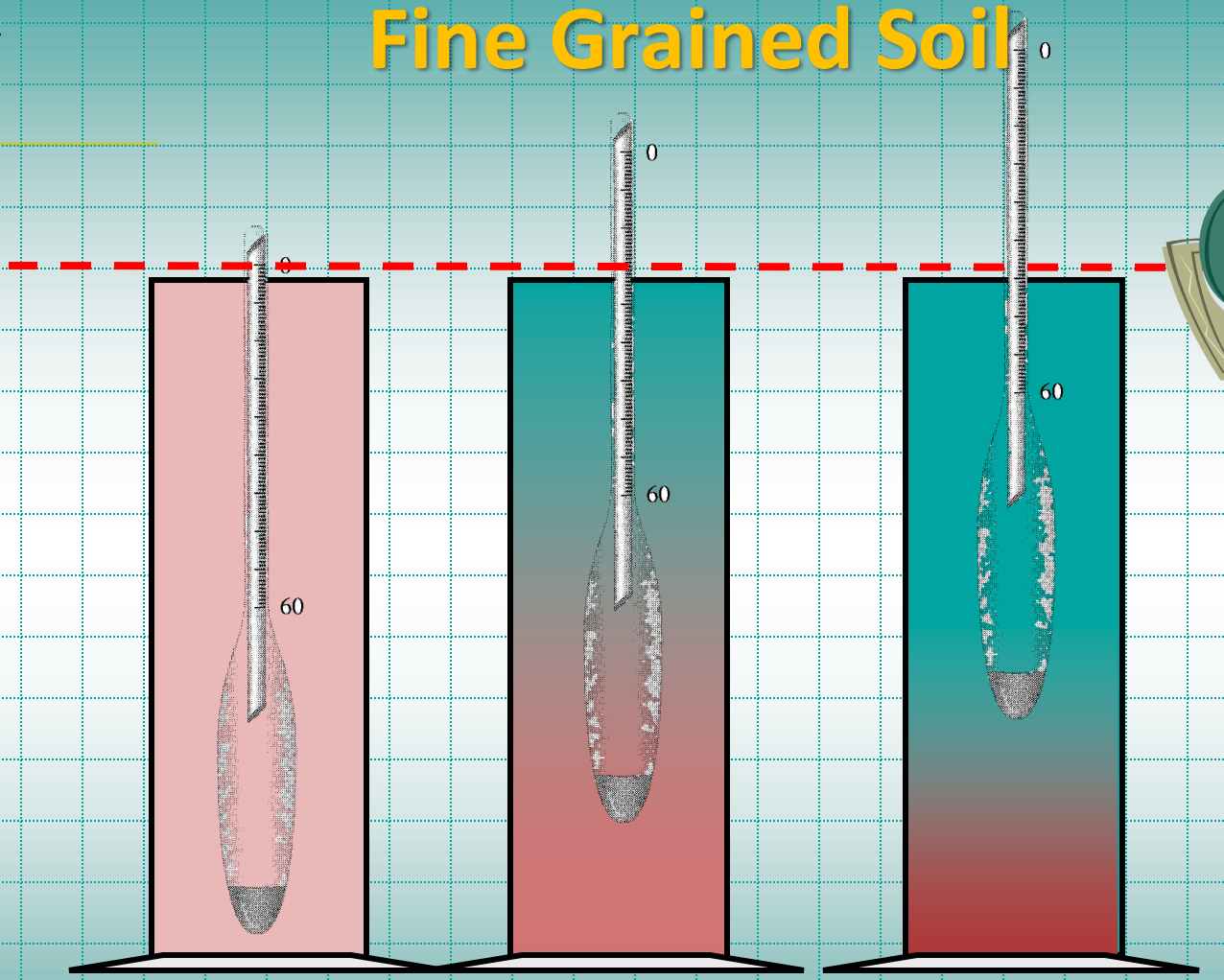


Hydrometer (Wet) Analysis: Fine Grained Soil

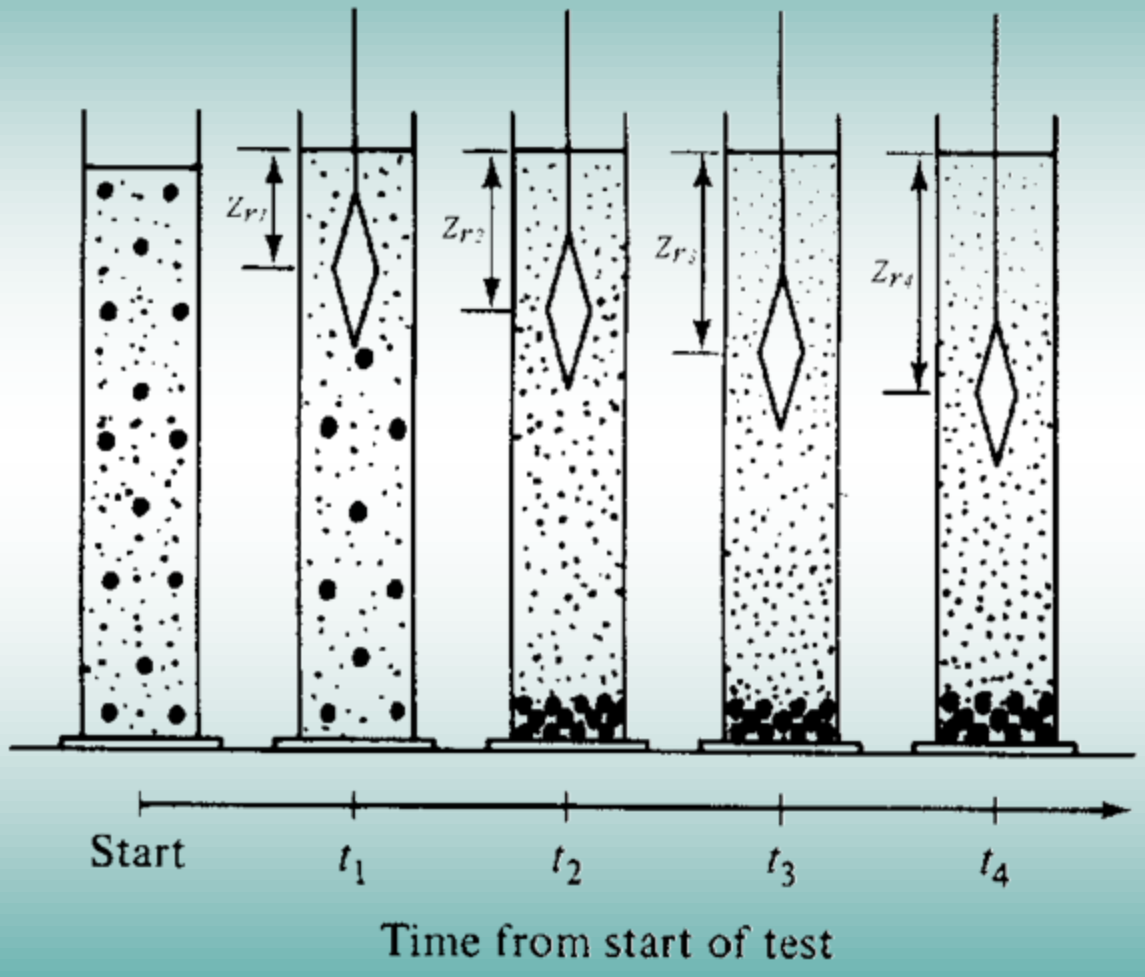




Hydrometer (Wet) Analysis: Fine Grained Soil

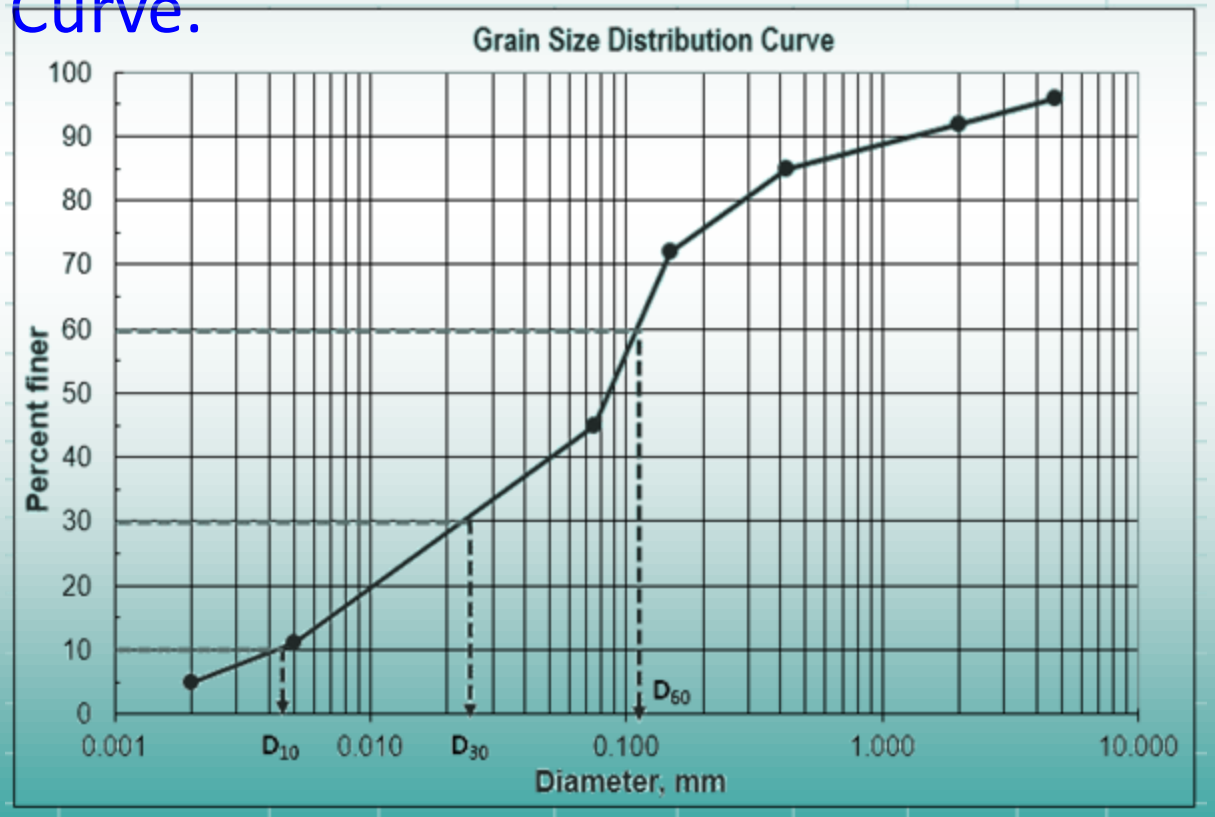


Hydrometer (Wet) Analysis: Fine Grained Soil



Hydrometer (Wet) Analysis: Fine Grained Soil

The results of mechanical analysis (sieve and hydrometer analysis) are generally presented by semi logarithmic plots known as Particle-size Distribution Curve.



1. Effective Grain Size

$$D_{10}\ (in\ mm)$$

2. Uniformity Coefficient

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

3. Coefficient of Gradation/ Curvature

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

MZA

Hydrometer (Wet) Analysis: Fine Grained Soil

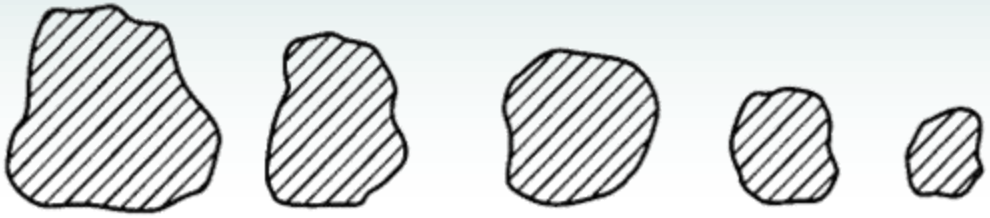


- When a grain size distribution curve is spread over a wide range, it means to contain all sizes of the grains in the sample. Usually the curve is 'S' shaped and the soil is known as well graded.
- A soil composed of mainly of one size particles is called uniform or poorly graded soil. The curve lies within a narrow range.
- The 3rd type of soil is a mixture of large and small size particles with some of the intermediate sizes missing is gap graded.
- Uniform and gap graded soils are known as poorly graded.

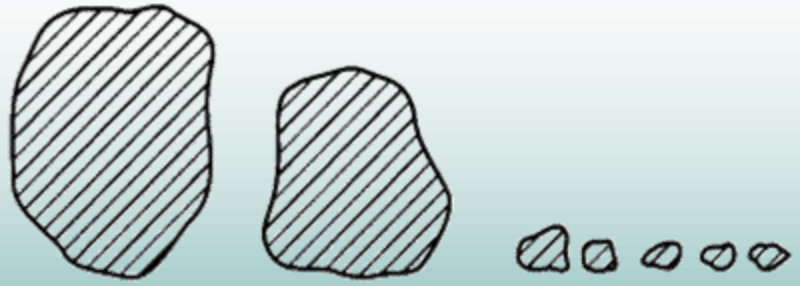
Hydrometer (Wet) Analysis: Fine Grained Soil



(a) Uniform Size Particles; Uniform Graded



(b) Non-uniform Size Particles; Well Graded



(c) Missing Particles; Gap Graded

↑ Particle sizes distribution.

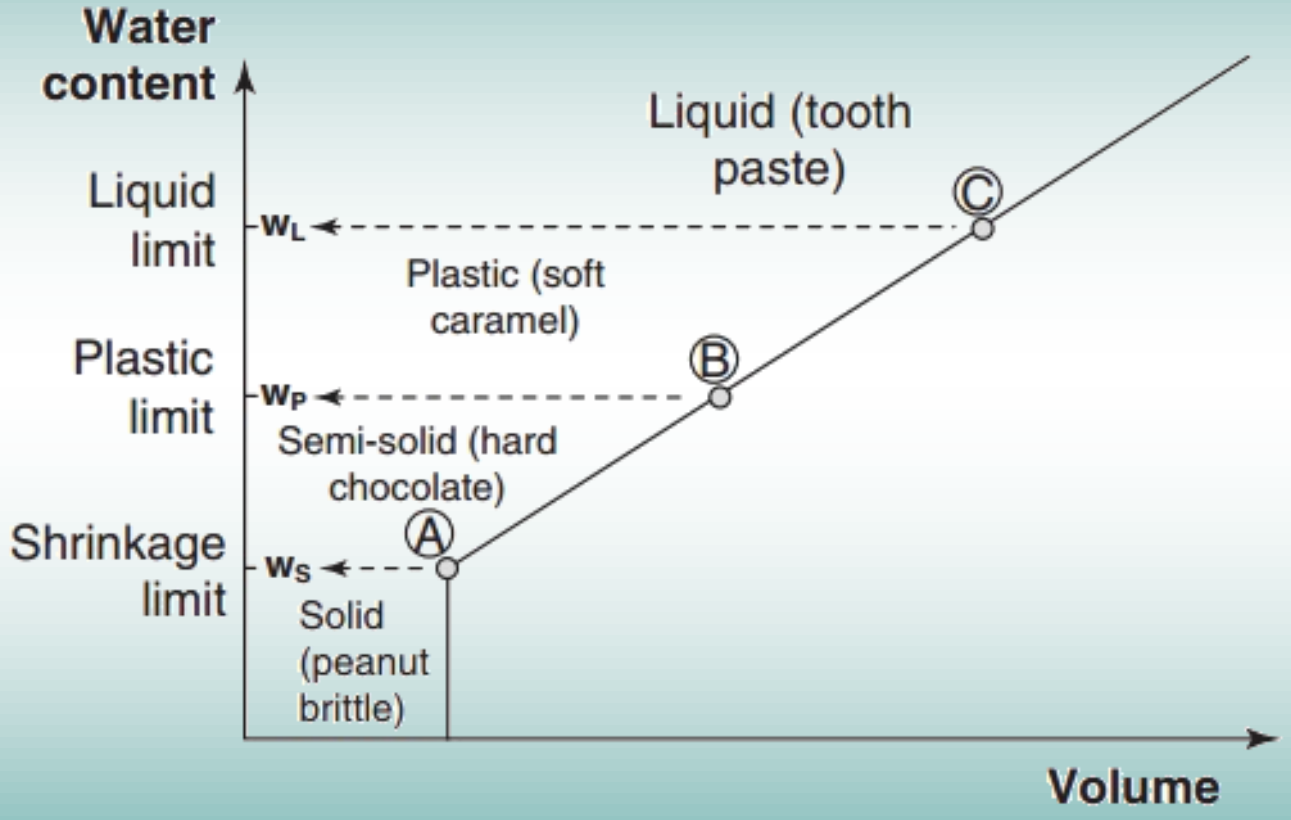
Consistency Tests (Atterberg's Limits): Fine Grained Soil



Consistency Test: Depending on water content, a soil could have 4 states or conditions & 3 limiting values or limits

Liquid State: Flows on its own weight	Plastic State: **Can be remolded to any shape without development of cracks**	Semi-Solid State: **Can be remolded to any shape only with development of cracks**	Solid State: Can not be remolded (breaks)
	Liquid Limit	Plastic Limit	**Shrinkage Limit**

Hydrometer (Wet) Analysis: Fine Grained Soil



↑ States of consistency and Atterberg limits (Briaud, 2013).

Atterberg Limits

Definitions of Limits



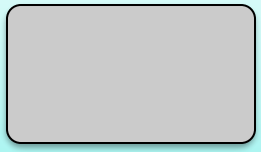
Liquid Limit

The liquid limit (w_L or LL), is the water content at the transition of liquid state to plastic state, whereby it gains a certain small shearing strength.



Plastic Limit

The plastic limit (w_P or PL) is the minimum moisture content at which the soil can be deformed plastically.

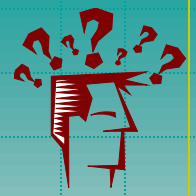


Shrinkage Limit

The shrinkage limit (w_S or SL) is the smallest water content below which a soil sample will not reduce its volume.

MZA

Determination of Liquid Limit of Soil



Determination of Liquid Limit

Two Methods

Cassagrande's Cup Method

Cone Penetration Method

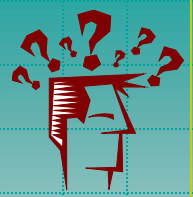
Determination of Liquid Limit of Soil



Preparation of Test Sample

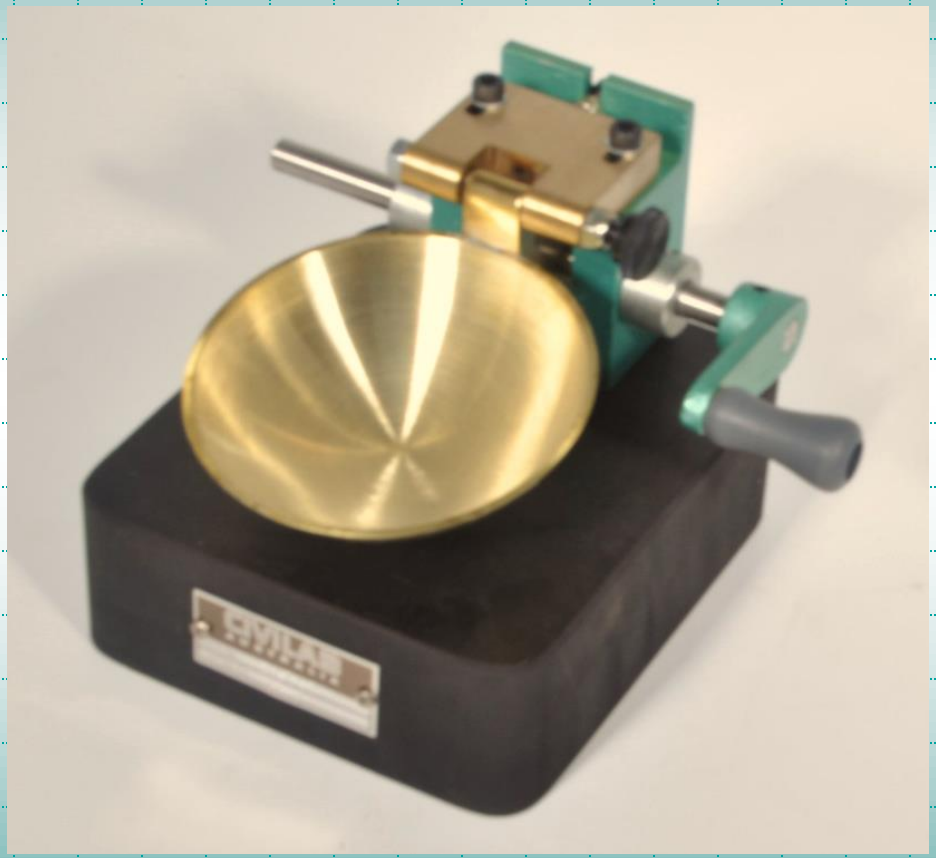
The soil is first dried in air sufficiently to be broken up by a mortar and pestle. It is then sieved using a 425 μm (No. 40) sieve and materials passing are taken for the limit tests. The soil sample is mixed thoroughly with water into a smooth thick paste, and stored in an air tight container for 24 hours to allow the water to mix thoroughly with all the soil grains.

Determination of Liquid Limit: Cassagrande's Method



Cassagrande (1932) developed a standard device for the determination of liquid limit suggesting that at the water content of liquid limit a clay soil has a small shearing strength of approximately 2.5 kPa. The device consists of a metal cup seated onto a hard rubber base and fixed to a crank shaft arrangement with a handle, so that the cup can be alternately raised and dropped.

Determination of Liquid Limit: Cassagrande's Method

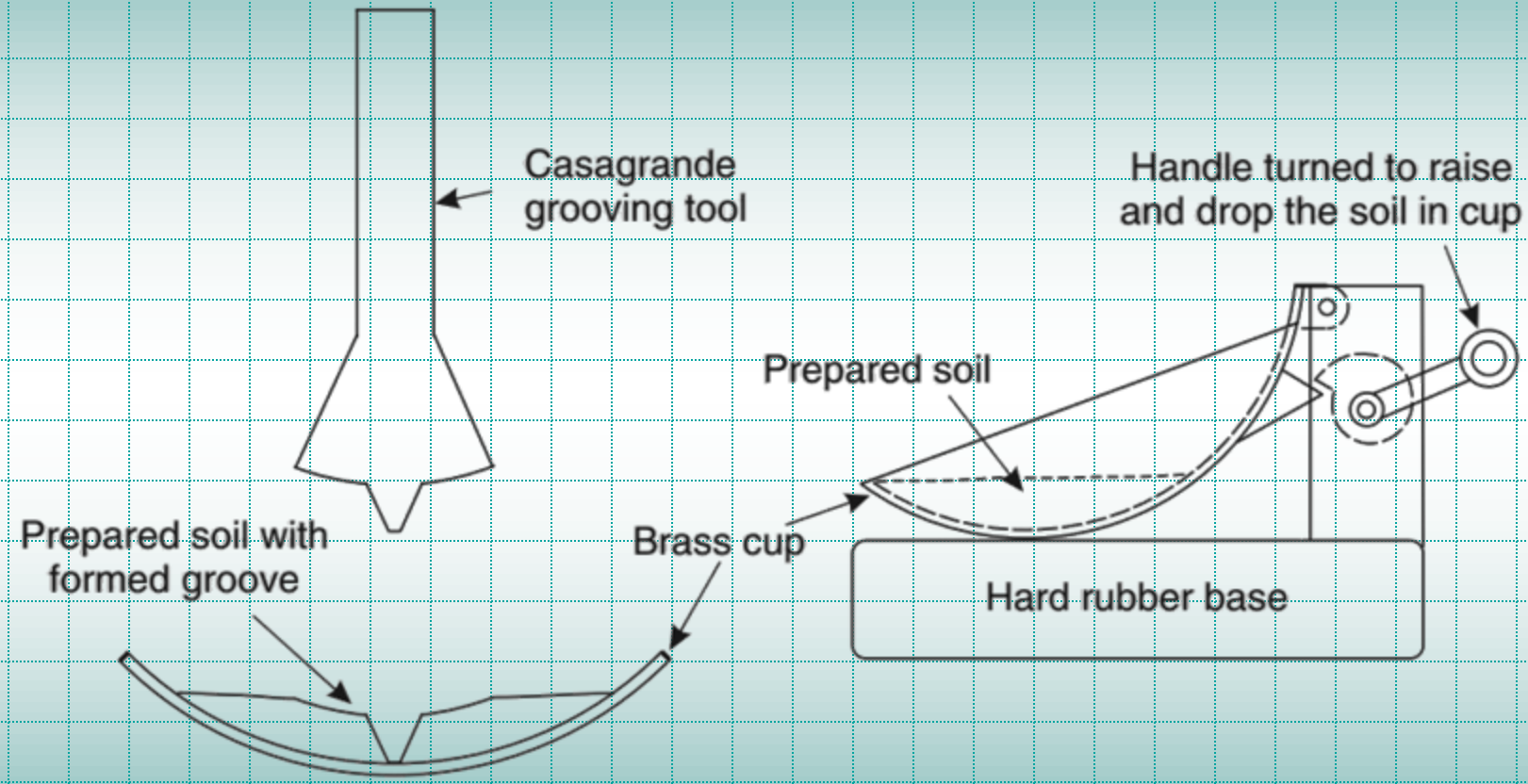


↑ Metallic cup.



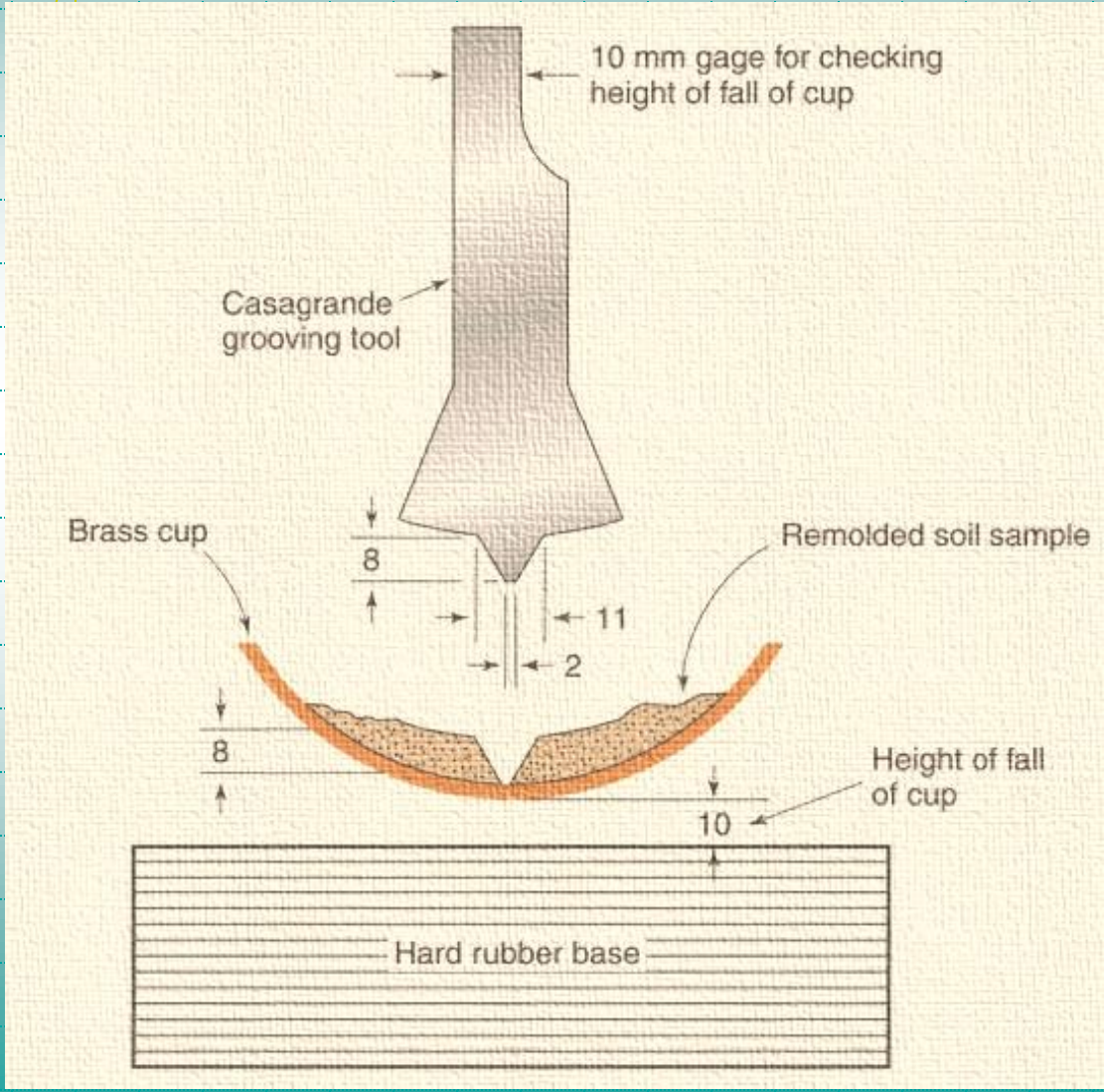
↑ Grooving tools.

Determination of Liquid Limit: Cassagrande's Method



↑ Schematic diagram of the Casagrande liquid-limit device and grooving tool (after Wesley, 2009).

Determination of Liquid Limit: Cassagrande's Method



← Schematic diagram of the Casagrande liquid-limit device and grooving tool; with dimensions in millimeters (after Holtz & Kovacs, 2023).

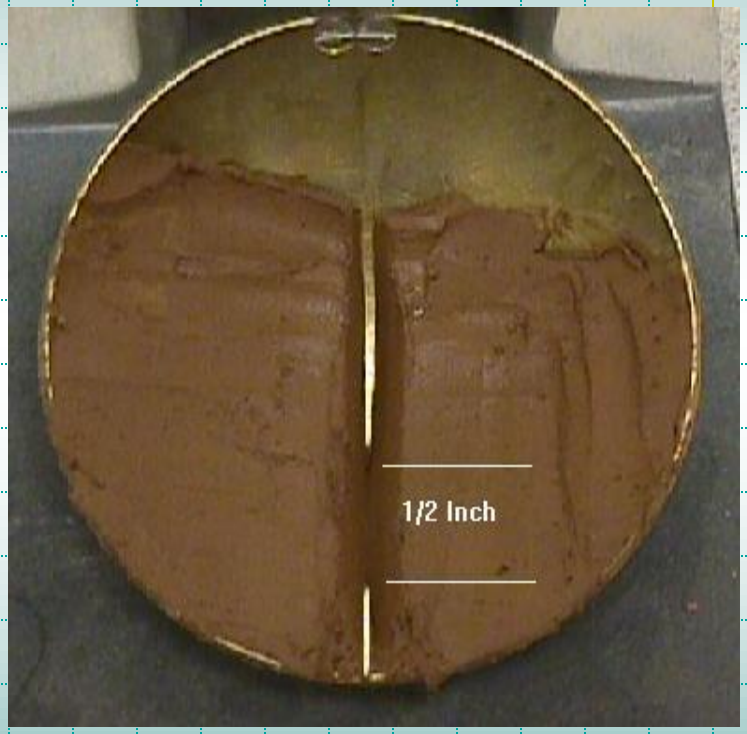
Determination of Liquid Limit: Cassagrande's Method

- **The soil is remixed to paste and portion of it placed in the metal cup.**
- The soil paste is leveled off in the cup to give a maximum depth of 8 mm.
- **A groove is formed in the soil along the mid section of the cup, using a standard grooving tool.**
- The handle is turned at 2 rev/sec and number of blows is counted until two parts of the soil come in continuous contact at the bottom of the groove along a distance of about 12 mm.



Determination of Liquid Limit: Cassagrande's Method

- A sample is taken from the closed portion of the groove for moisture content determination.
- The remaining soil is removed from the cup to mix with the original paste adding further water, and the test is repeated for several times.
- The number of blows and moisture content in each trial are recorded.
- It is desirable to have the tests in the blow range of 15 to 35.
- The liquid limit, according to this method, is defined as the moisture content at which 25 blows are required to close the groove..

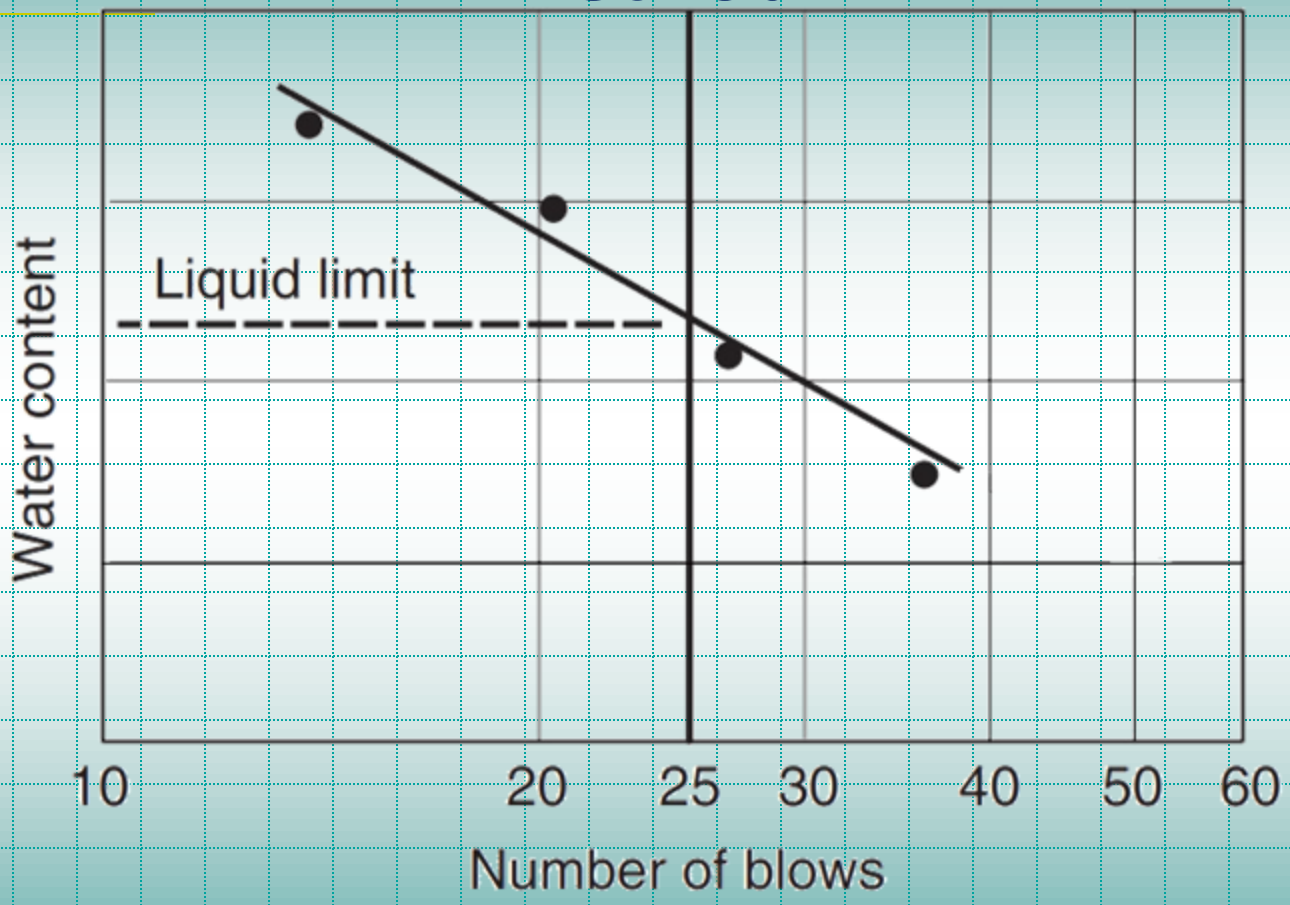


Determination of Liquid Limit: Cassagrande's Method



A semilog plot of the points is obtained with number of blows as abscissa in logarithmic scale, as against moisture content in linear scale. A best fitting straight line is drawn which is termed as flow curve. The moisture content corresponding to 25 blows is read from the flow curve as the liquid limit of soil.

Determination of Liquid Limit: Cassagrande's Method



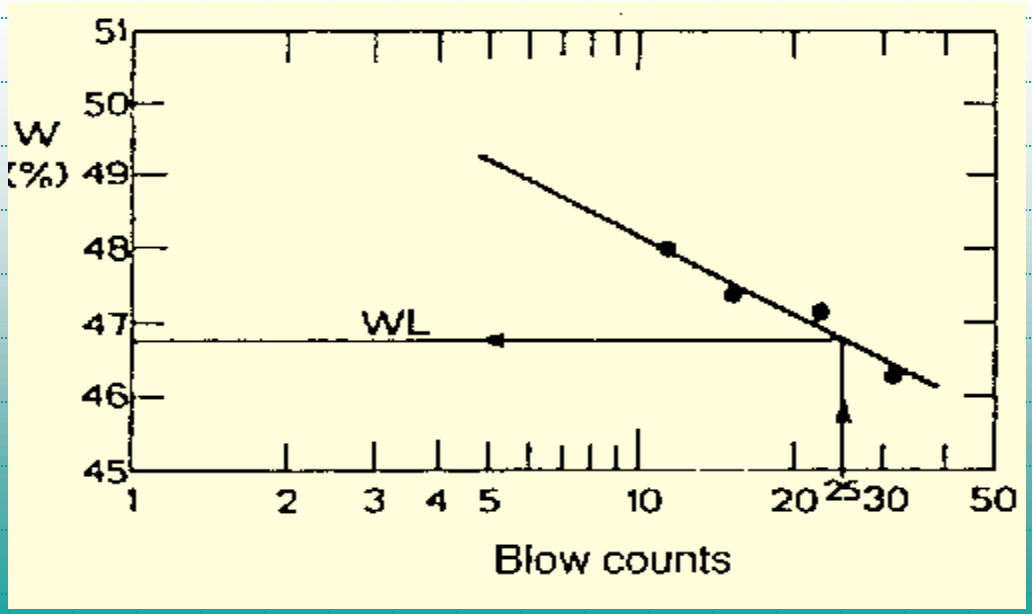
↑ Water content versus log of number of blows: Flow curve (after Holtz & Kovacs, 2023).

Determination of Liquid Limit: Cassagrande's Method

The slope of the flow curve is termed as flow index, I_F and may be expressed as,

$$I_F = \frac{w_1 - w_2}{\log_{10} N_2 - \log_{10} N_1} = \frac{w_1 - w_2}{\log_{10}\left(\frac{N_2}{N_1}\right)}$$

If $N_1 = 10$ and $N_2 = 100$, then $I_F = w_1 - w_2$



MZA

Determination of Liquid Limit: Cassagrande's Single Point Method



Lambe (1951) suggested that flow curves plotted on a double log scale should give parallel straight lines represented by the following general equation:

$$w_L = w\left(\frac{n}{25}\right)^e$$

Where, w = moisture content in percent at n blows. The value of exponent e is suggested as 0.10 by Kapre and Kulkarni (1972). This is commonly known as the one point method of determining the liquid limit by Cassagrande's apparatus.

Determination of Liquid Limit: Cassagrande's Single Point Method



Nagaraj and Jayadeva (1981) proposed an alternative relation for one point method of determining liquid limit. According to them,

$$w_L = \frac{w}{1.3215 - 0.23 \log_{10} N}$$

Where, w = moisture content in percent at blows n, ranging in between 15 to 35.

Determination of Liquid Limit: Cone Penetration Method



The cone penetrometer apparatus mainly consists of a stainless steel cone 35 mm long with an apex angle of 30° and having a mass including its connecting shaft of 80 gms (0.78 N).



Determination of Liquid Limit: Cone Penetration Method



The cone is mounted on a stand which will allow it to be dropped and then held in position while its vertical movement is measured. The assembly is mounted on a stand having a base, locking device, dial gauge and other adjustment screws. A cylindrical metal cup, approximately 55 mm in diameter and 40 mm deep is used to contain the test soil sample.

Determination of Liquid Limit: Cone Penetration Method



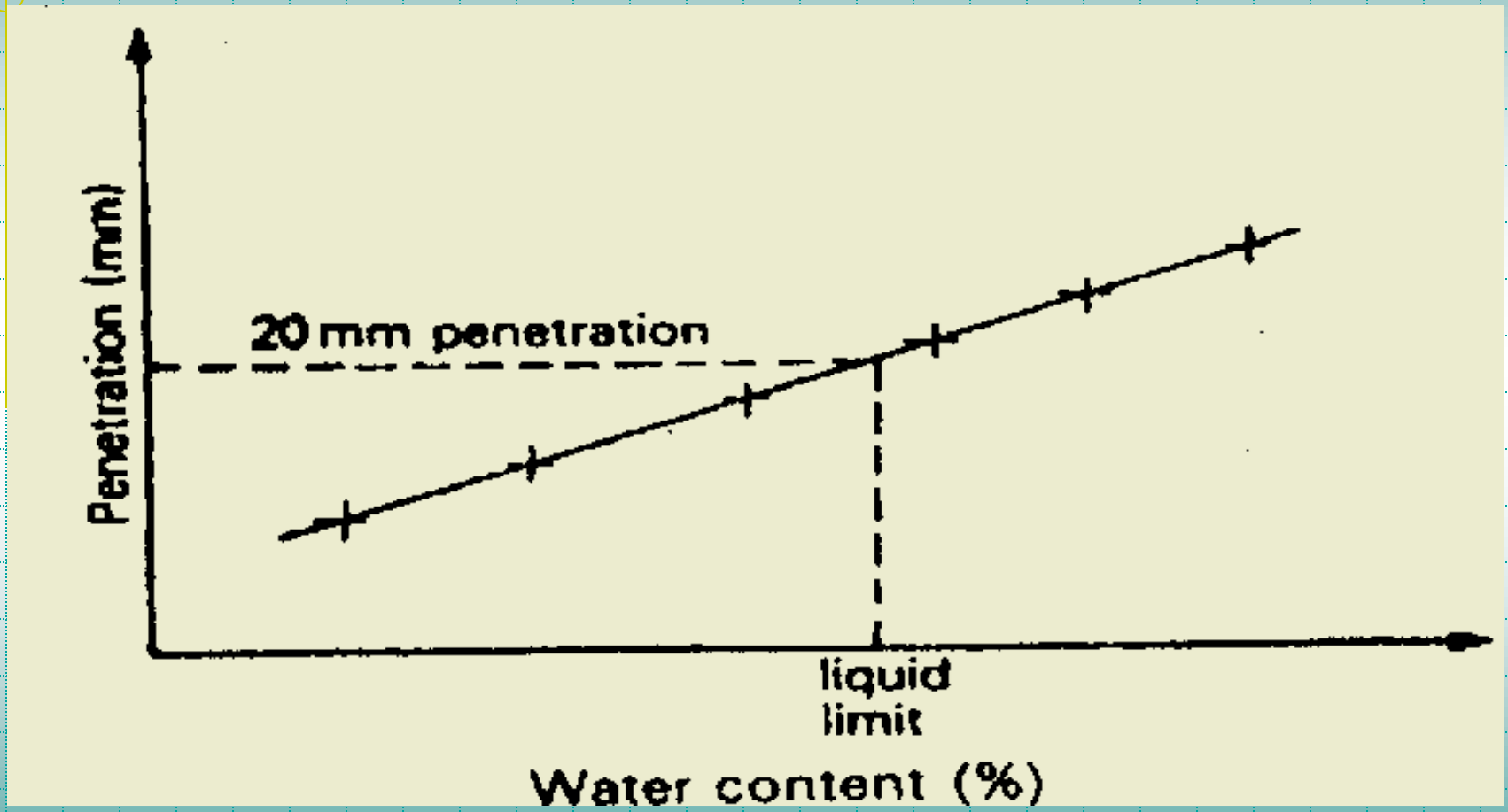
- The preparation of soil sample is similar to that of Cassagrande's method. The soil paste is filled in the metal cup and the top surface is struck off level. After placing the cup on the base of the stand, the cone is lowered to just touch the surface of the soil paste.
- The dial gauge is then set and the reading noted. The cone is released to penetrate the soil paste for 5 seconds and relocked in its new position. The second dial gauge reading is then taken. The difference between the first and the second dial gauge readings gives the amount of cone penetration.

Determination of Liquid Limit: Cone Penetration Method



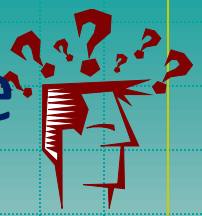
- A small portion of soil is taken from the cup for moisture content determination.
- The soil paste is taken out from the cup, remixed with the original sample paste adding further water. Thus the penetration and moisture content test procedures are repeated several times.
- A plot is drawn of cone penetration against moisture content. The liquid limit of the soil is taken as the water content corresponding to a penetration of 20 mm.

Determination of Liquid Limit: Cone Penetration Method



MZA

Determination of Liquid Limit: Single Point Cone Penetration Method



Nagaraj and Jayadeva (1981) also proposed for cone penetration method an expression for determining liquid limit as:

$$w_L = \frac{w}{0.65+0.0175D}$$

Where, w is the moisture content corresponding to penetration D (ranging in between 16 to 26 mm).

MZA

Determination of Plastic Limit: Cassagrande's Method



The preparation of soil sample is for plastic limit is similar to that of liquid limit. The following steps are followed.

- **Approximately 20 gm of soil paste is moulded in hand until it dries sufficiently for slight cracks to appear.**
- **The sample is then divided into two approximately equal portions and these divided into four sub-samples.**
- **One of the sub-samples is taken and rolled into a ball, and then rolled on a glass sheet to form a thread of soil. The rolling, using the palm and fingers**

MZA

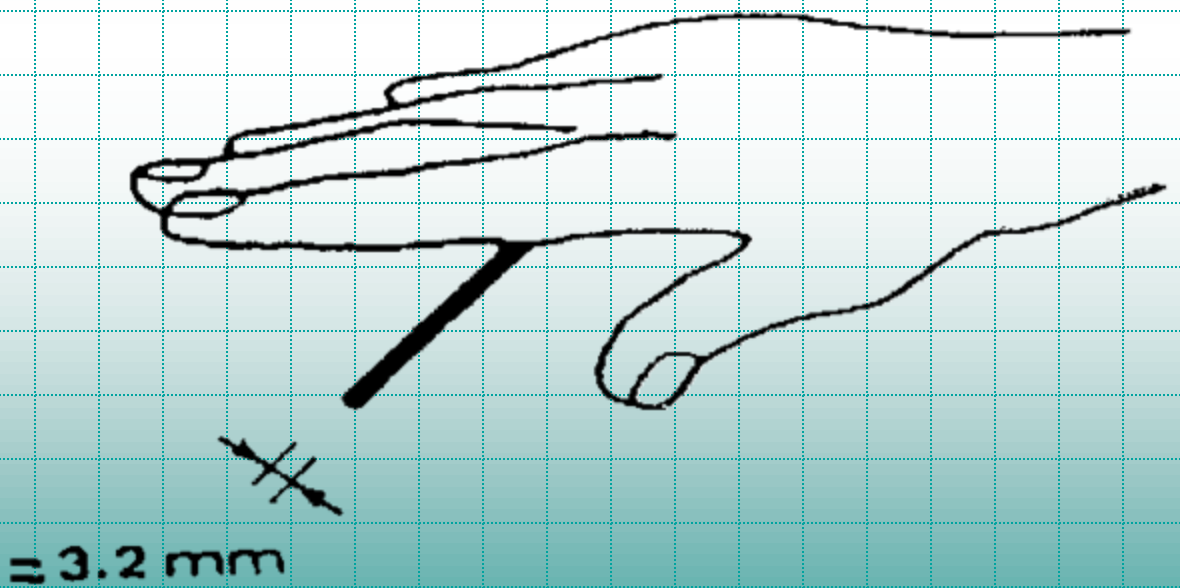
Determination of Plastic Limit: Cassagrande's Method



- The soil is again reformed into a ball; the action of handling the soil has the effect of drying it.
- It is then re-rolled on the glass sheet until the thread starts to crumble just as the diameter reached approximately 3 mm. At this stage the thread fragments are taken into an air tight container.
- The process is repeated for the other three sub-samples and the thread fragments are collected in the same container, and their combined water content determined.

Determination of Plastic Limit: Cassagrande's Method

- The procedure is also repeated for other half portion of the original sample and moisture content is determined. The average of the two water contents is reported as the plastic limit, w_p.



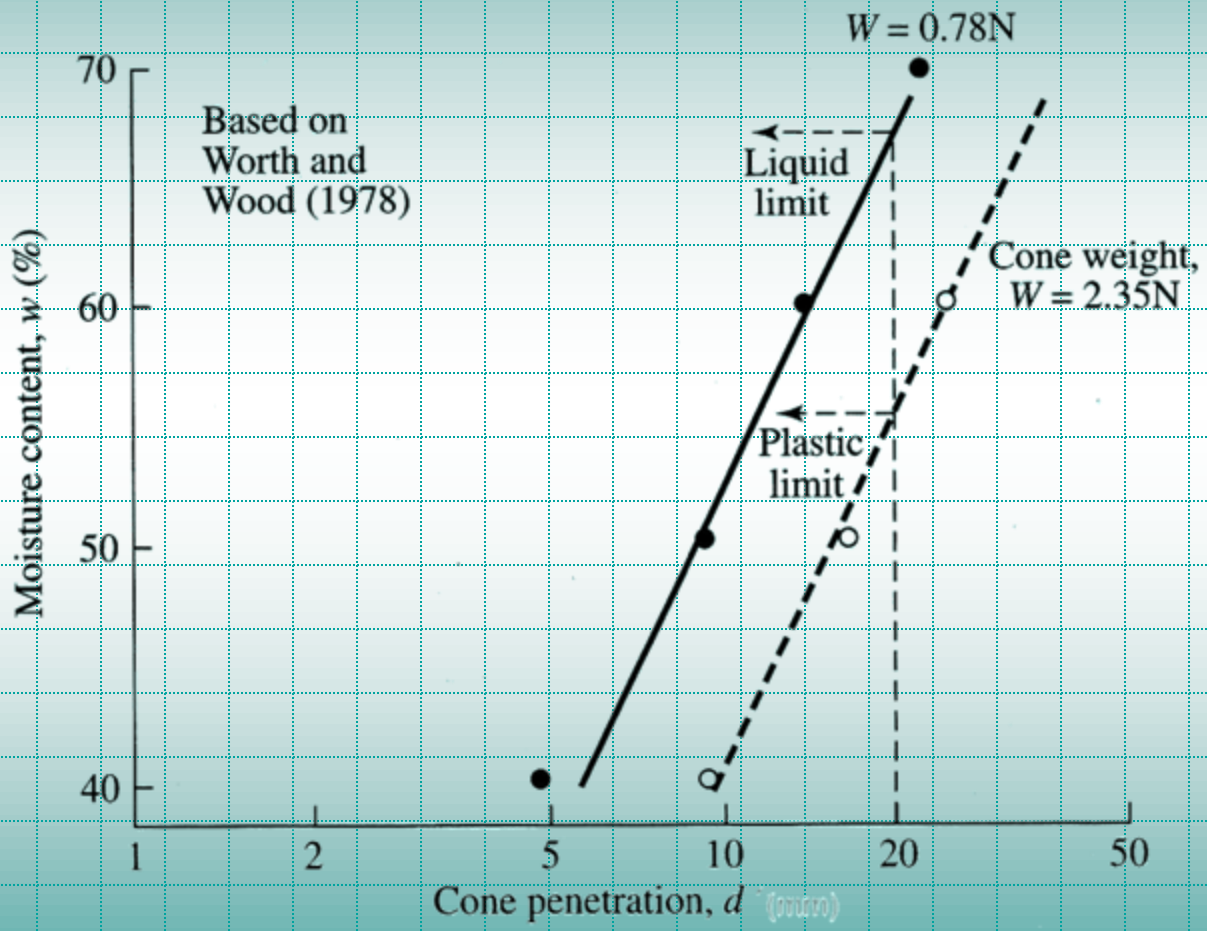
Determination of Plastic Limit: Cone Penetration Method



Wroth and Wood (1978) suggested a method of determining the plastic limit using cone penetration apparatus, as used for liquid limit.

- This can be done by using a cone of similar geometry but with a mass of 240 gm (2.35 N) instead of 80 gm 0.78 N).
- Three or four tests at varying moisture contents of soil are conducted, and the corresponding cone penetrations are determined.
- The moisture content corresponding to a cone penetration of 20 mm is the plastic limit.

Determination of Plastic Limit: Cone Penetration Method



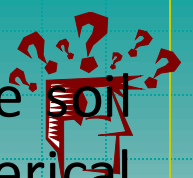
Indices from Limit Tests



Consistency Indices

- Plasticity Index, PI or I_P
- Liquidity Index, LI or I_L
- Consistency Index, CI or I_C
- Flow Index, FI or I_L
- Toughness Index, TI or I_T

Indices from Limit Tests



Plasticity Index: The range of water contents over which the soil remains plastic is the plasticity index, I_P. It is the numerical difference between liquid $(w_L)$and plastic (w_P)limits.

$$I_P = w_L - w_P$$

Liquidity Index: The current state of a soil, in terms of Atterberg limits, is defined by the Liquidity Index.

$$I_L or\ LI = \frac{w_n - w_P}{w_L - w_P} = \frac{w_n - w_P}{I_P}$$

Consistency Index: The current state of a soil, in terms of Atterberg limits, may also be defined as the Consistency index.

$$I_C or\ CI = \frac{w_L - w_n}{w_L - w_P} = \frac{w_L - w_n}{I_P}$$

$$I_F = \frac{w_1 - w_2}{\log n_2 - \log n_1} = \frac{w_1 - w_2}{\log \frac{n_2}{n_1}}$$

Liquidity Index: The current state of a soil, in terms of Atterberg

Indices from Limit Tests



Flow Index: The slope of the flow curve is termed as flow index, I_F.

$$I_F = \frac{w_1 - w_2}{\log n_2 - \log n_1} = \frac{w_1 - w_2}{\log\left(\frac{n_2}{n_1}\right)}$$

Toughness Index: Toughness index, I_T is defined as the ratio of plasticity index (I_P) to the flow index (I_F).

$$I_T = \frac{I_T}{I_F}$$

The toughness index of a soil is a measure of shearing strength of the soil at the plastic limit.

MZA

Indices from Limit Tests



Let us assume that the flow curve is a straight line between the liquid limit and the plastic limit. As the shearing resistance of the soil is directly proportional to number of blows in Cassgrande's device. Thus,

$ks_L = n_L$ and, $ks_P = n_P$

Where,

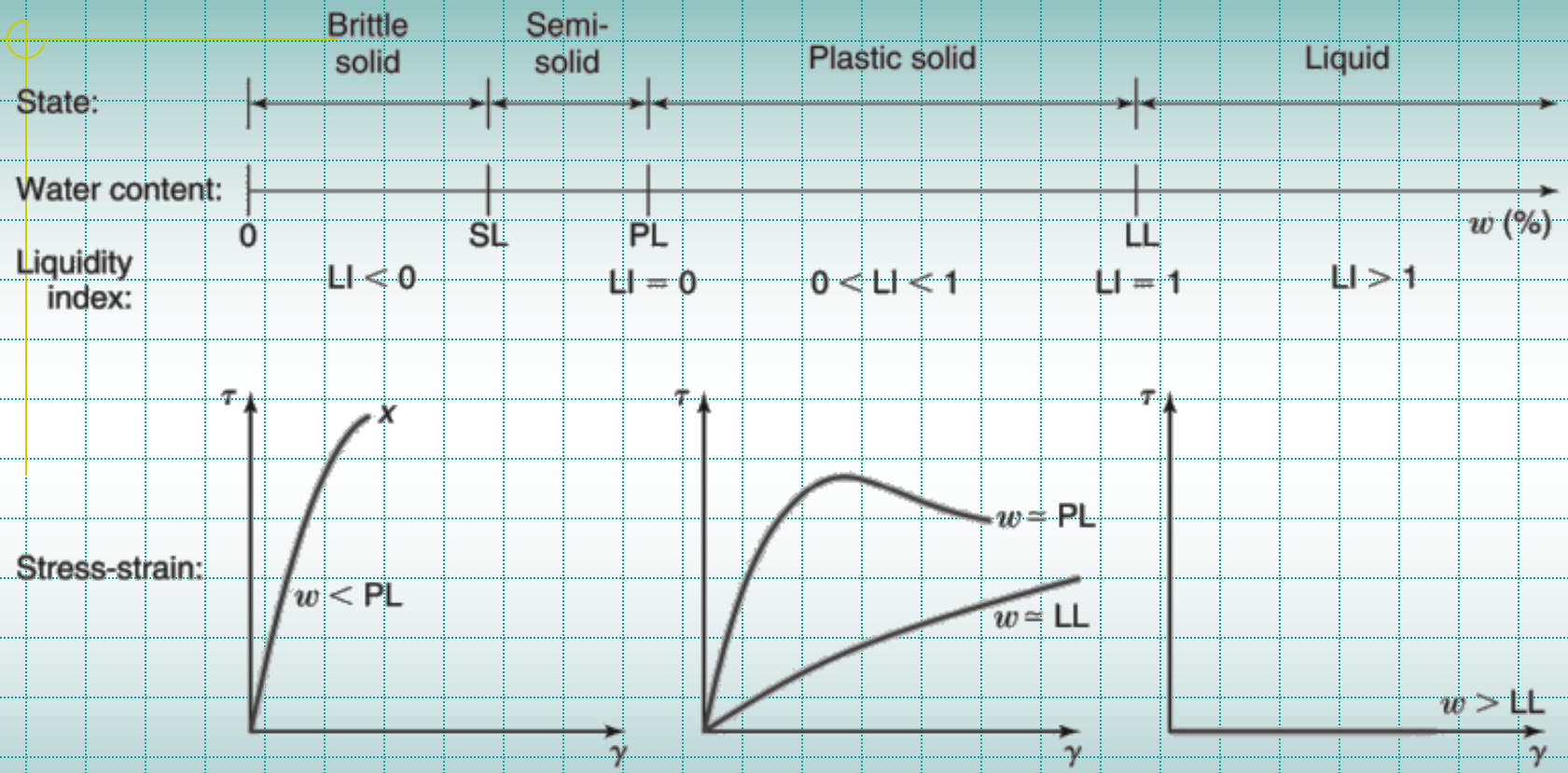
n_L = No. of blows at liquid limit when the shear strength is s_L

n_p = No. of blows at plastic limit when the shear strength is s_P

$$\therefore \quad I_T = \frac{I_P}{I_F} = \frac{w_L - w_P}{\dfrac{w_2 - w_1}{\log\left(\dfrac{n_2}{n_1}\right)}} = \frac{w_L - w_P}{w_L - w_P} \times \log\frac{n_P}{n_L} = \log\frac{kS_P}{kS_L} = \log\frac{S_P}{S_L}$$

MZA

Indices from Limit Tests



↑ Water content continuum showing the various states of a soil as well as their generalized stress-strain response.(after Holtz & Kovacs, 2023)

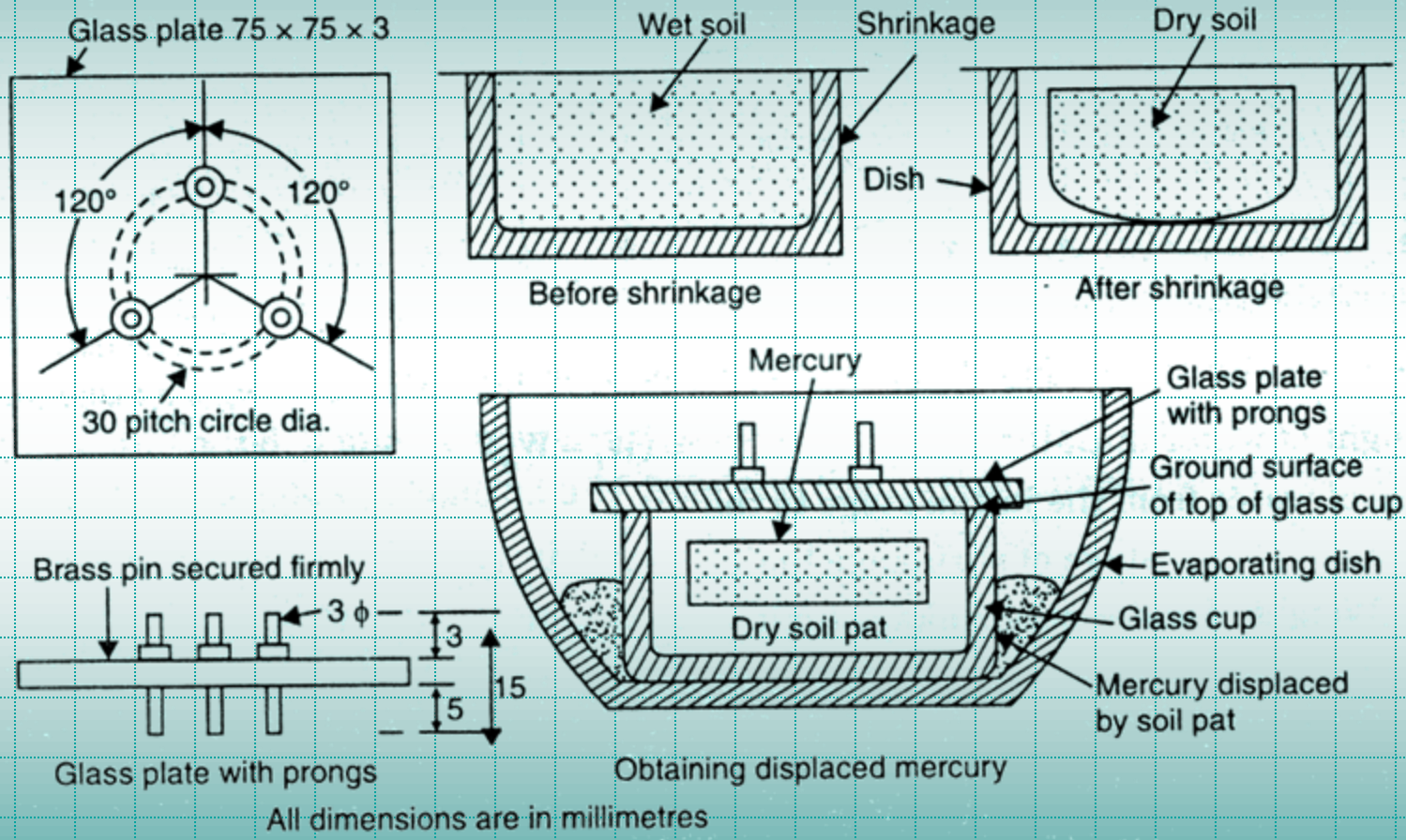
Determination of Shrinkage Limit: Mercury Cup Method



The preparation of soil sample is similar to that of liquid limit. The shrinkage characteristics of a soil can be estimated in many ways. Of which shrinkage limit and linear shrinkage tests are most common. The apparatus determining the shrinkage limit mainly consists of a stainless steel or porcelain shrinkage dish, a mercury cup and a glass plate with prongs as in Figure below**. The procedure may be described as follows.**

- Soil sample passing 425 μm sieve is mixed with water to form a creamy paste that is filled in shrinkage dish in level with rim.

Determination of Shrinkage Limit: Mercury Cup Method



MZA

Determination of Shrinkage Limit: Mercury Cup Method



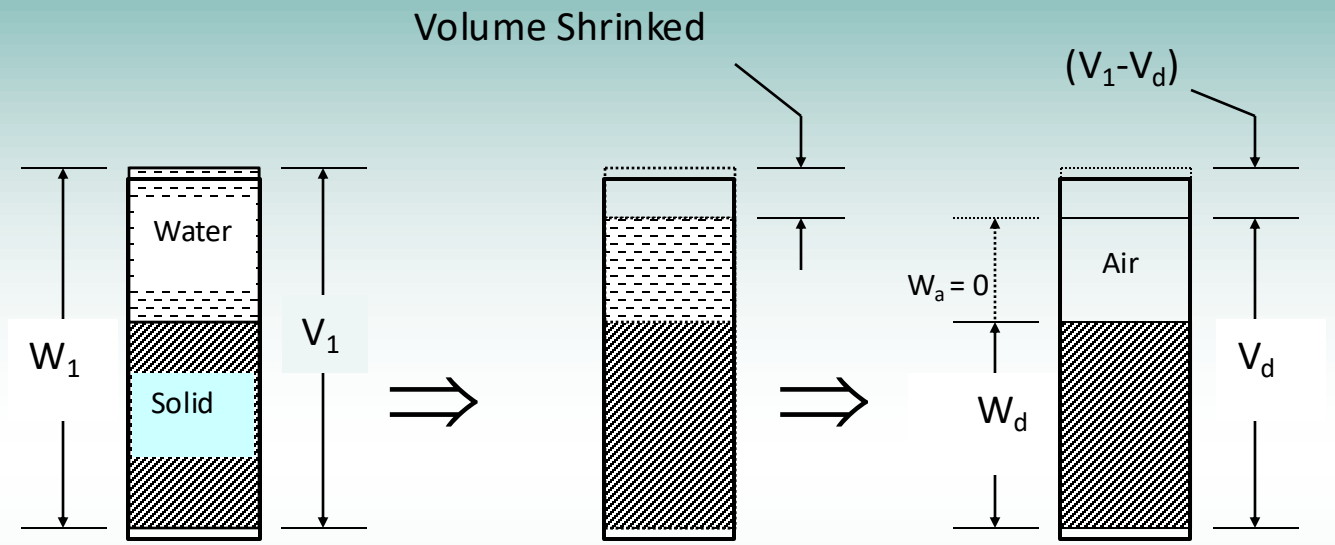
- The weight of the soil paste is taken. It is dried gradually first in air and then in oven to form a soil pat.
- The dry weight of the soil pat is taken and volume is determined by displacement of mercury using mercury cup and glass plate.

Now, there are two ways of estimating the shrinkage limit of soil.

- ❑ While specific gravity of the soil solid is unknown.
- ❑ When the specific gravity of the soil solid is known.

Determination of Shrinkage Limit

Unknown Specific Gravity of Soil Solids

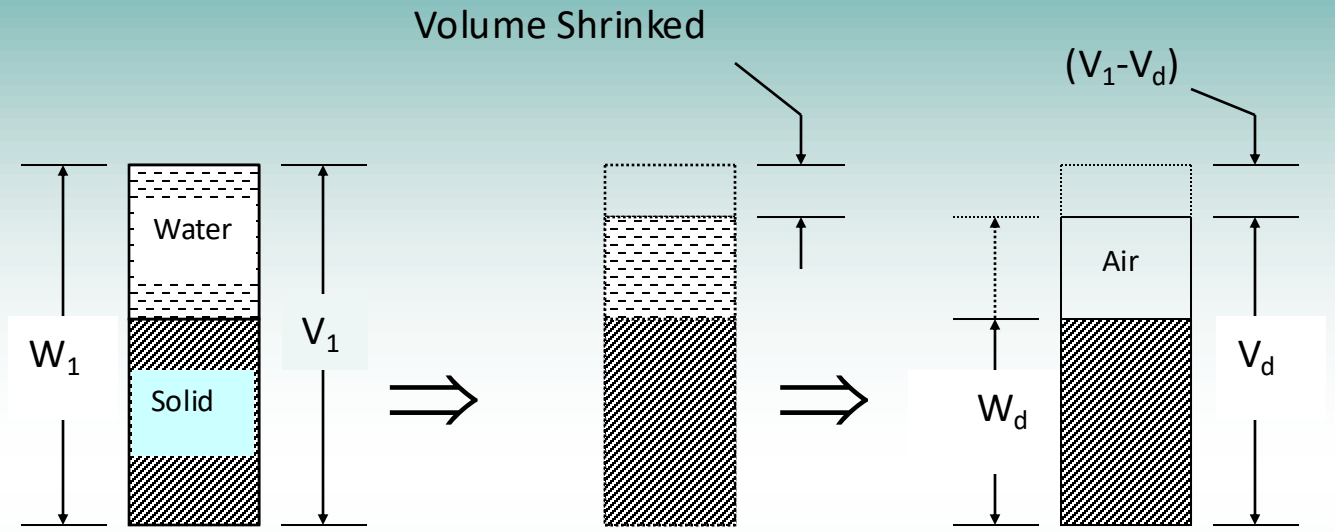


$$Shrinkage\ Limit, w_L\ or\ SL = \frac{Weight\ of\ water\ at\ shrinkage\ limit}{Weight\ of\ soil\ solid}$$

$$= \frac{(W_1 - W_d) - (V_1 - V_d)\gamma_w}{W_d}$$

Determination of Shrinkage Limit

Known Specific Gravity of Soil Solids



$$Shrinkage\ Limit, w_L\ or\ SL$$

$$= \frac{Weight\ of\ water\ at\ shrinkage\ limit}{Weight\ of\ soil\ solid}$$

$$= \frac{\left(V_d - \frac{W_d}{G_s}\right)\gamma_w}{W_d} = \left(\frac{V_d}{W_d} - \frac{1}{G_s}\right)$$

MZA

Determination of Linear Shrinkage



The linear shrinkage is a measure of degree of decrease of a soil sample in one dimension. The preparation of soil sample is similar to that of liquid limit. The prepared soil sample is thoroughly remixed with distilled water to form a smooth homogeneous paste at approximately the liquid limit of soil. The soil water paste is placed in to a brass mould, taking care not to entrap air, and the surface struck off level. The soil is air dried until it has shrunk clear of the mould and then placed in an oven at 105^{o}C – 110^{o}C to complete the drying. After cooling the of the sample is measured and the linear shrinkage obtained as follows.

MZA

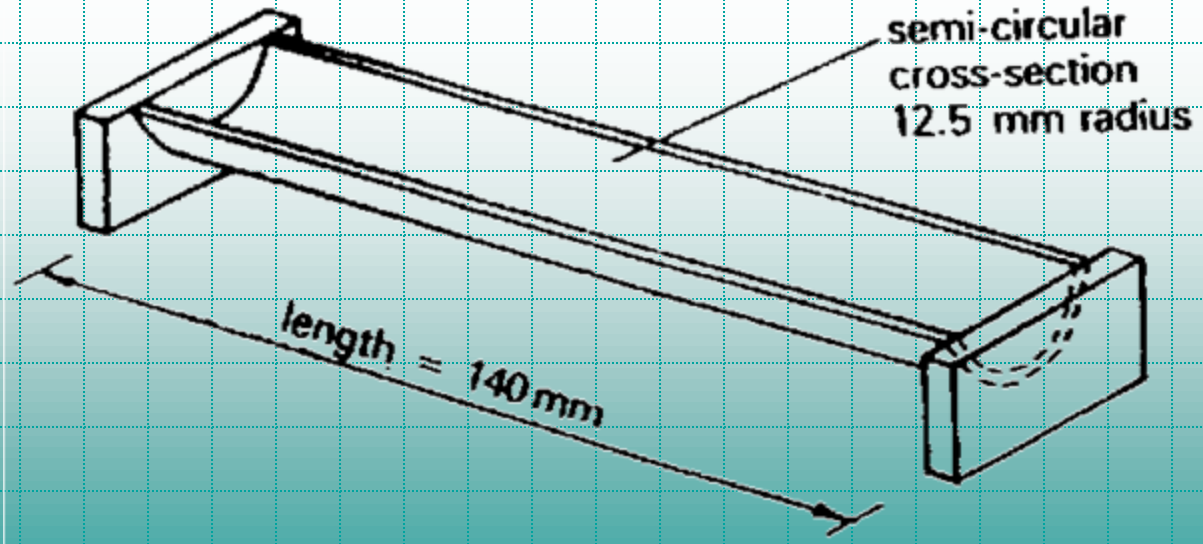
Determination of Linear Shrinkage



$$Linear\ shrinage\ , LS(\%) = \left(1 - \frac{Length\ after\ drying}{Initial\ length}\right) \times 100$$

$$= \left(1 - \frac{L_d}{L_m}\right) \times 100$$

Where, L_m is the length of the mould (usually 140 mm) and L_d is the length of the dried soil in the mold.



MZA

Determination of Linear Shrinkage



For soils with very small clay content the liquid and plastic limits may not produce reliable results. An approximation of the plasticity index, I_p or PI, may be obtained by measuring the linear shrinkage and using the following expression (Whitlow, 1996).

$$Plasticity\ index, I_P\ or\ PI = 2.13LS$$

MZA

Plasticity Index and Soil Properties



Soil	Liquid limit, w_L	Plastic limit, w_P
Silt clay mixture	25-40	20-30
Kaolinite clay	40-70	20-40
Montmorillonite clay	300-600	100-200

Plasticity index, I_P	Terms used to describe the soil	Dry strength	Field test
0 - 3	Nonplastic	Very low	Grains fall apart easily
4 - 6	Slightly plastic	Low	Easily crushed by fingers
7 - 15	Moderately plastic	Low to medium	Slight pressure required to crush
16 - 35	Plastic	Medium to high	Difficult to crush
Over 35	Highly plastic	High	Impossible to crush with fingers

MZA

Shrinkage Limit, Linear Shrinkage & Swelling Potential



Shrinkage limit, w_S	Linear shrinkage, LS	% Colloids (<0.001 μm)	Liquid limit, w_L	Plasticity index, I_P	Swelling potential
> 15	0-5	< 15	< 39	< 18	Low
10 - 16	5-8	13 – 23	39 – 50	15 – 28	Medium
7 - 12		20 - 31	50 – 63	25 – 41	High
< 11	> 8	> 28	>63	> 35	Very High

MZA

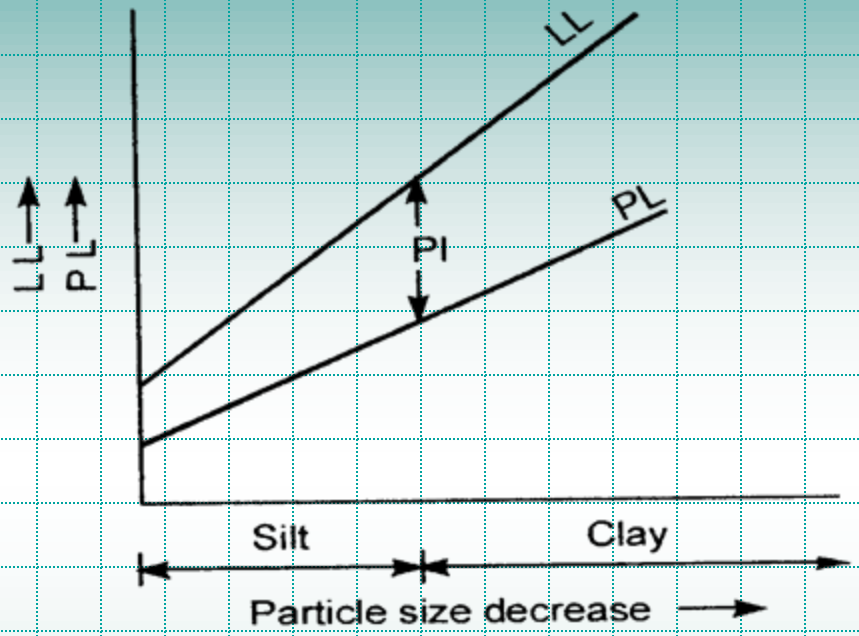
Significance of Indices



- Both the liquid and plastic limits depend on the type and amount of clay in a soil. However, the plasticity index depends mainly on the amount of clay. Thus, the plasticity index of a soil is a measure of the amount of clay in soil.
- As the particle size decreases, both the liquid and plastic limits increase, but the liquid limit increases at a greater rate. Therefore, the plasticity index increases at a rapid rate.

MZA

Significance of Indices



- Plasticity index is a measure of the fineness of the particles.
- The study of plasticity index, in combination with liquid limit gives information about the type of clay.

MZA

Significance of Indices



- Sandy soils do not possess plasticity and are classified as non-plastic (NP). Soils with the liquid limit less than 20% are generally classified as sands.
- Plastic limit of a soil increases if organic matter is added, without any significant increase in the liquid limit. Therefore, soils with high organic content have low plasticity index.
- Liquid limit of a soil is an indicator of the compressibility of a soil. The compressibility of a soil generally increases with an increase in liquid limit.

MZA

Significance of Indices



- Shrinkage index is directly proportional to % of clay-size fraction present in soil. It can be used as an indicator of amount of clay.
- The flow index is the rate at which a soil mass looses its shear strength with an increase in water content.
- The toughness index is a measure of the shearing strength of the soil at the plastic limit. A high value of toughness index indicates a high percentage of colloidal clay containing mineral montmorillonite.

MZA

Significance of Indices



- When comparing the properties of two soils with plasticity index, as the liquid limit increases, the dry strength and toughness decreases, whereas compressibility and permeability increase.
- When comparing the properties of two soils with equal liquid limits, as the plasticity index increases, the dry strength and toughness increase, whereas the permeability decrease. However, the compressibility remains almost the same.

MZA

Unified Soil Classification System



In Unified soil classification system, soils are basically classified into two groups:

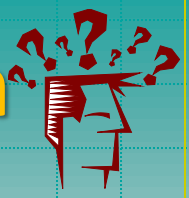
- Coarse Grained Soil (Gravel and Sand)
- Fine Grained Soil (Silt and Clay)

However, two other additional groups are also included though not precise enough in classification criteria:

- Organic Soil
- Peat soil

In this system coarse grained soils are classified according to their grain size characteristics, whereas, the fine grained are to their plasticity characteristics.

Unified Soil Classification System



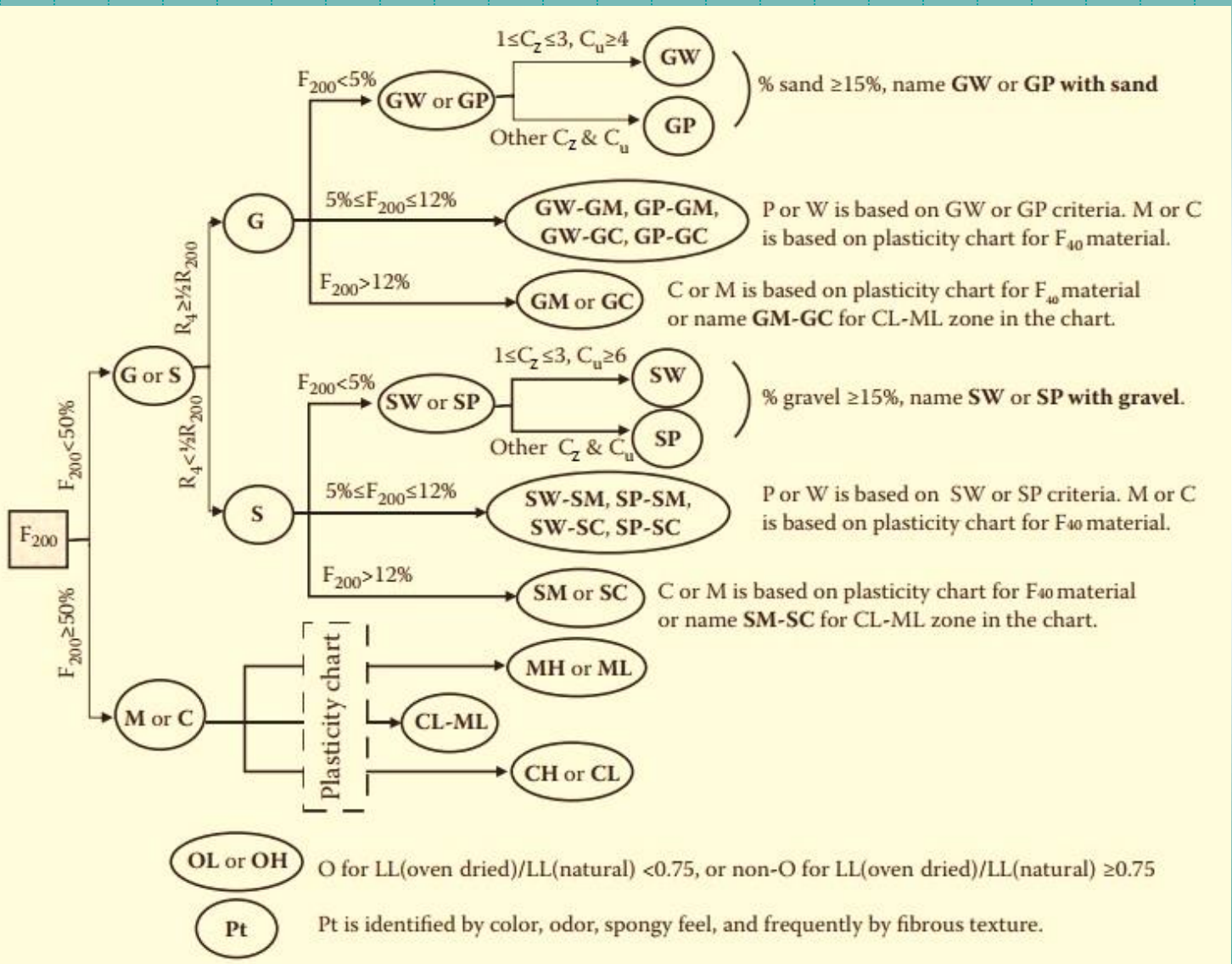
In this classification system, soils are usually given two-letter designation. The first letter indicates the main soil type, and the second modifies the first. The symbols used are presented below.

	Symbol	Description
Ist Letter	G	Gravel
	S	Sand
	M	Silt
	C	Clay
	O	Organic
	Pt	Peat
2nd Letter	W	Well graded
	P	Poorly graded
	M	Silty
	C	Clayey
	H	High plasticity
	L	Low plasticity

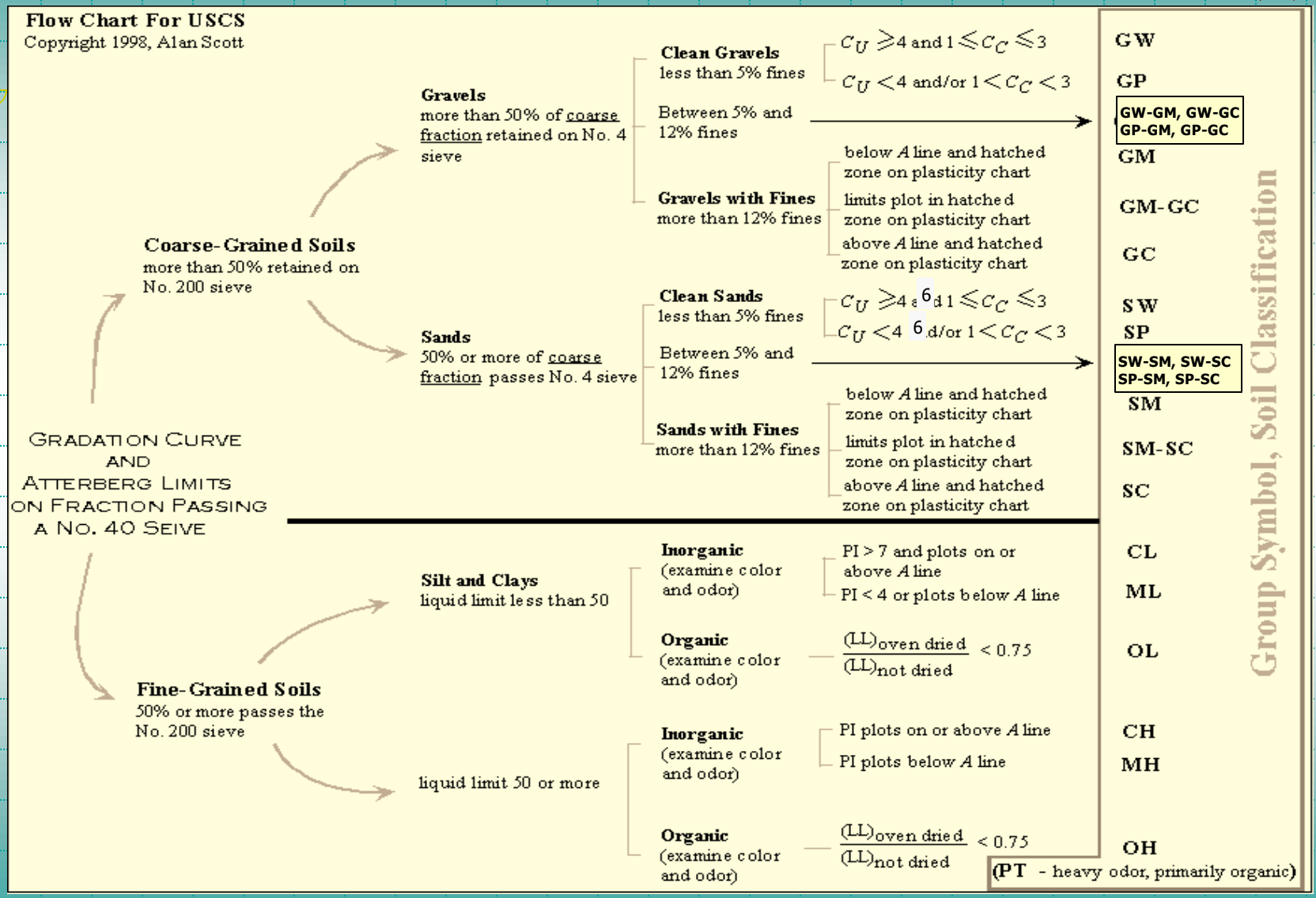
MZA

Unified Soil Classification System

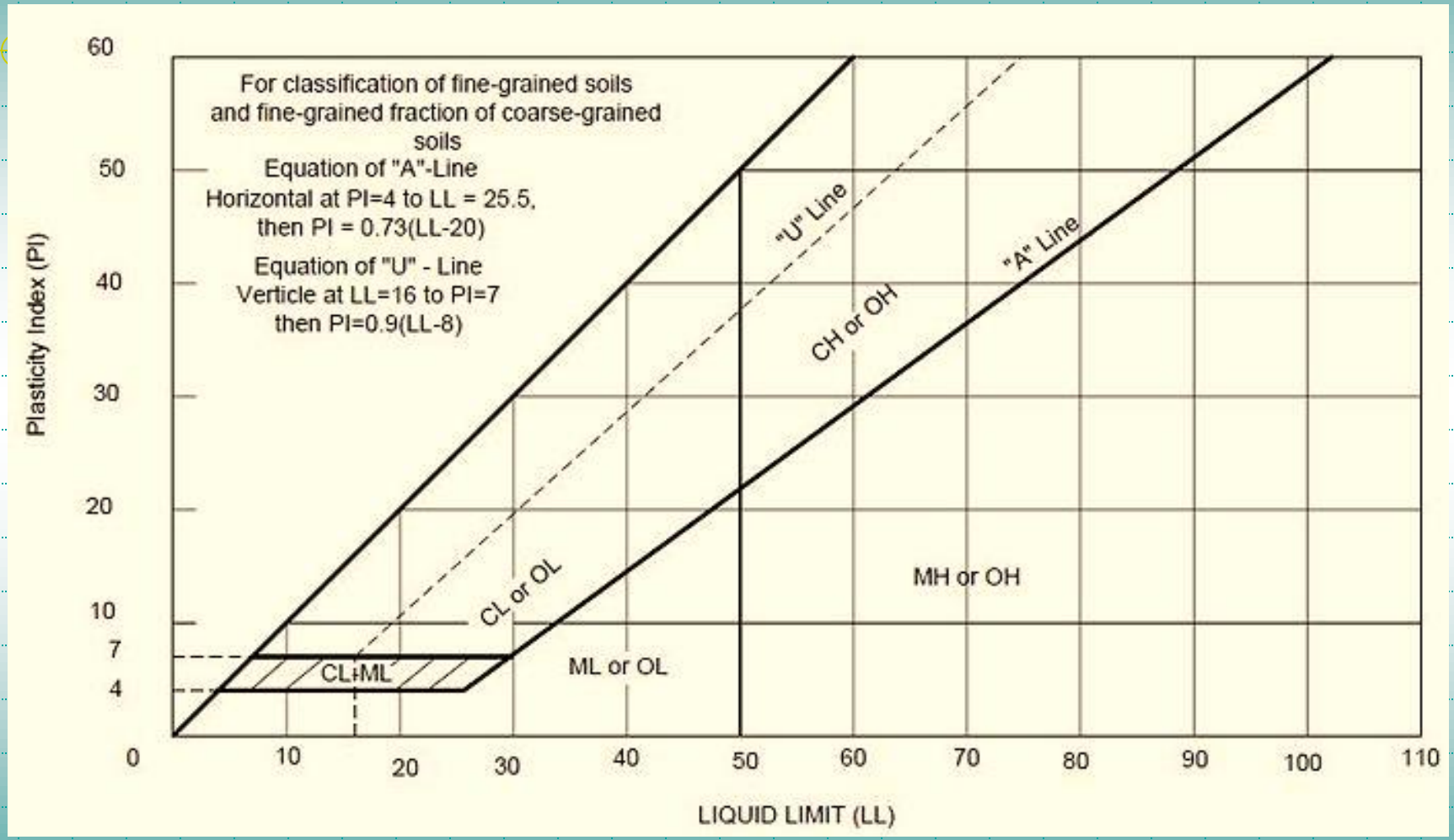




Unified Soil Classification System



Unified Soil Classification System



MZA

AASHTO Soil Classification System



Origin of AASHTO: (For Road Construction)

- Terzaghi and Hogentogler developed one of the first engineering soil classification system in 1928.
- It was intended specifically for use in highway construction. It rates soil according to the suitability for support of roadway pavements.
- The AASHTO classification system uses both particle size distribution and Attreberg limits data to assign a group classification and a group index to the soil.
  - ✓ Group classification ranges from A-1 (best soil) to A-8 (worst soil).
  - ✓ Group index values near zero indicate good soils, whereas values of 20 or more indicate very poor soils.

MZA

AASHTO Soil Classification System



Origin of AASHTO: (For Road Construction)

- However, it is important to remember that a soil that is good for use as a highway subgrade might be very poor for some other purpose.
- The AASHTO classification system divides inorganic soil into seven main groups, A-1 to A-7, based generally on the desirability of the soil as a subgrade for highway construction. Similar to Unified classification, it also uses grain size distribution and plasticity values as the criteria to classify the soils.
- In this system organic soils are placed in group A-8, that again uses characteristic black colour and bad odour as the criteria of classification.

AASHTO Soil Classification System

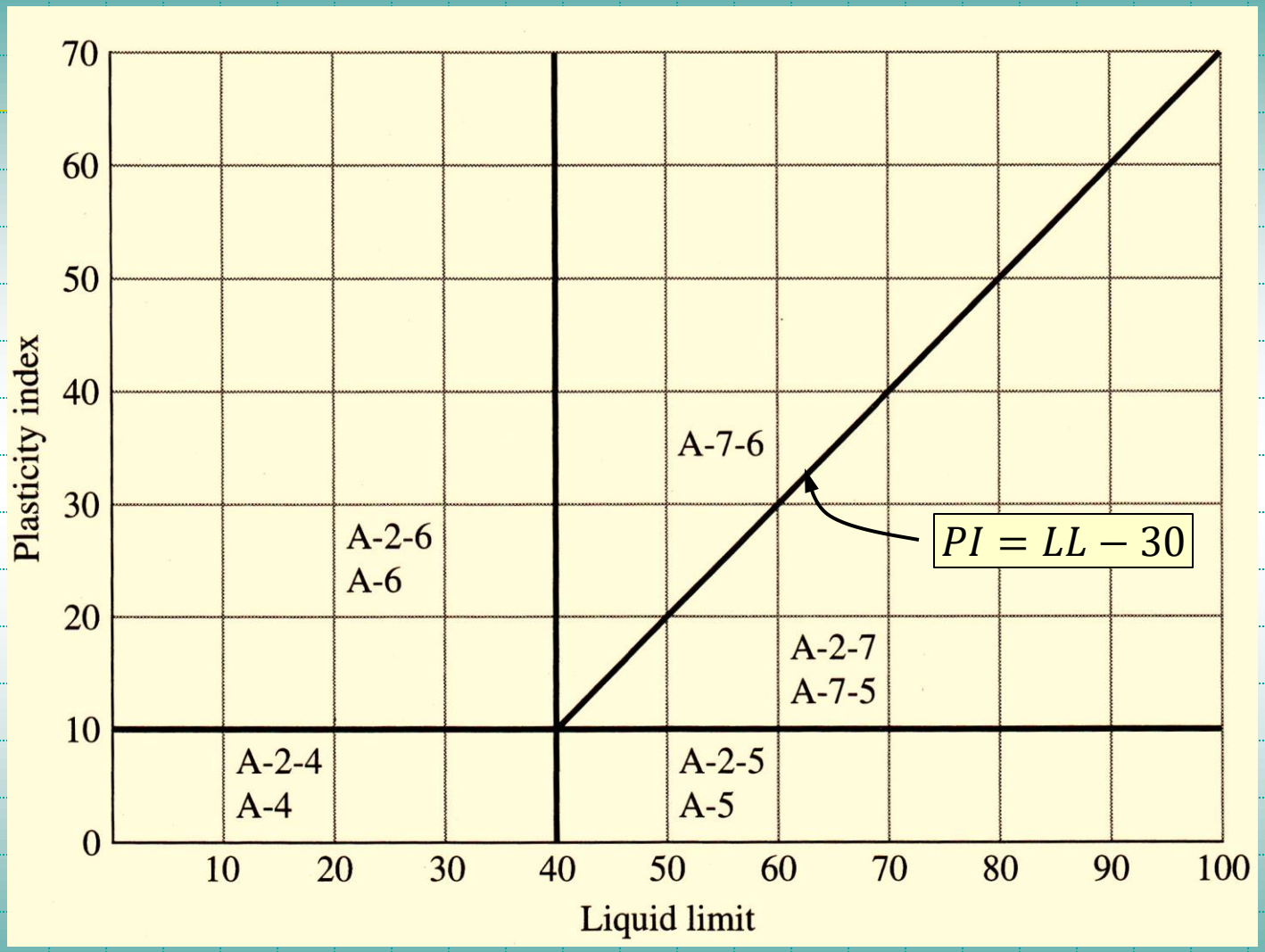
General Classification	Granular Materials (35% or less of total sample passing No. 200 [0.075 mm])							Silt-Clay Materials (More than 35% of total sample passing No. 200 [0.075 mm])				
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7	
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 [a]	A-7-6 [b]
Sieve Analysis (Percent Passing)												
No. 10 (2.00 mm)	50% max.	—	—	—	—	—	—	—	—	—	—	—
No. 40 (0.425 mm)	30% max.	50% max.	51% min.	—	—	—	—	—	—	—	—	—
No. 200 (0.075 mm)	15% max.	25% max.	10% max.	35% max.	35% max.	35% max.	35% max.	36% min.	36% min.	36% min.	36% min.	36% min.
Characteristics of Fraction Passing No. 40 (0.425 mm)												
Liquid Limit	—	—	—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	41 min.
Plasticity Index	6 max.	6 max.	NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.	11 min.
Usual Types of Significant Constituent Materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils		
General Subgrade Rating	Excellent to Good							Fair to Poor				

[a] *For A-7-5, PI ≤ LL – 30*

[b] *For A-7-6, PI > LL – 30*

Source: Table 1 of M 145-91 (2017) in *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, by the American Association of State Highway and Transportation Officials, Washington, DC, used with explicit permission

AASHTO Soil Classification System



AASHTO Soil Classification System



In AASHTO SOIL Classification System, a group index is used to further evaluate soils within a group. The group index is based on the service performance of many soils, especially while used as pavement subgrades. Group index is a function of liquid limit and plasticity index, and given by

$$Group\ Index, GI = (F - 35)[0.2 + 0.005(w_L - 40)] + 0.01(F - 15)(I_P - 10)$$

Where,

$F =$ % passing No. 200 sieve (i.e. finer than 0.075 μm)

$w_L =$ liquid limit (%)

$I_P =$ plasticity index (%)

AASHTO Soil Classification System



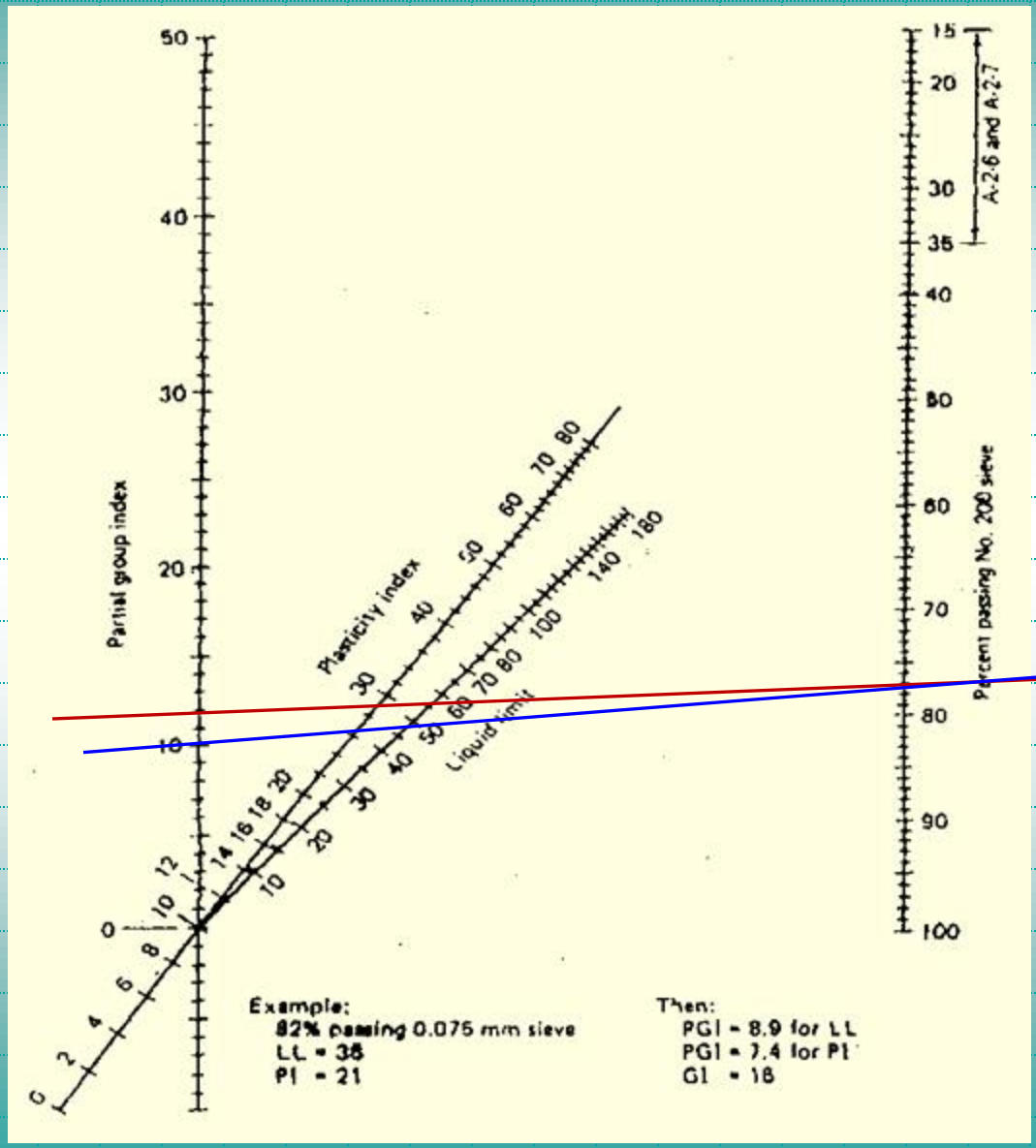
The group index is usually expressed as a whole number in parenthesis along with the soil group. The negative value is considered as zero. When working with A-2-6 and A-2-7 subgroups the Partial Group Index (PGI) if determined from the term containing plasticity index, I_P only.

$$Group\ Index, PGI = 0.01(F - 15)(I_P - 10)$$

As a general guide, the higher is the value of group index less suitable is the soil for subgrade material. Group index can also be estimated using the nomograph

AASHTO Soil Classification System

Nomograph for Group Index in AASHTO Soil Classification System →



AASHTO Soil Classification System



Rules for Group Index

- If the equation for group index gives a negative value for GI, it is taken as zero.
- The group index calculated from the equation is rounded off to the nearest whole number (for example, GI = 4.4 is rounded off to 4; and GI = 4.5 is rounded off to 5).
- There is no upper limit for the group index. However, the usual range is 0-20.
- The group index of soils belonging to groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3 will always be zero.
- When calculating the group index for soils belonging to groups A-2-6, and A-2-7, the partial group index equation related to plasticity index should be used.

$$GI = 0.01(F200 - 15)(PI - 10)$$

AASHTO Soil Classification System



Alternative Formula for Group Index

The GROUP INDEX formula can be rewritten as:

$$GI = 0.2(F - 35) + 0.005(F - 35)(w_L - 40) + 0.01(F - 15)(I_p - 10)$$

$$GI = 0.2a + 0.005ac + 0.01bd$$

$$a \; and \; b \equiv \%\, passing \; \#200 \; sieve$$

$$c \equiv Liquid \; limit$$

$$d \equiv Plasticity \; index = LL - PL$$

$$a(\%\, passing \; \#200) \equiv [35\% - 75\%] \; varies \; from \; 0 - 40; \; \leq 35\% = 0; \geq 75\% = 40$$

$$b(\%\, passing \; \#200) \equiv [15\% - 55\%] \; varies \; from \; 0 - 40; \; \leq 15\% = 0; \geq 55\% = 40$$

$$c(LL) \equiv [40\% - 60\%] \; varies \; from \; 0 - 20; \; \leq 40\% = 0; \geq 60\% = 20$$

$$d(PI) \equiv [10\% - 30\%] \; varies \; from \; 0 - 20; \; \leq 10\% = 0; \geq 30\% = 40$$

AASHTO Soil Classification System



Group Index and Quality of Soil as Subgrade Material

Group Index value	[0 (good) – 20 (very poor)]
0 – 1	Good
2 – 4	Fair
5 – 9	Poor
10 – 20	Very Poor