Basics of soil mechanics

Lecture Outline

Topics for discussion

1. Origin of Soils
2. Three Phase Diagram
3. Important Terms
4. Phase Relationships
5. Atterberg's limits

Origin of Soils

- Soils are formed by weathering of rocks due to mechanical disintegration or chemical decomposition.
- Exposed rocks are eroded and degraded by various physical and chemical processes.
- The products of erosion are picked up and transported to some other place by wind water etc.
- This shifting of material disturbs the equilibrium of forces on the earth and causes large scale movements and upheavals.

Types of Soils

(1) **Glacial soils**: formed by transportation and deposition of glaciers.

(2) **Alluvial soils**: transported by running water and deposited along streams.

(3) **Lacustrine soils**: formed by deposition in quiet lakes (e.g. soils in Taipei basin).

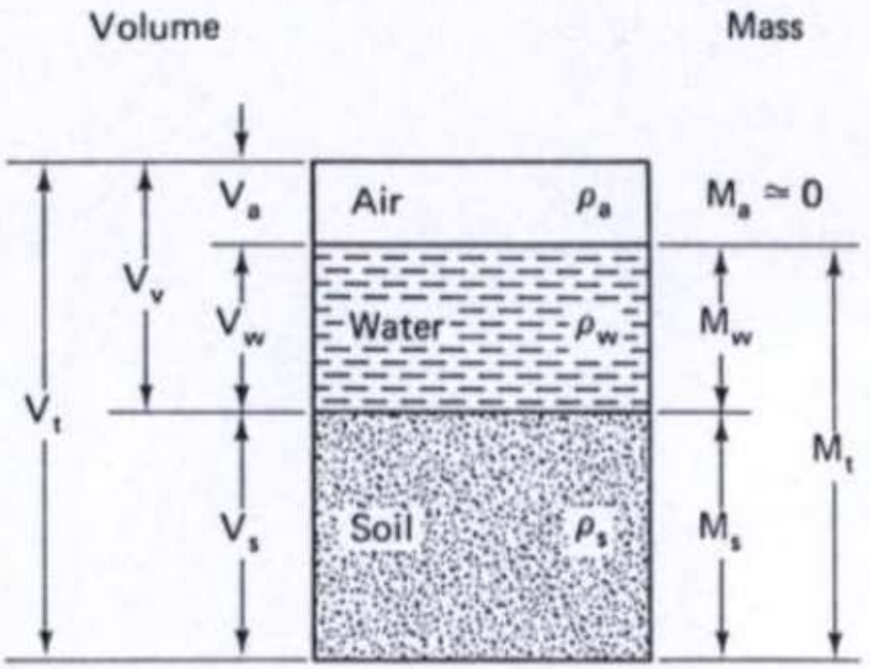
(4) **Marine soils**: formed by deposition in the seas (Hong Kong).

(5) **Aeolian soils**: transported and deposited by the wind (e.g. soils in the loess plateau, China).

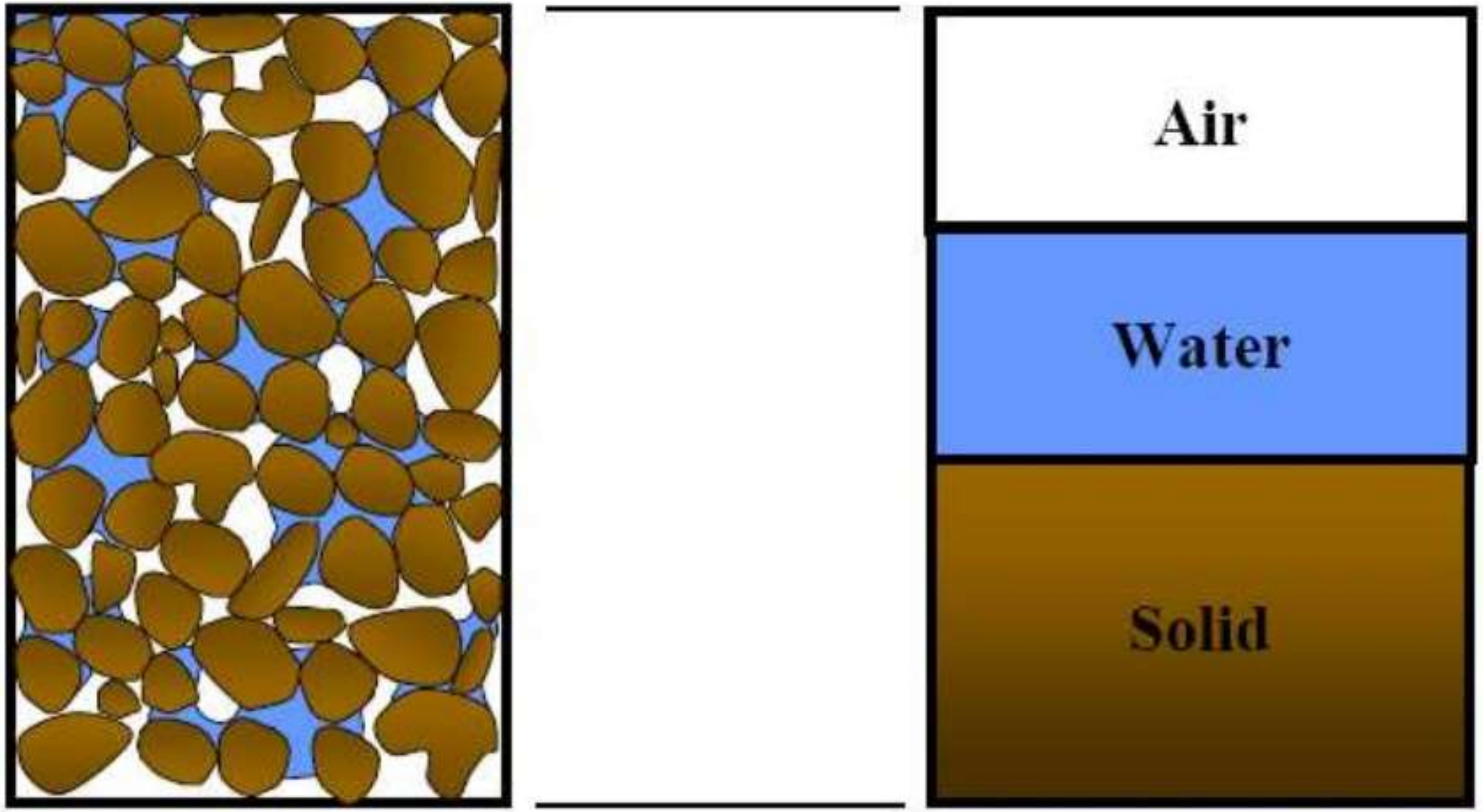
(6) **Colluvial soils**: formed by movement of soil from its original place by gravity, such as during landslide (*Hong Kong*). (from Das, 1998)

Three Phases in Soils

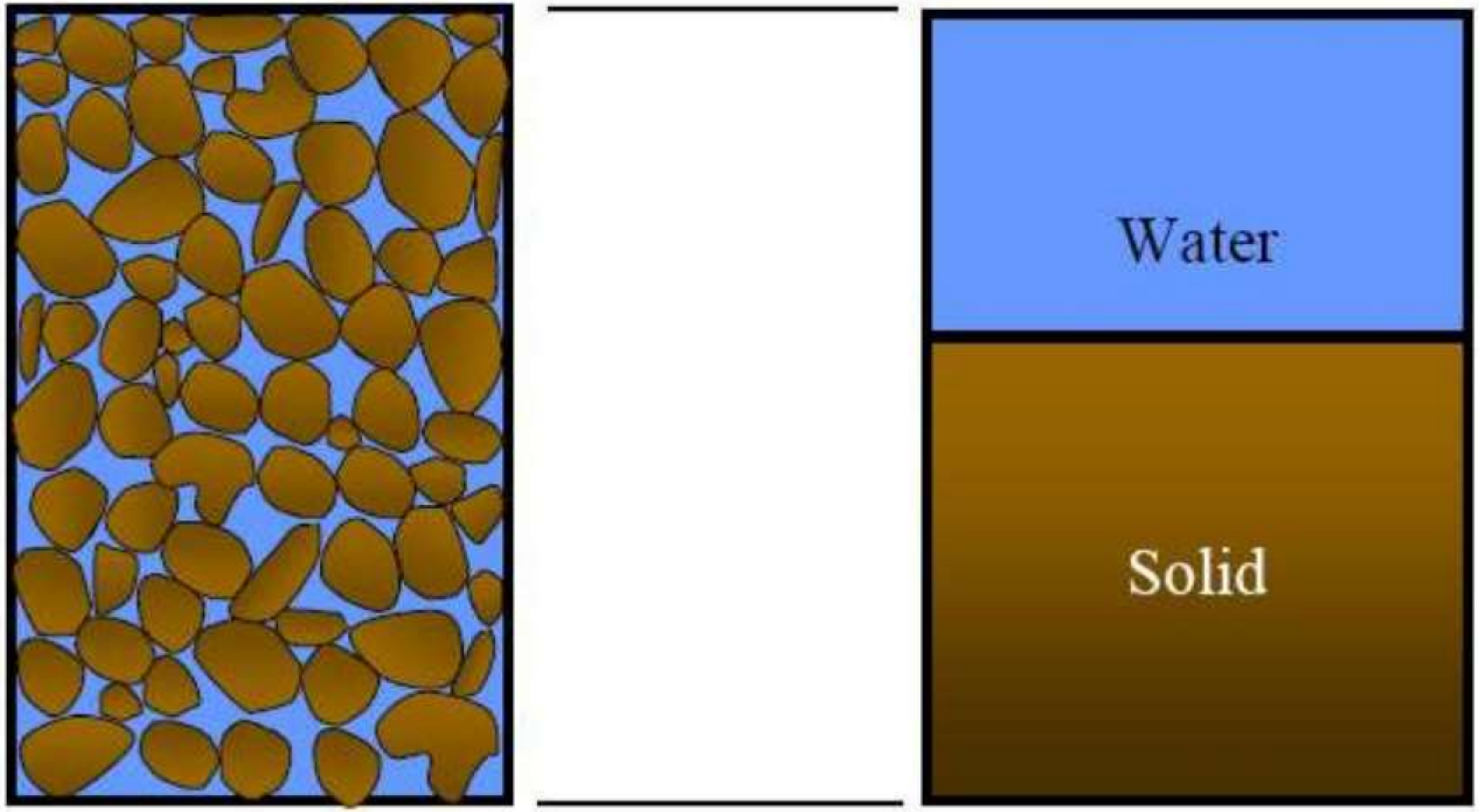
S :	Solid	Soil particle
W:	Liquid	Water (electrolytes)
A:	Air	Air



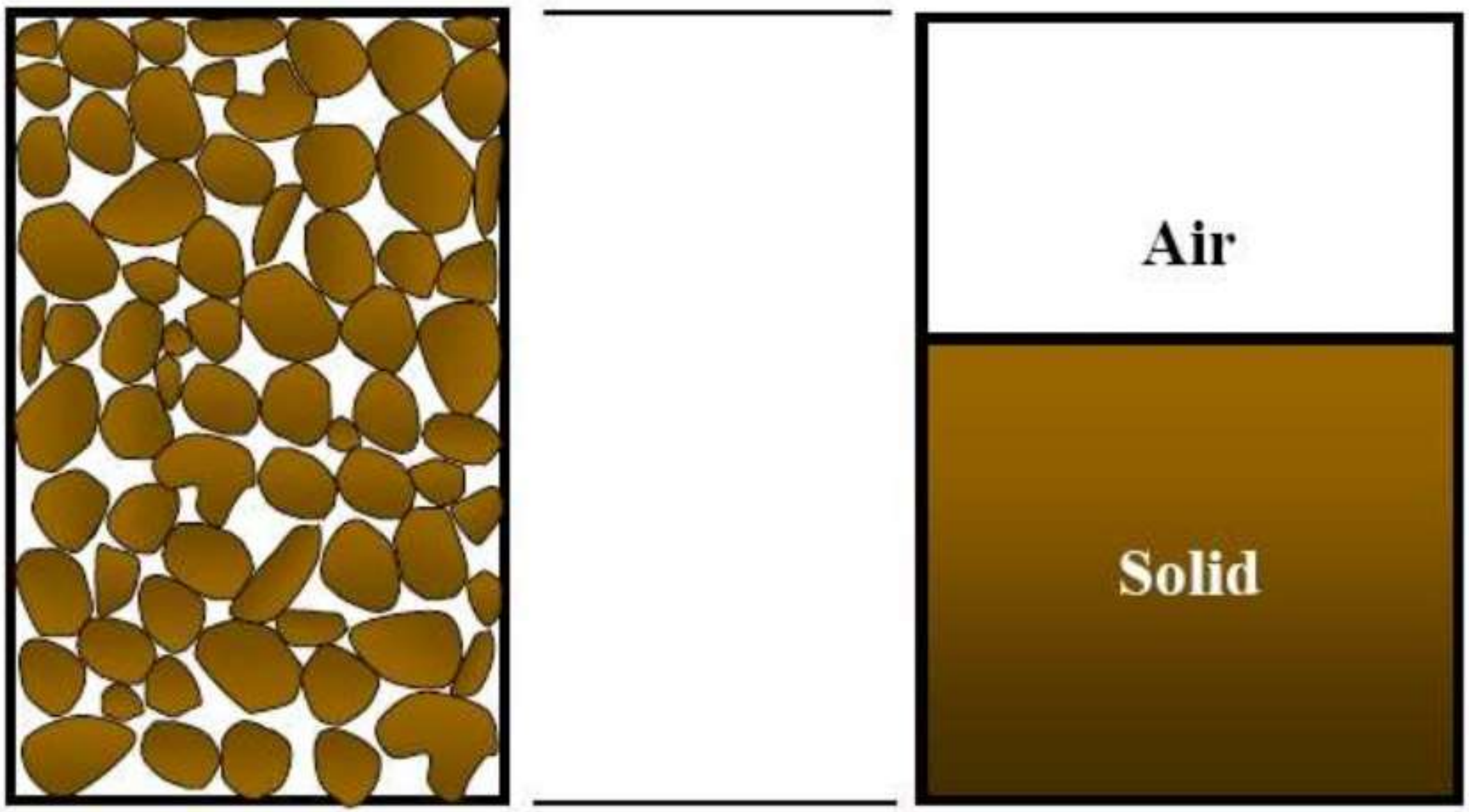
Three Phase Diagram



Fully Saturated Soils (**Two** phase)

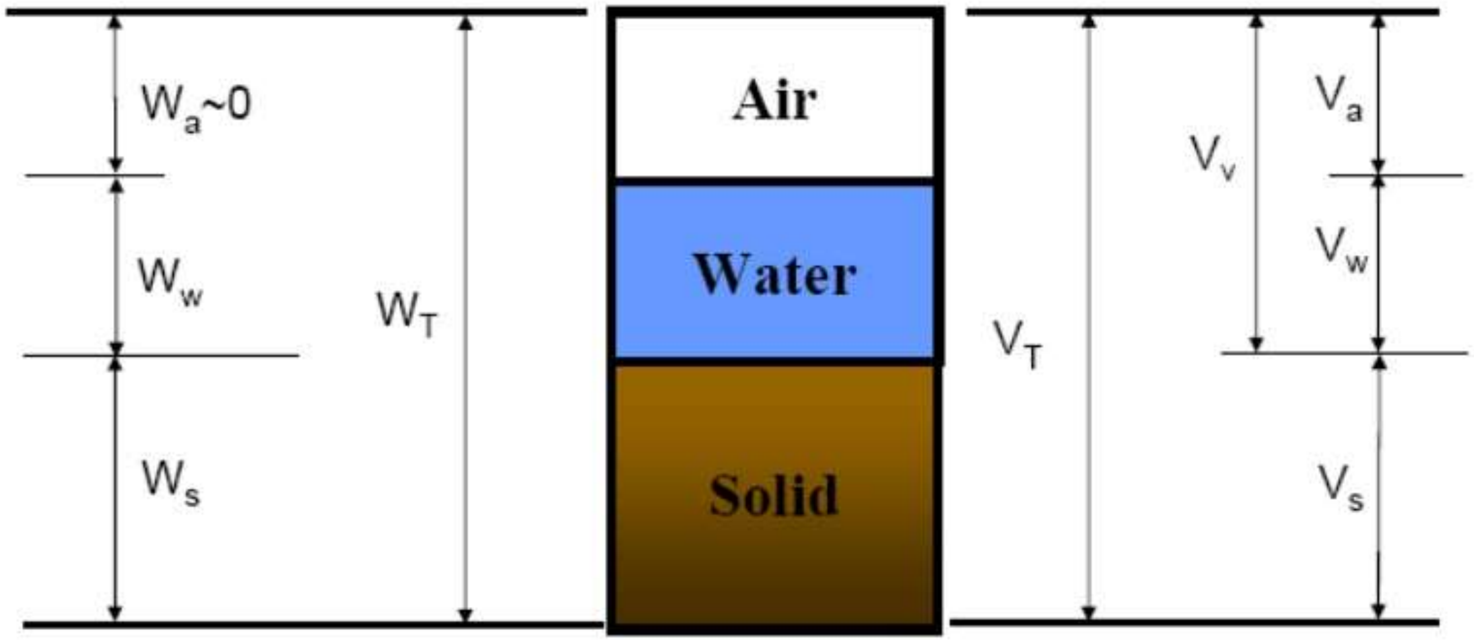


Dry Soils (**Two** phase) [Oven Dried]



PHASE DIAGRAM

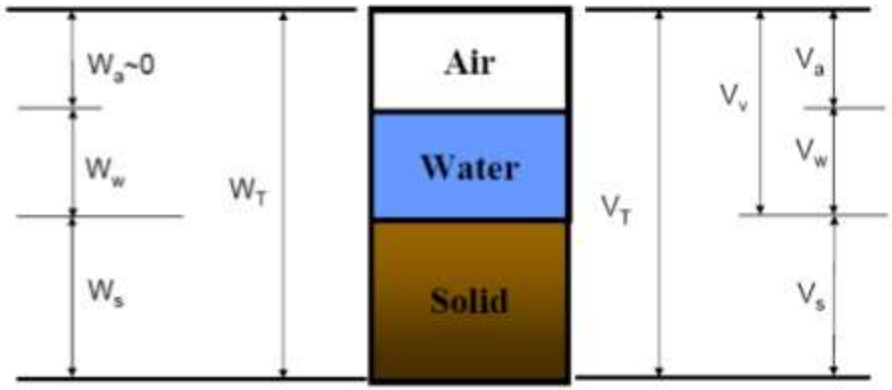
For purpose of study and analysis, it is convenient to represent the soil by a PHASE DIAGRAM, with part of the diagram representing the solid particles, part representing water or liquid, and another part air or other gas.



Wt: total weight
Ws: weight of solid
Ww: weight of water
Wa: weight of air = 0

Vt: total volume
Vs: volume of solid
Vw: volume of water
Vv: volume of the void

Soil unit weights



(1) Dry unit weight

$$\gamma_d = \frac{Weight\ of\ soil\ solids}{Total\ volume\ of\ soil} = \frac{W_s}{V_t}$$

(2) Total, Wet, Bulk, or Moist unit weight

$$\gamma = \frac{Total\ \text{weight}\ of\ soil}{Total\ volume\ of\ soil} = \frac{W_s + W_w}{V_t}$$

(3) Saturated unit weight (considering S=100%, V_a =0)

$$\gamma_{sat} = \frac{Weight\ of\ soil\ solids + water}{Total\ volume\ of\ soil} = \frac{W_s + W_w}{V_t}$$

(4) Submerged unit weight

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

Note: The density/or unit weight are ratios which connects the volumetric side of the PHASE DIAGRAM with the mass/or weight side.

Specific gravity, G_s

The ratio of the weight of solid particles to the weight of an equal volume of distilled water at 4°C

$$G_s = \frac{W_s}{V_s \, \gamma_w}$$

i.e., the specific gravity of a certain material is ratio of the unit weight of that material to the unit weight of water at 4° C.

The specific gravity of soil solids is often needed for various calculations in soil mechanics.

$$G_s = \frac{\gamma_s}{\gamma_w}$$

- $G_{w = 1}$
- $G_{mercury} = 13.6$

- Expected Value for Gs

Type of Soil	Gs
Sand	2.65 - 2.67
Silty sand	2.67 – 2.70
Inorganic clay	2.70 – 2.80
Soils with mica or iron	2.75 – 3.00
Organic soils	< 2.00

Relationships Between Various Physical Properties

All the weight- volume relationships needed in soil mechanics can be derived from appropriate combinations of six fundamental definitions. They are:

1. **Void ratio**
2. **Porosity**
3. **Degree of saturation**
4. **Water content**
5. **Unit weight**
6. **Specific gravity**

1. Relationship between e and n

$$e = \frac{V_v}{V_s} = \frac{V_v}{V - V_v} = \frac{\left(\frac{V_v}{V}\right)}{1 - \left(\frac{V_v}{V}\right)} = \frac{n}{1 - n} \qquad (3.6)$$

Also, from Eq. (3.6),

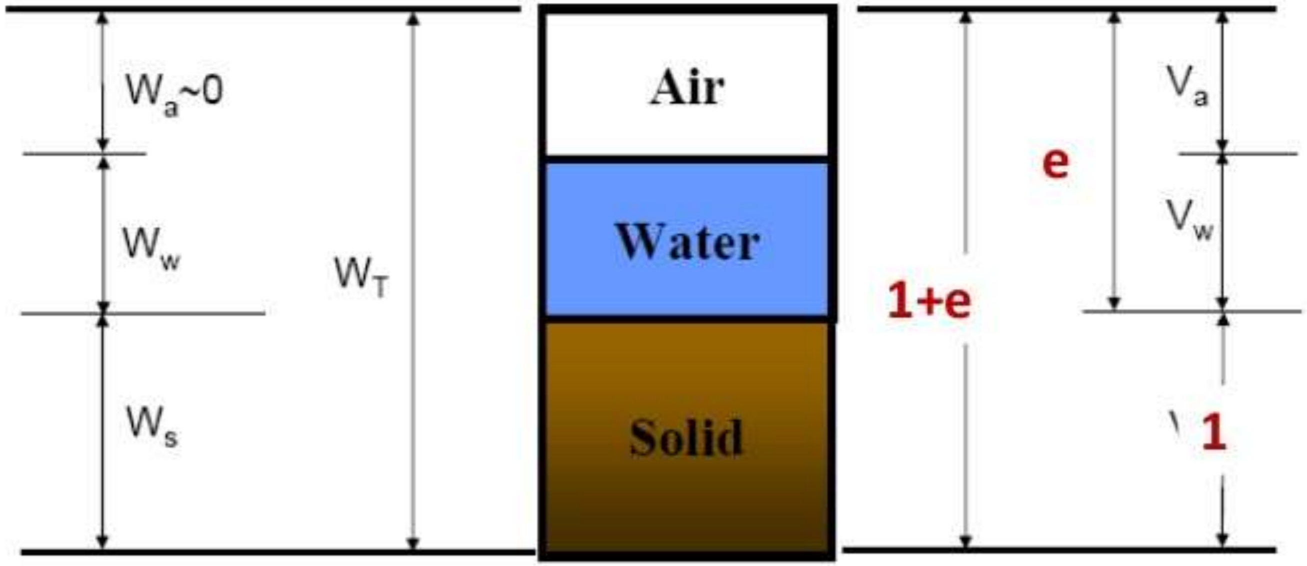
$$n = \frac{e}{1 + e} \qquad (3.7)$$

Using phase diagram

Given : e

required: n

$$n = \frac{V_v}{V_t} = \frac{e}{1+e}$$



2. Relationship among e, S, w, and Gs

$$w = \frac{W_w}{W_s} = \frac{\gamma_w V_w}{\gamma_s V_s} = \frac{\gamma_w V_w}{\gamma_w G_s V_s} = \frac{V_w}{G_s V_s}$$

- **Dividing the denominator and numerator of the R.H.S. by V_v** ***yields:***

$$Se = wG_s$$

- **This is a very useful relation for solving THREE-PHASE RELATIONSHIPS.**

3. Relationship among γ, e, S and G_s

$$\gamma = \frac{W}{V} = \frac{W_w + W_s}{V_s + V_v} = \frac{\gamma_w V_w + \gamma_s V_s}{V_s + V_v} = \frac{\gamma_w V_w + \gamma_w G_s V_s}{V_s + V_v}$$

$$\gamma = \frac{(Se + G_s)}{1 + e} \gamma_w$$

- **Notes:**
  - **Unit weights for dry, fully saturated and submerged cases can be derived from the upper equation**
  - **Water content can be used instead of degree of saturation.**

Method to solve Phase Problems

Method : Memorize relationships

$$Se = wG_s$$

$$\gamma = \frac{(Se + G_s)}{1+e}\gamma_w$$

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

$$\gamma_d = \frac{\gamma}{1+w}$$

Example 1

The moist unit weight of a soil is 19.2 kN/m^3. Given that G_s 2.69 and $w = 9.8\%$, determine

a. Dry unit weight
b. Void ratio
c. Porosity
d. Degree of saturation

a. $$\gamma_d = \frac{\gamma}{1+w} = \frac{19.2}{1+\frac{9.8}{100}} = \mathbf{17.5\ kN/m^3}$$

b. $$\gamma_d = 17.5 = \frac{G_s \gamma_w}{1+e} = \frac{(2.69)(9.81)}{1+e}; \quad e = \mathbf{0.51}$$

c. $$n = \frac{e}{1+e} = \frac{0.51}{1+0.51} = \mathbf{0.338}$$

d. $$S = \frac{wG_s}{e} = \frac{(0.098)(2.69)}{0.51} \times 100 = \mathbf{51.7\%}$$

Example 2

Field density testing (e.g., sand replacement method) has shown bulk density of a compacted road base to be 2.06 g/cc with a water content of 11.6%. Specific gravity of the soil grains is 2.69. Calculate the dry density, porosity, void ratio and degree of saturation.

Solution:

$$w = \frac{Se}{G_s}$$

$$\therefore \mathrm{Se} = (0.116)(2.69) = 0.312$$

$$\rho_m = \frac{G_s + Se}{1+e}\rho_w$$

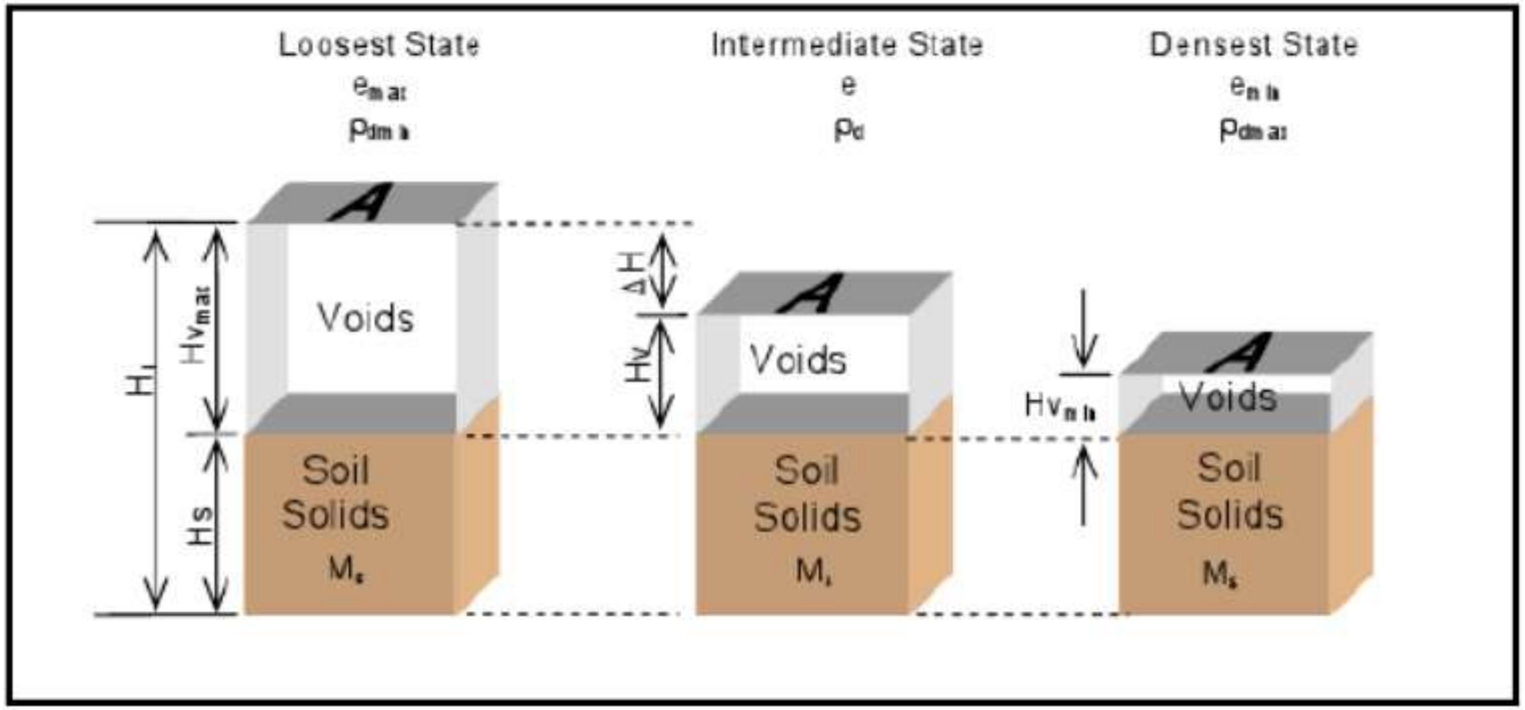
$$\therefore 2.06 = \frac{2.69 + 0.312}{1+e} \times 1.0$$

$$\therefore \mathrm{e} = 0.457$$

•Relative Density

- The relative density is the parameter that compare the volume reduction achieved from compaction to the maximum possible volume reduction

- The relative density Dr, also called density index is commonly used to indicate the IN SITU denseness or looseness of granular soil.



Volume reduction from compaction of granular soil

- **D_r can be expressed either in terms of void ratios or dry densities.**

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

where D_r = relative density, usually given as a percentage
e = *in situ* void ratio of the soil
e_{max} = void ratio of the soil in the loosest state
e_{min} = void ratio of the soil in the densest state

$$D_r = \frac{\left[\dfrac{1}{\gamma_{d(min)}}\right] - \left[\dfrac{1}{\gamma_d}\right]}{\left[\dfrac{1}{\gamma_{d(min)}}\right] - \left[\dfrac{1}{\gamma_{d(max)}}\right]} = \left[\frac{\gamma_d - \gamma_{d(min)}}{\gamma_{d(max)} - \gamma_{d(min)}}\right]\left[\frac{\gamma_{d(max)}}{\gamma_d}\right]$$

where $\gamma_{d(min)}$ = dry unit weight in the loosest condition (at a void ratio of e_{max})
γ_d = *in situ* dry unit weight (at a void ratio of e)
$\gamma_{d(max)}$ = dry unit weight in the densest condition (at a void ratio of e_{min})

• **Remarks**

- The range of values of D_r may vary from a minimum of zero for very LOOSE soil to a maximum of 100% for a very DENSE soil.

- Because of the irregular size and shape of granular particles, it is not possible to obtain a ZERO volume of voids.

- Granular soils are qualitatively described according to their relative densities as shown below

Relative Density (%)	Description of soil deposit
0-15	Very loose
15-50	Loose
50-70	Medium
70-85	Dense
85-100	Very dense

- The use of relative density has been restricted to granular soils because of the difficulty of determining e_{max} in clayey soils. Liquidity Index in fine-grained soils is of similar use as D_r in granular soils.

ATTERBERG LIMITS

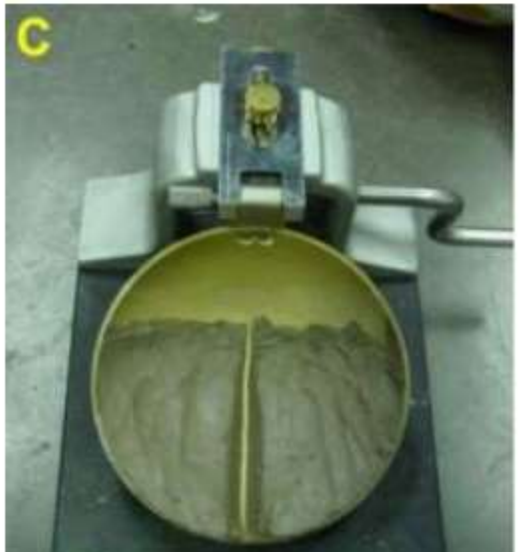
- **Liquid limit test:**

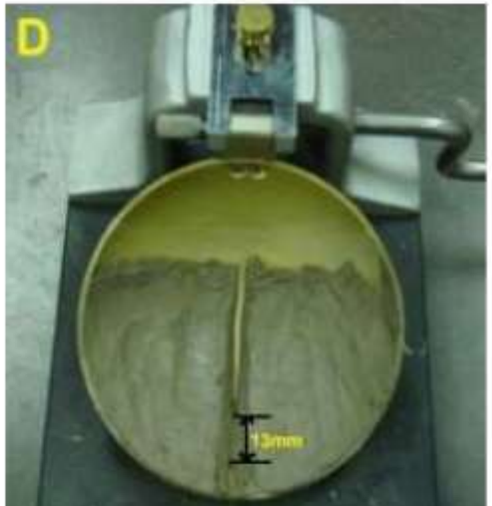
- A soil is place in the grooving tool which consists of brass cup and a hard rubber base.
- A groove is cut at the center of the soil pat using a standard grooving tool.
- The cup is then repeatedly drooped from a height of 10mm until a groove closure of 12.7 mm.
- The soil is then removed and its moisture content is determined.
- The soil is said to be at its liquid limit when exactly 25 drops are required to close the groove for a distance of 12.7 mm (one half of an inch)

APPARATUS


A
Spatula
Liquid limit device
Grooving tool
Soil specimen
Moisture cans


B


C


D
13mm

➢ Plastic limit test:

A soil sample is rolled into threads until it becomes thinner and eventually breaks at 3 mm.

it is defined as the moisture content in percent at which the soil crumbles when rolled into the threads of 3.0 mm.

If it is wet, it breaks at a smaller diameter; if it is dry it breaks at a larger diameter.

Soil classification system

PURPOSE

- Arrange various types of soils into groups according to their engineering or various other characteristics.

- Soil possessing similar characteristics can be placed in the same group.

SOIL CLASSIFICATION SYSTEMS

1. Particle Size Classification
2. Textural Classification
3. Highway Research Board (HRB) Classification
4. Unified Soil Classification System (USCS)
5. Indian Standard Classification System (ISCS)

ORIGIN OF USCS

- First developed by Professor A. Cassagrande (1948) for the purpose of airfield construction during World War II.

- Afterwards, it was modified to enable the system to be applicable to dams, foundations, and other construction .


FOUR MAJOR DIVISIONS
COURSE GRAINED
ORGANIC SOIL
FINE GRAINED
PEAT

CLASSIFICATION GROUPS

- The soil is classified into 15 groups(uscs) & in 18 groups (iscs).
- Each group is designated a symbol consisting of two capital letters.
- The first letter is based on main soil type.
- The second letter is based on gradation and plasticity .

SYMBOLS

- **Soil symbols:**
- G: Gravel
- S: Sand
- M: Silt
- C: Clay
- O: Organic
- Pt: Peat

Example: SW, Well-graded sand
SC, Clayey sand
SM, Silty sand,
MH, High plastic silt

Liquid limit symbols:
L: Low plastic(LL<35)
I: Intermediate plastic (35<LL<50)
H: High plastic (LL>50)

Gradation symbols:
W: Well-graded
P: Poorly-graded

Well – graded soil
$1 < C_c < 3$ and $C_u \geq 4$
(for gravels)
$1 < C_c < 3$ and $C_u \geq 6$
(for sands)

CLASSIFICATION OF GROUP SYMBOLS

Main Soil Type	Prefix	Subgroup	Suffix	Classification Group symbols
Gravel	G	Well-graded Poorly-graded Silty Clayey	W P M C	GW GP GM GC
Sand	S	Well-graded Poorly-graded Silty Clayey	W P M C	SW SP SM SC
Silt	M	LL < 50% LL > 50%	L H	ML MH
Clay	C	LL < 50% LL > 50%	L H	CL CH
Organic	O	LL < 50% LL > 50%	L H	OL OH
Peat	Pt			Pt

CLASSIFICATION OF SOIL GROUPS
(BY ISCS)

Main Soil Type	Prefix	Subgroup	Suffix	Classification Group symbols
Gravel	G	Well-graded Poorly-graded Silty Clayey	W P M C	GW GP GM GC
Sand	S	Well-graded Poorly-graded Silty Clayey	W P M C	SW SP SM SC
Silt	M	LL < 35% 35<LL<>50 LL > 50%	L I H	ML MI MH
Clay	C	LL < 35% 35<LL<>50 LL > 50%	L I H	CL CI CH
Organic	O	LL < 35% 35<LL<>50 LL > 50%	L I H	OL OI OH
Peat	Pt			Pt

COURSE GRAINED CLASSIFICATION

- THE COURSE GRAINED ARE THOSE WHICH ARE RETAINED ON 75μm SIEVE. IF MORE THAN 50% OF PARTICLES BY WEIGHT ARE RETAINED ON 75μm SIEVE THE SOIL IS CALLED COURSE GRAINED SOIL.

FACTORS RESPONSIBLE FOR COURSE GRAINED ANALYSYS

- Fineness modulus
- Coefficient of uniformity(cu)
- Coefficient of curvature(cc)
- Plasticity index(IP)

FINENESS MODULUS:-

- It represents % of fine soils present in course soil. i.e % of particles less than 75µm present in soil.

- if a soil contains 5% clay and 7% silt then fineness modulus of the course soil is (7+5=12%).

COEFFICIENT OF UNIFORMITY(CU) :-

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

- If (cu>4), it is well graded gravel.
- If (cu>6), it is well graded sand.
- If cu not in above range soil is poorly graded/uniformly graded.
- If (cu=1), means all particle of equal size , i.e perfectlu graded.

- COEFFICIENT OF CURVATURE(CC):-

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

➢If (1≤cu≤3), it is well graded soil.

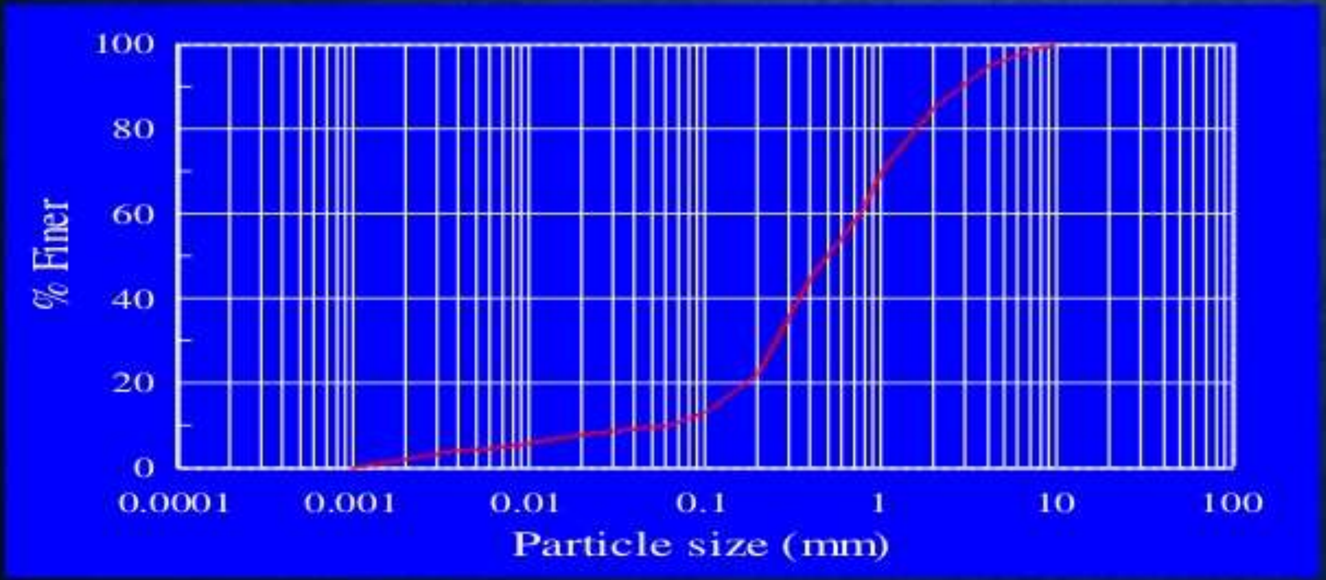
➢If cc not in above range, soil is poorly graded/uniformly graded.

To determine W or P, calculate C_u and C_c

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

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

x% of the soil has particles smaller than D_x



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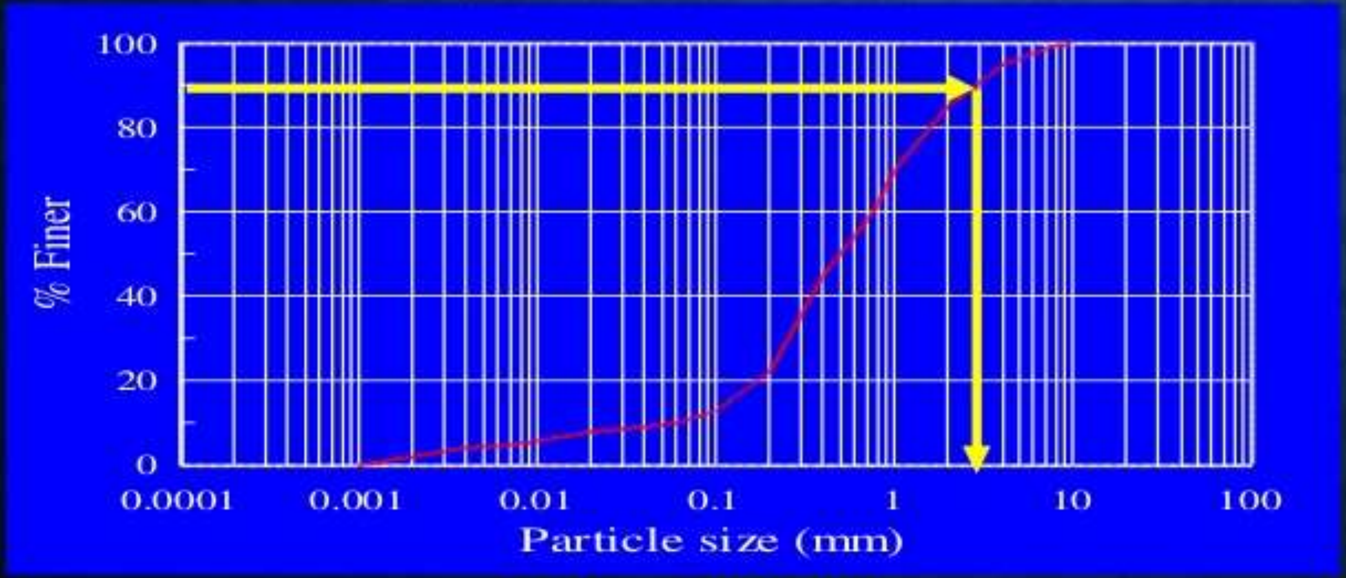


D_{90} = 3 mm

- To determine W or P, calculate C_u and C_c

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

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

- If prefix is G then suffix is W if $C_u > 4$ and C_c is between 1 and 3

  otherwise use P

- If prefix is S then suffix is W if $C_u > 6$ and C_c is between 1 and 3

  otherwise use P

- Each soil is given a 2 letter classification (e.g. SW). The following procedure is used.
  - Coarse grained (>50% larger than 75 mm)
    - Prefix S if > 50% of coarse is Sand
    - Prefix G if > 50% of coarse is Gravel
    - Suffix depends on %fines
    - if %fines < 5% suffix is either W or P
    - if %fines > 15% suffix is either M or C
    - if 5% < %fines < 15% Dual symbols are used

CASE 1 (WHEN FINENESS MODULUS IS LESS THAN 5%)

SOIL SYMBOL	NAME	CU RANGE	CC RANGE	QUANTITY
GW	Well graded gravel	Cu>4	1≤cc≤3	G>S
GP	Poorly graded gravel	Not in range	Not in range	G>S
SW	Well graded sand	Cu>6	1≤cc≤3	S>G
SP	Poorly graded sand	Not in range	Not in range	S>G

CASE 2 (WHEN FINENESS MODULUS IN BTW (5-15)%)

SYMBOL	NAME	CU RANGE	CC RANGE	QUANTITY(S,G)	QUANTITY(M,C)
GW-GC	Well graded gravel containing clay	Cu>4	$1 \leq cc \leq 3$	G>S	C>M
GW-GM	Well graded gravel containing silt	Cu>4	$1 \leq cc \leq 3$	G>S	M>C
SW-SC	Well graded sand containing clay	Cu>6	$1 \leq cc \leq 3$	S>G	C>M
SW-SM	Well graded sand containing silt	Cu>6	$1 \leq cc \leq 3$	S>G	M>C
GP-GC	Poorly graded gravel containing clay	Not in range	Not in range	G>S	C>M
GP-GM	Poorly graded gravel containing silt	Not in range	Not in range	G>S	M>C
SP-SC	Poorly graded sand containing clay	Not in range	Not in range	S>G	C>M
SP-SM	Poorly graded sand containing silt	Not in range	Not in range	S>G	M>C

CASE 3 (FINENESS MODULUS GREATER THAN 15%)

SYMBOL	NAME	QUANTITY(G,S)	QUANTITY(C,M)	PLASTICITY INDEX
GC	Clayey gravel	G>S	C>M	IP> 7%
GM	Silty gravel	G>S	M>C	IP< 7%
SC	Clayey sand	S>G	C>M	IP> 7%
SM	Silty sand	S>G	M>C	IP< 7%

FINE GRAINED CLASSIFICATION

THE FINE GRAINED ARE THOSE, IF MORE THAN 50% OF PARTICLES BY WEIGHT ARE PASS THROUGH 75μm SIEVE THE SOIL IS CALLED FINE GRAINED SOIL.

FACTORS RESPONSIBLE FOR FINE GRAINED ANALYSIS

- Liquid limit
- Plasticity index
- Equation of A line (given by A CASSAGRANDE)

LIQUID LIMIT:-

- It is that meaning of water content at which soil has a tendency to flow
- It is the boundary between plastic & liquid state
- At liquid limit soil shows negligible shear strength
- According to (A CASSAGRANDE) liquid limit is defined as a water content which requires 25 blows to cover the groove

- <u>ONE POINT METHOD</u>

$$WL = W(N/25)^n$$

(W) Is the water content corresponding to (N) no blows

(n= 0.068-0.12)

- <u>STATIC CONE PENETROMETRE</u>

$$WL= W + 0.01(25-Y)\ (W+15)$$

A soil of soft consistency is filled in a cylinder and a cone having a cone angle of 31° and mass 148gm is slowly allowed to fall freely on the surface of the soil .
Let Y is the penetration depth after 30sec.
W is the water content of soil.

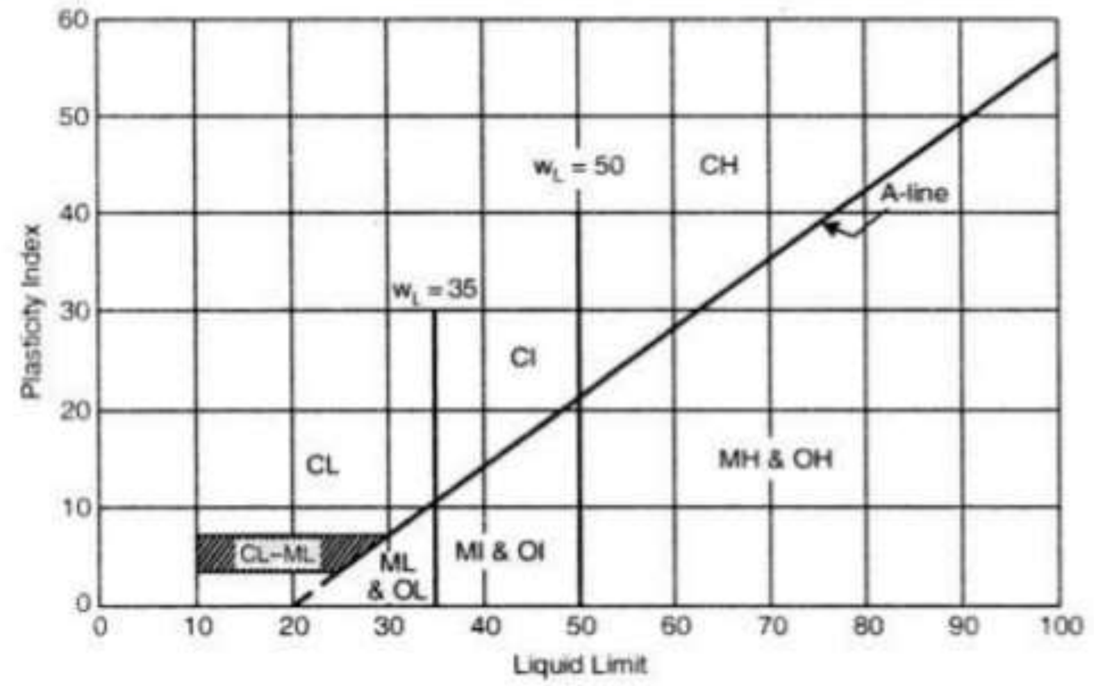
PLASTICITY INDEX:-

- It represents the consistency range of soil with in which soil has plastic behavior.

$$(I_p = w_l - w_p)$$

IP %	PLASTICITY OF SOIL
0	Non plastic
1-5	Slight plastic
5-10	Low plastic
10-20	Medium plastic
20-40	High plastic
>40	Very high plastic

EQUATION OF (A & U) LINE:-



PLASTICITY CHART (IS SOIL CLASSIFICATION SYSTEM).

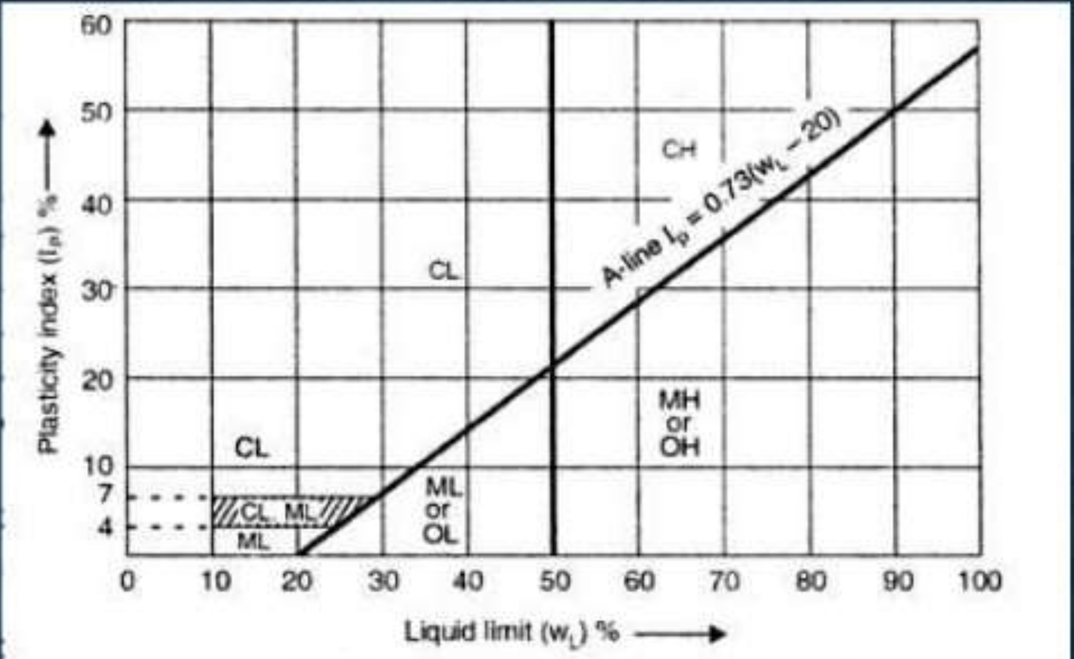
Below A-line, use M (Silt) or O (Organic)

Above A-line, use C - Clay

High Plasticity use H - $w_L > 50$

Intermediate Plasticity use I – 35< $w_L > 50$

Low Plasticity use L - $w_L < 35$



CASAGRANDE'S PLASTICITY CHART (USCS)

"The soil's liquid limit (w_L) after oven drying is less than 75 % of its liquid limit before oven drying." If the above statement is true, then it is Organic Soil (OL or OH). Otherwise, it is Inorganic Soil (ML or MH)

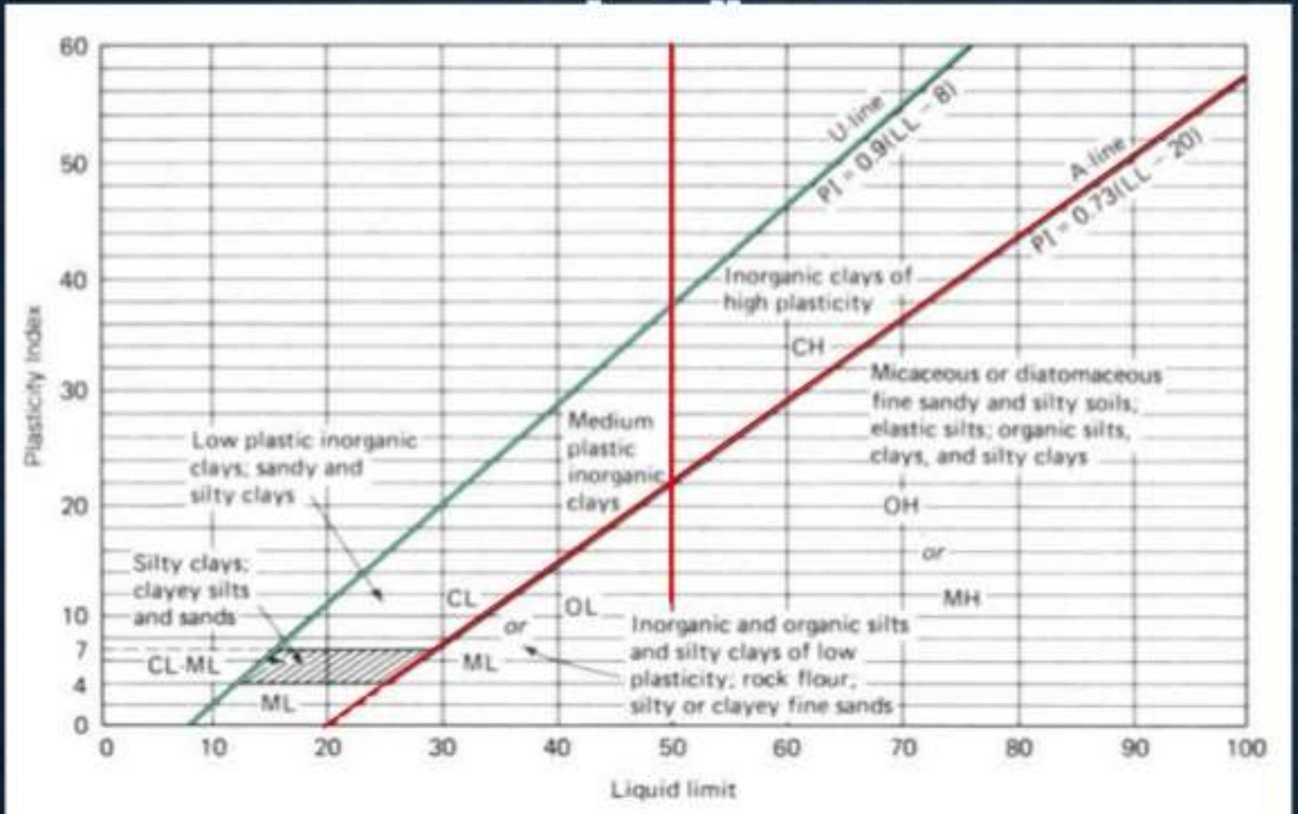


Fig. 3.2 Casagrande's plasticity chart, showing several representative soil types (developed from Casagrande, 1948, and Howard, 1977).

$IP_A = 0.73\ (WL-20)$

$IP_U = 0.9\ (WL-8)$

IMPORTANT POINTS

- If IP of soil is more than IP of A line i.e it lies above 'A line' then soil is strictly inorganic clay(c) and if it is less, soil may be organic(o) or silt(m).
- If IP of soil is more than IP of 'U line' then the test for liquid limit must be reconducted because no soil can have IP above 'U line' because it is a upper boundary.

- **Highly organic soils- Peat (Group symbol PT)**
  - A sample composed primarily of vegetable tissue in various stages of decomposition and has a fibrous to amorphous texture, a dark-brown to black color, and an organic odor should be designated as a highly organic soil and shall be classified as peat, PT.
- **Organic clay or silt(group symbol OL or OH):**
  - "The soil's liquid limit (LL) after oven drying is less than 75 % of its liquid limit before oven drying." If the above statement is true, then the first symbol is O.
  - The second symbol is obtained by locating the values of PI and LL (not oven dried) in the plasticity chart.

CASE 1 (WHEN WL<35%)

SYMBOL	NAME
CL	LOW PLASTIC INORGANIC CLAY
OL	LOW PLASTIC ORGANIC CLAY
ML	LOW PLASTIC SILT

CASE 2 (WHEN WL IN BTW (35-50)%)

SYMBOL	NAME
CI	MEDIUM/INTERMEDIATE PLASTIC INORGANIC CLAY
OI	MEDIUM/INTERMEDIATE PLASTIC ORGANIC CLAY
MI	MEDIUM/INTERMEDIATE PLASTIC SILT

CASE 3 (WHEN WL>50%)

SYMBOL	NAME
CH	HIGH PLASTIC INORGANIC CLAY
OH	HIGH PLASTIC ORGANIC CLAY
MH	HIGH PLASTIC SILT

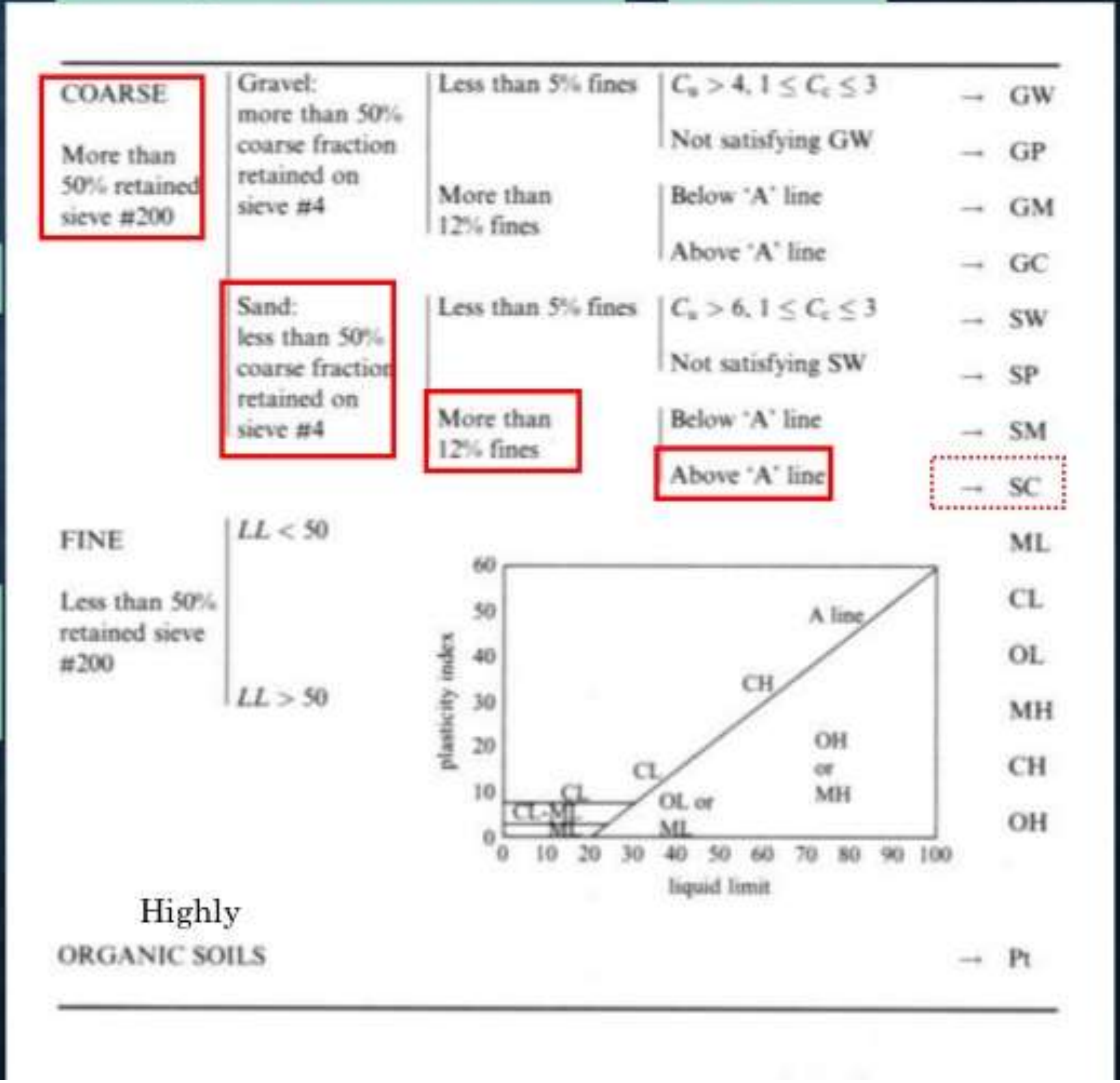
Example

Passing No.200 sieve 30 %

LL= 33

Passing No.4 sieve 70 %

PI= 12



Passing No.200 sieve 30%

Passing No.4 sieve 70 %

LL= 33

PI= 12

PI= 0.73(LL-20), A-line

PI=0.73(33-20)=9.49

Soil Type= SC

Clayey sand