B. Tech. III yr

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GEOTECHNICAL ENGINEERING -I

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CED, MMMUT, GORAKHPUR

UNIT-I

Preview of Geotechnical field problems in Civil Engineering, Soil formation, transport and deposit, Soil composition, Basic definitions, Clay minerals, Index properties, Particle size analysis, Soil classification. 9

UNIT-II

Soil-water systems, capillarity-flow, Darcy‟s law, permeability, field and lab tests, piping, quick sand condition, seepage, flow nets, flow through dams, filters.

Soil compaction, water content – dry unit weight relationships, OMC, field compaction control, Proctor needle method. 9

UNIT-III

Effective stress principle, Stresses due to applied loads, Boussinesq and Westergaard equations, Compressibility and consolidation characteristics, Rate of consolidation, Terzaghi‟s one dimensional theory of consolidation and its applications, Over Consolidation Ratio, determination of coefficient of consolidation and secondary consolidation (creep). 9

UNIT-IV

Shear strength - direct & triaxial shear tests, Mohr – Coulomb strength criterion, drained, consolidated, undrained and unconsolidated tests, strength of loose and dense sands, Normally Consolidated and Over Consolidated soils, dilation, pore pressure, Skempton‟s coefficient. Stability of slopes with or without pore pressure, limit equilibrium methods, methods of slices and simplified Bishop method, factor of safety.

BooKs

Text Book:

1. Modern Geotechnical Engineering by Alam Singh
2. Basic and Applied Soil mechanics by Gopal Ranjan and A.S. R. Rao

Reference Books:

1. Geotechnical Engineering by B. M. Das
2. Text book of Geotechnical Engineering by I. H. Khan
3. Soil Mechanics and Foundation Engineering by K. R. Arora
4. Geotechnical Engineering by Shashi Gulati and Manoj Dutta
5. www.dfi.org
6. www.nptel.ac.in

UNIT -I

BASICS OF SOIL MECHANICS

LECTURE 1

Naturally occurring deposits on earth crust

- **Soil**
  - Is the natural product of weathering of rocks and decomposition of organic matter
  - (Particulate Material)
- **Rock**
  - Natural aggregation of mineral particles bonded by strong and permanent cohesive forces.

Terzaghi defined Soil Mechanics as follows:

Soil Mechanics is the application of the laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles produced by the mechanical and chemical disintegration of rocks regardless of whether or not they contain an admixture of organic constituents.

The application of the principles of soil mechanics to the design and construction of foundations for various structures is known as "Foundation Engineering".

'

Geotechnical Engineering'' may be considered to include both soil mechanics and foundation engineering. In fact, according to Terzaghi, it is difficult to draw a distinct line of demarcation between soil mechanics and foundation engineering; the latter starts where the former ends.

Currently, Geotechnical Engineering is defined as the speciality of Civil Engineering which deals with the properties, behaviour and use of earth materials (Rock & Soil) in Engineering Works

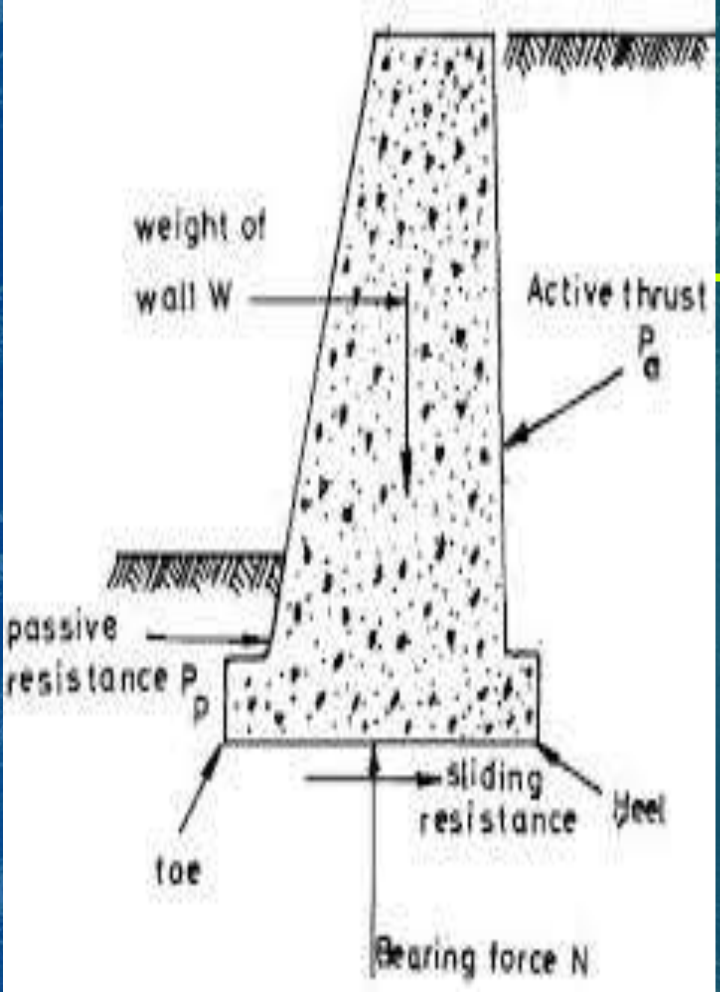
Father of Soil Mechanics (Prof Karl Terzaghi)

- **Karl von Terzaghi. Karl von Terzaghi** (October 2, 1883 – October 25, 1963) was an Austrian mechanical **engineer**, geotechnical **engineer**, and geologist known as the "father of soil mechanics and geotechnical engineering"

Civil Engineering Problems Related to Soil Mechanics

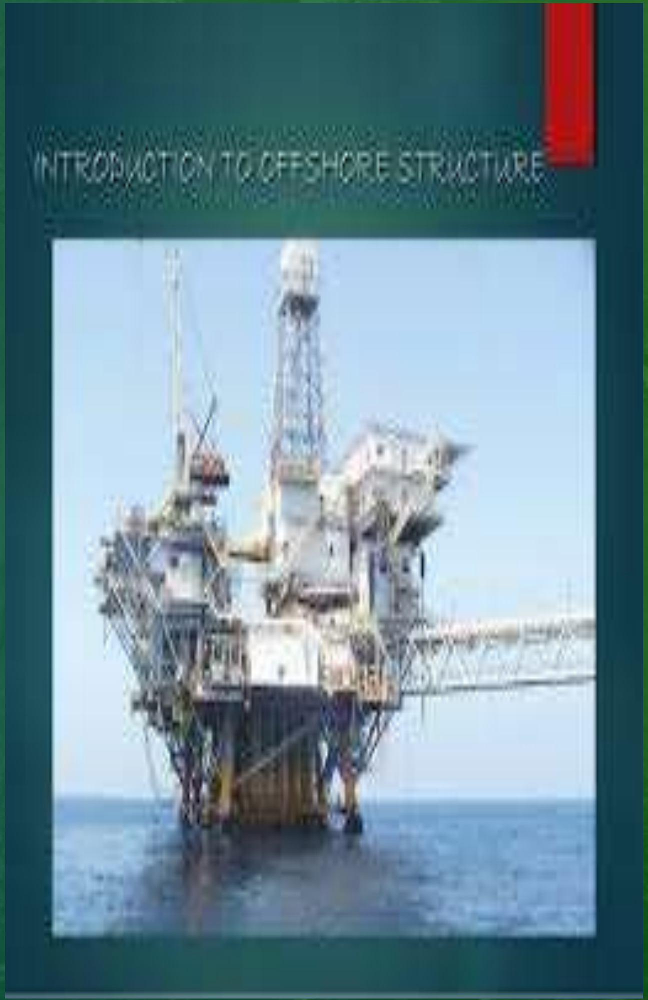
Foundation

Roads & slope



Retaining wall

Tunnel



Offshore structures

Landslides

Scouring of foundation

Limitations of Geotechnical Engineering

1. It is not an exact Science.

2. Because of nature and variability of soils, sweeping assumptions were made in the derivation of equations.

3. Solutions obtained in most cases are for an idealized hypothetical material, which may not truly represents the actual soil

ORIGIN OF SOIL

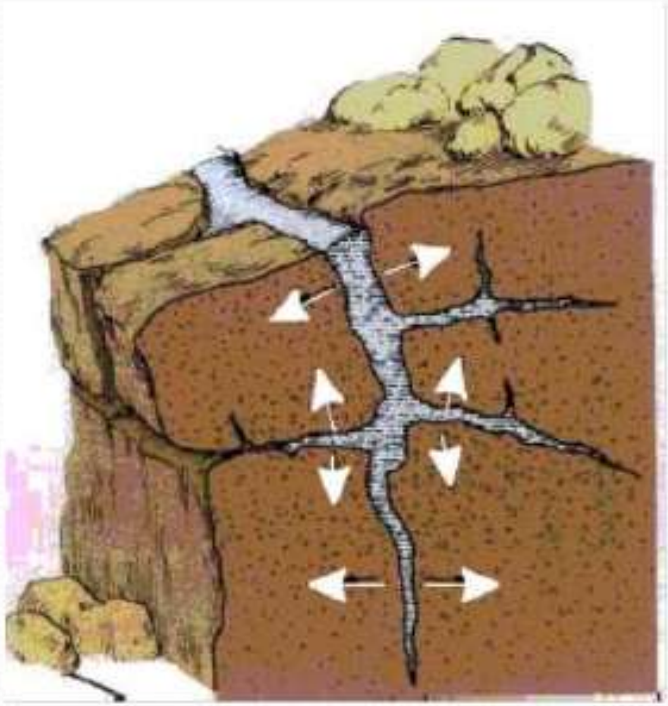
Soils are formed by weathering of rocks

Weathering of Rocks

- Weathering is the process of breaking down rocks by physical and chemical process into smaller particles.
- There are two main types of weathering processes:
  - Physical (or mechanical) Weathering
  - Chemical Weathering
- Biological weathering is caused by activities of living organisms - for example, the growth of roots or the burrowing of animals. Tree roots are probably the most occurring, but can often be by animals!

Physical Weathering

- Physical (or mechanical) Weathering is the disintegration of rocks into smaller particles through physical processes, including:
  - The erosive action of water, ice and wind.
  - Opening of cracks as a result of unloading due to erosion of overlying soil and rock.
  - Loosening through the percolation and subsequent freezing (and expansion) of water.
  - Thermal Expansion and contraction from day to day and season to season.
  - Landslides and rockfalls.
  - Abrasion from the downhill movement of nearby rock and soil.



ADD

Chemical Weathering

Deposition of parent materials and their transformation into new compounds such as clay/silt particles
by the process of
hydration, oxidation, carbonization, etc
in presence of
Water, temperature and dissolved materials

Biological Weathering

Bacteria and other micro-organisms which induces chemical changes in surroundings by contributing organic acids plays an important role in further weathering of soil leads to formation of Organic Soil.

SOIL DEPOSITS BASED ON ORIGIN

Residual Soil

(Soil remains at the location of their original formation)

Transported Soil

(Soil which have been moved from the original place of formation by other places of deformation by different agencies such as water, wind etc.)

Residual Soils

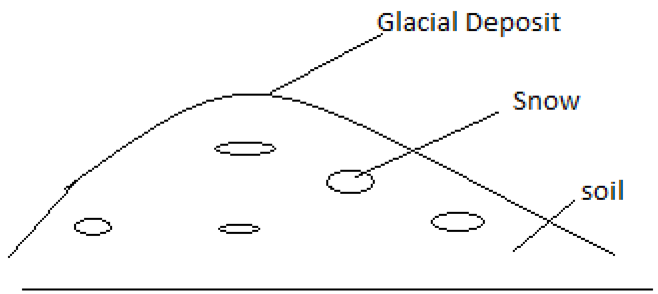
- Residual soils are found at the same location where they have been formed. Generally, the depth of residual soils varies from 5 to 20 m.

- Accumulation of residual soils takes place as the rate of rock decomposition exceeds the rate of erosion or transportation of the weathered material. In humid regions, the presence of surface vegetation reduces the possibility of soil transportation.

- Residual soils comprise of a wide range of particle sizes, shapes and composition.

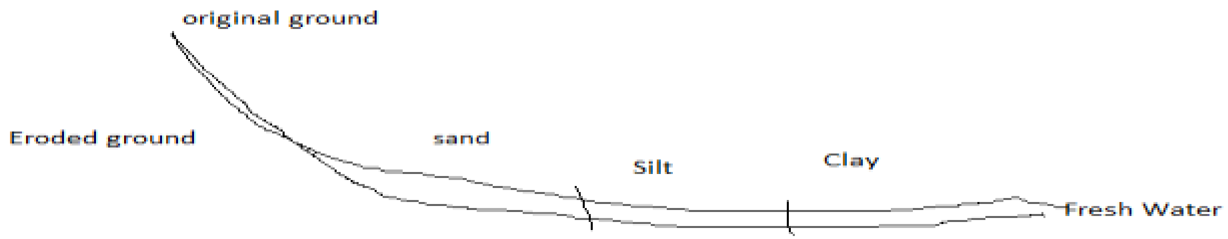
1.Glacial Soil/Deposits/Drift:

- This type of soil is developed, transported and deposited by the actions of **glaciers**.
- Glaciers are large masses of ice formed by accumulation and compaction of snow.
- As Glacial grow and move, they carry soil deposits.
- These deposits consists of rocks fragments, boulders, gravels, sand, silt and clay in various proportions (i.e., a heterogeneous mixture of all sizes of particles).



2. Alluvial Deposits/Soil:

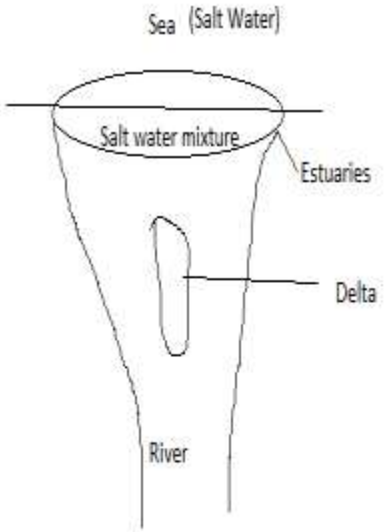
- The soil transported and deposited by water is called alluvial soil. As flowing water (stream or river) looses velocity, it tends to deposit some of particles that it was carrying in suspension or by rolling, sliding or skipping along the river bed. Coarser or heavier particles are dropped first. Hence on the higher reaches of a river, gravel and sand are found.
- However on the lower parts, silt and clay dominate where the flow velocity is almost zero or very small.
- Known as Stratified deposits



3. Lacustrine/Marine Deposit

- Fine grained materials(silt and clay) are deposited in layers when flowing water comes to rest as in lake, estuaries and delta.

- If deposited in fresh water lake ⟶ Lacustrine
- If deposited in Salt water lake ⟶ Marine Soil
- If deposited in $CaCo_3$ rich water ⟶ Marl
- (contains organic matter and are highly compressible)



4. Wind blown Soil or Aeolian Soil Deposit :

The soil transported by ‘wind’ and subsequently deposited is known as **wind blown soil or Aeolian Soil**. Aeolian soil as two main types namely: Dune sand and Loess.

a) Dune or Dune Sand:

- In arid parts of the world, wind is continually forming sand deposits in the form of dunes characterized by low hill and ridge formation.
- They generally occur in deserts and comprise of sand particles, which are fairly rounded and uniform in size. The particles of the dune sand are coarser than the particles of loess. Dune material is generally, a good source of sand for construction purposes.

Dune Sand Qatar

b) **Loess:**

Accumulations of wind blown dust (mainly siliceous silt or silty clay) laid down in a loose condition is known as loess.

- Silt soil in arid regions have no moisture to bond the particles together and are very susceptible to the effects of wind and therefore can be carried great distances by wind storms.

- An important engineering property of loess is its low density and high permeability. Saturated loess is very weak and always causes foundation problems e.g., liquefaction.

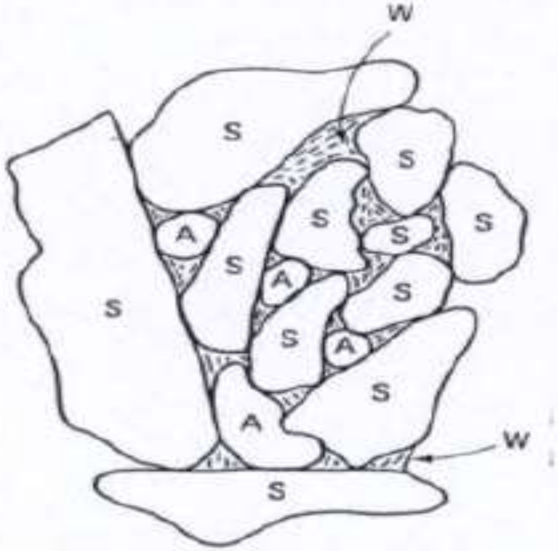
MAJOR SOIL DEPOSITS OF INDIA

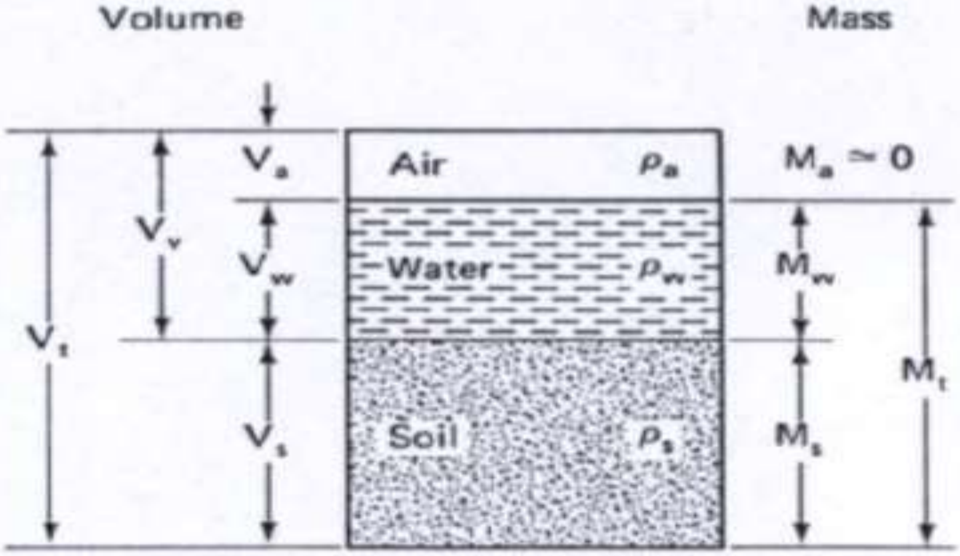
The soil deposits of India can be broadly classified into the following five types:

1. **Black cotton soils**, occurring in Maharashtra, Gujarat, Madhya Pradesh, Karnataka, parts of Andhra Pradesh and Tamil Nadu. These are expansive in nature. On account of high swelling and shrinkage potential these are difficult soils to deal with in foundation design.
2. **Marine soils**, occurring in a narrow belt all along the coast, especially in the Rann of Kutch. These are very soft and sometimes contain organic matter, possess low strength and high compressibility.
3. **Desert soils**, occurring in Rajasthan. These are deposited by wind and are uniformly graded.
4. **Alluvial soils**, occurring in the Indo-Gangetic plain, north of the Vindhyachal ranges.
5. **Lateritic soils**, occurring in Kerala, South Maharashtra, Karnataka, Orissa and West Bengal.

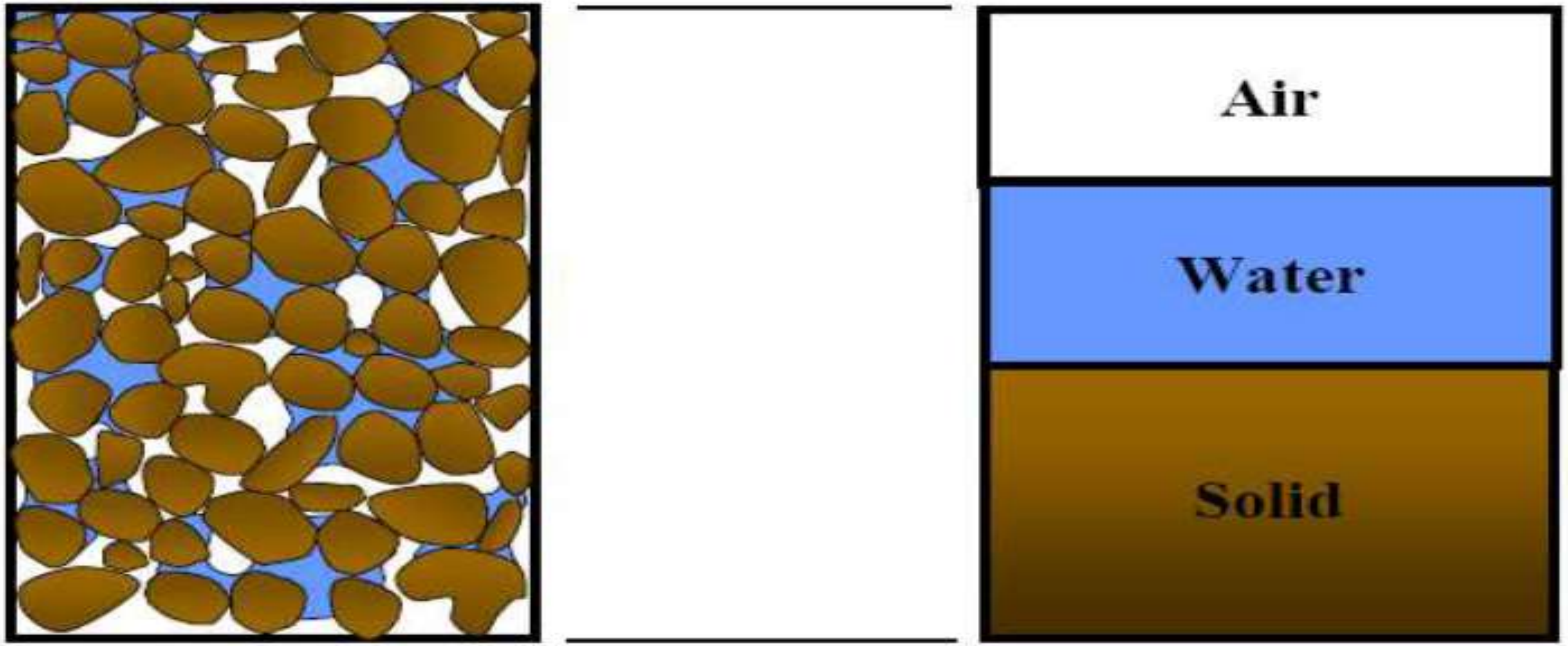
Three Phases in Soils

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

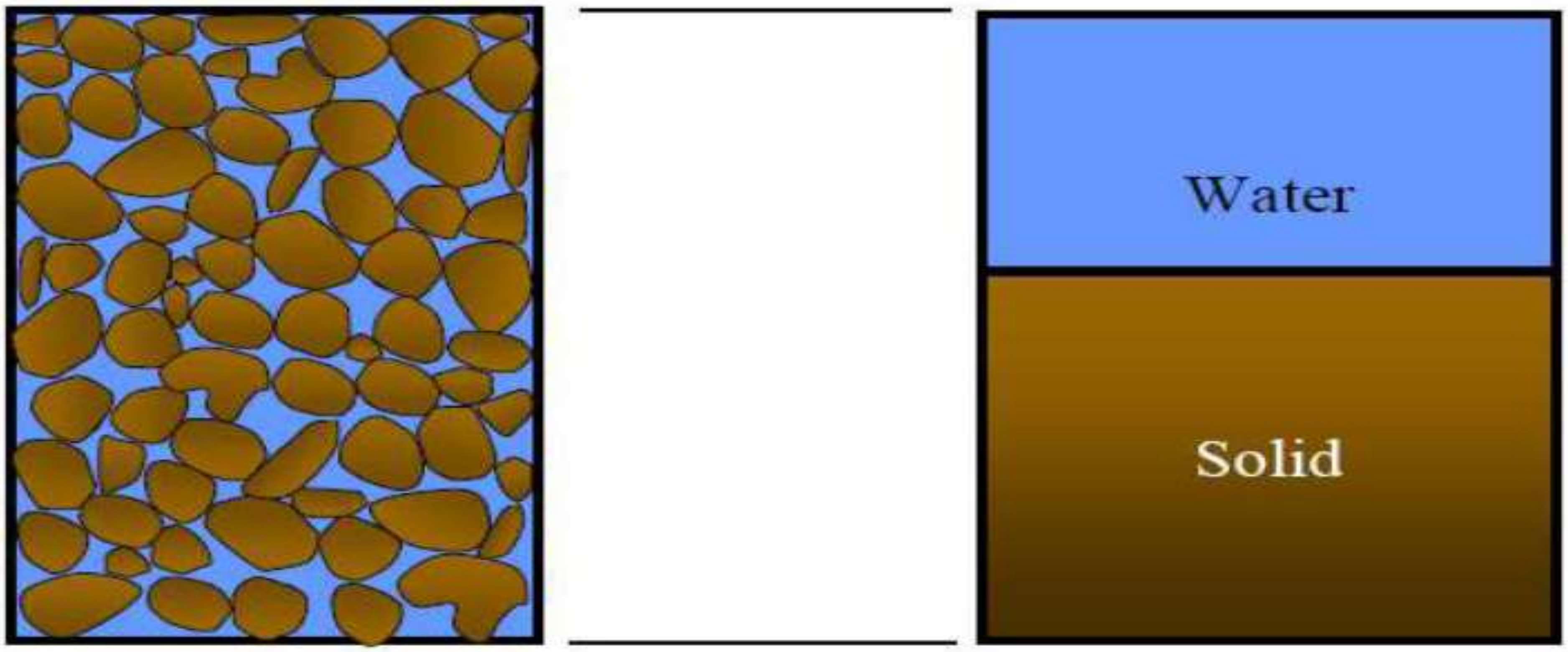




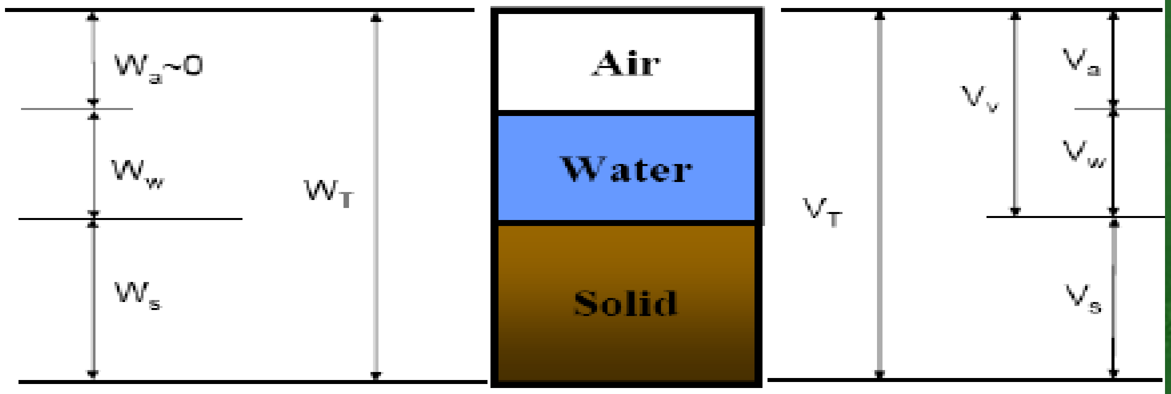
Three Phase Diagram



Fully Saturated Soils (Two phase)



Volumetric Ratios



(1) Void ratio **e**

$$e = \frac{Volume\ of\ voids}{Volume\ of\ solids} = \frac{V_v}{V_s}$$

(2) Porosity **n%**

$$n = \frac{Volume\ of\ voids}{Total\ volume\ of\ soil\ sample} = \frac{V_v}{V_t} \times 100$$

Dry

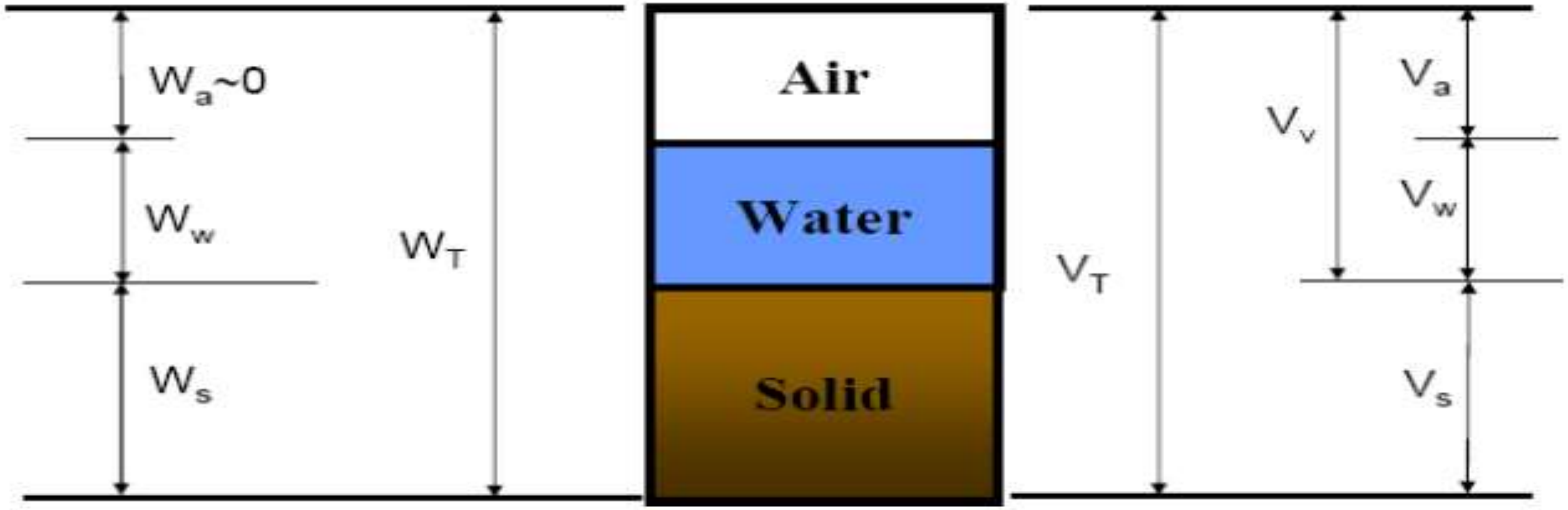
Saturated

(3) Degree of Saturation **S% (0 – 100%)**

$$S = \frac{Total\ volume\ of\ voids\ contains\ water}{Total\ volume\ of\ voids} = \frac{V_w}{V_v} \times 100\,\%$$

PHASE DIAGRAM

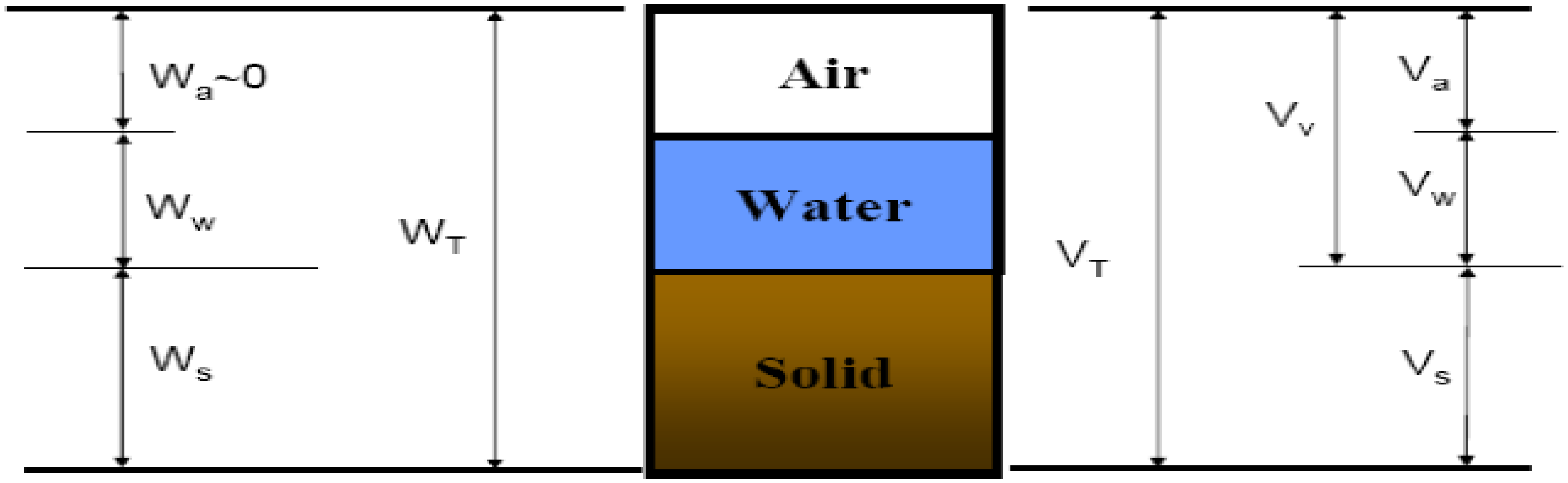
For purpose of study and analysis, it is convenient to represent the soil by a PHASE DIAGRAM, with part of the diagram representing the solid particles, part representing water or liquid, and another part air or other gas.



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

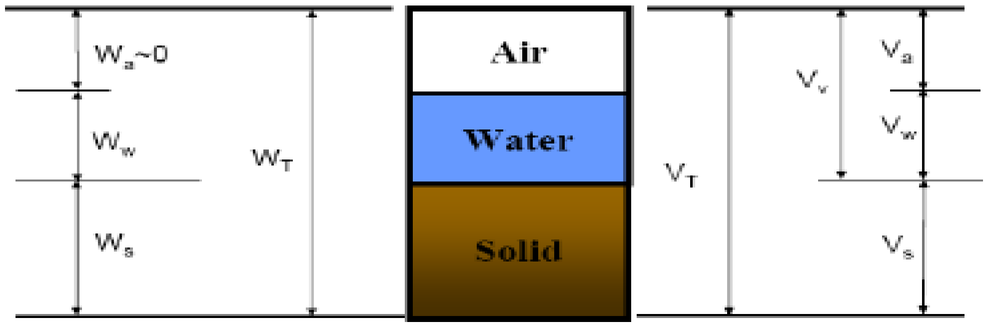
Weight Ratios



(1) Water Content ***w%***

$$w = \frac{Weight\ of\ water}{Weight\ of\ soil\ solids} = \frac{W_w}{W_s} \cdot 100\%$$

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

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

(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),

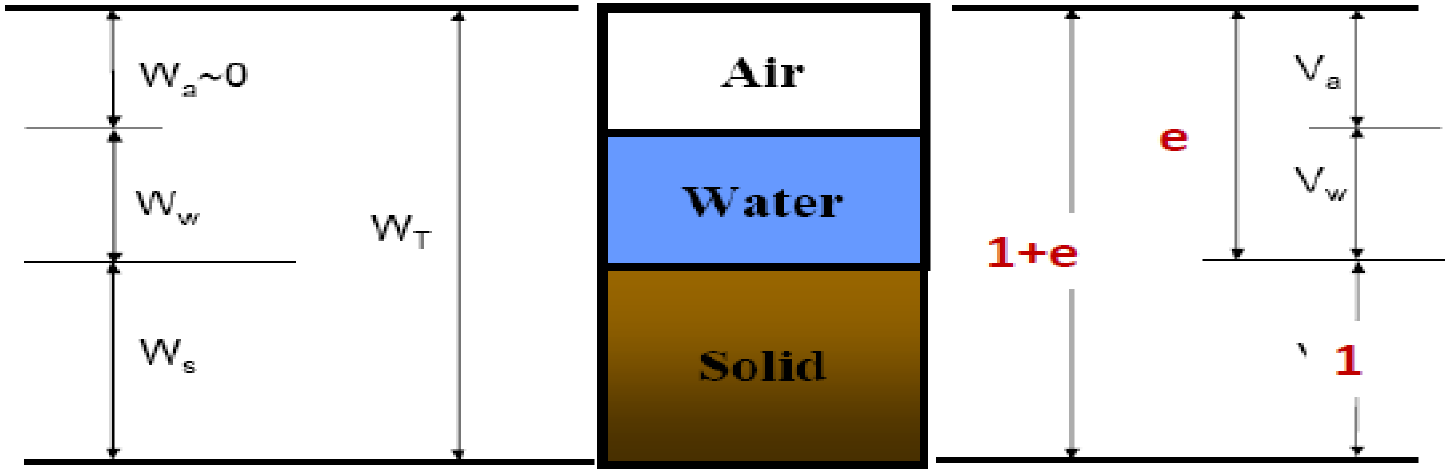
$$n = \frac{e}{1+e} \qquad (3.7)$$

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.**

$$e = \frac{Volume\ of\ voids}{Volume\ of\ solids} = \frac{V_v}{V_s}$$

$$S = \frac{Total\ volume\ of\ voids\ contains\ water}{Total\ volume\ of\ voids} = \frac{V_w}{V_v} \times 100\%$$

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/m³. 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:

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

$$\therefore Se = (0.116)(2.69) = 0.312$$

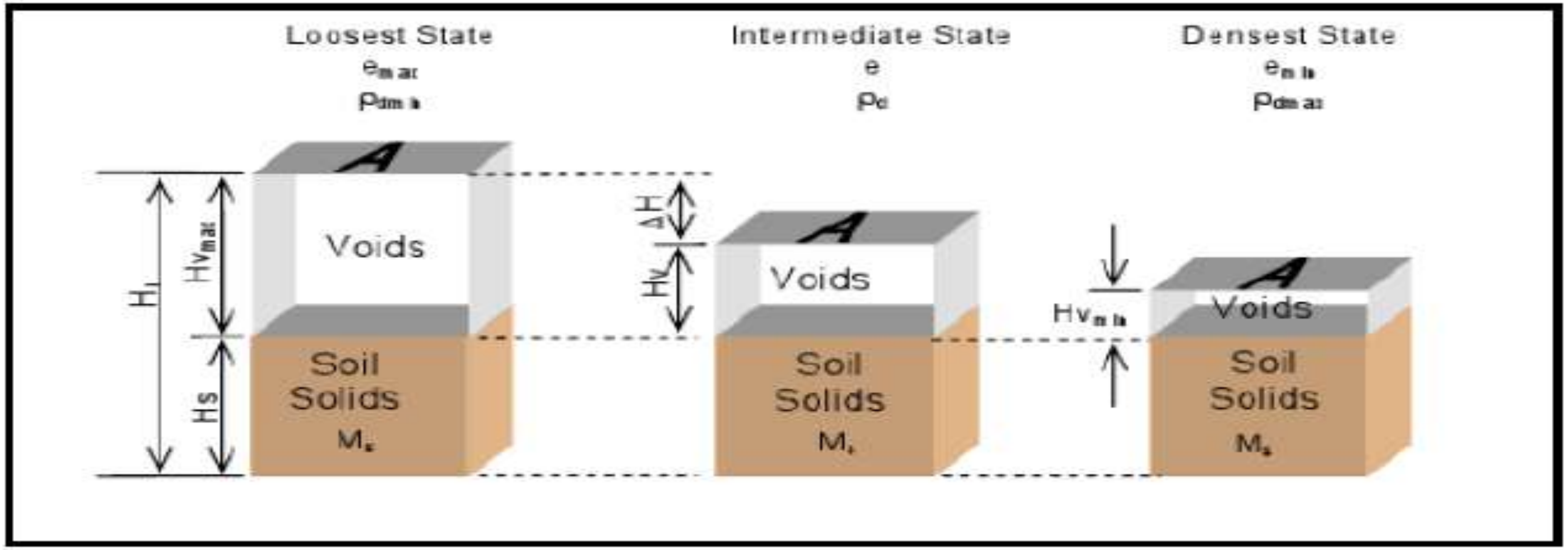
$$\rho_m = \frac{G_s + Se}{1+e}\rho_w$$

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

$$\therefore e = 0.457$$

•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

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

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 <u>qualitatively</u> 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.

INDEX PROPERTIES AND CLASSIFICATION TESTS

Those properties which help to assess the engineering behaviour of a soil and which assist in determining its classification accurately are termed 'Index Properties'.

WATER CONTENT

- 'Water content' or 'moisture content' of a soil has a direct bearing on its strength and stability.

- The water content of a soil in its natural state is termed its 'Natural moisture content', which characterizes its performance under the action of load and temperature.

Following are the various methods available for the determination of water content of soil:

1. Oven-Drying Method
2. Sand Bath Method
3. Alcohol Method
4. Infrared Lamp Torsion Balance Method
5. Calcium Carbide Method
6. Pycnometer Method.

1. Oven –Drying Method

- The oven-drying method is the standard method of the determination of water content in the laboratory.
- The principle of test is to determine the weight of a wet soil sample in a container, dry the sample along with the container for 24 h in an oven and then determine the weight of the dry soil sample. The sequence of steps in water content determination is illustrated in Fig.

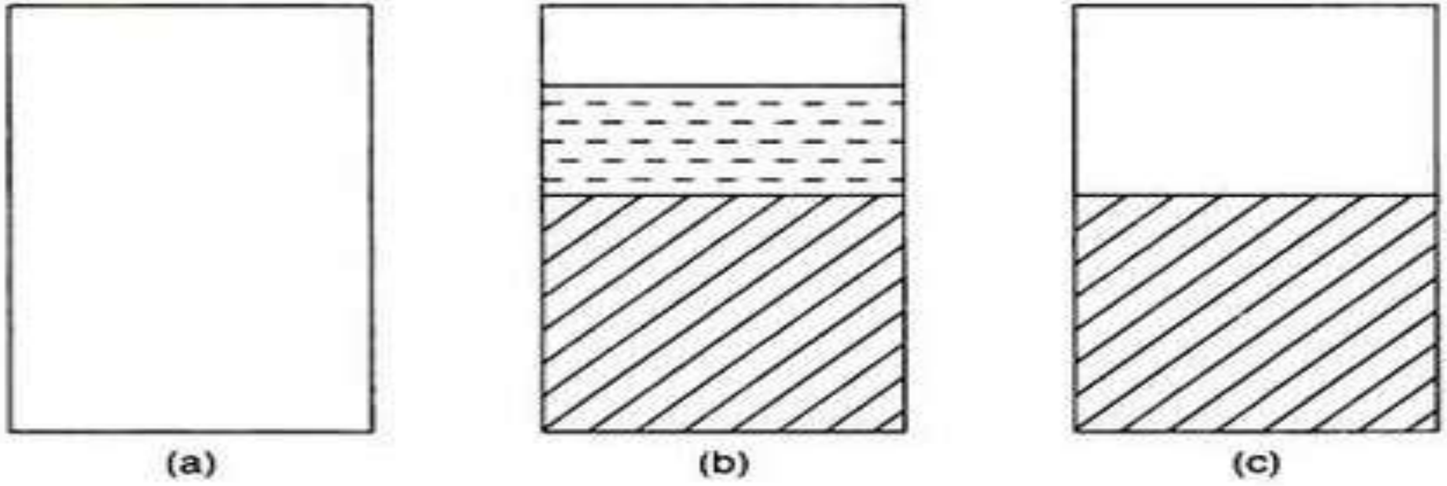


Figure 4.8 Principle of water content determination (schematic): (a) Empty container (W_1), (b) container + wet soil (W_2), and (c) container + dry soil (W_3).

The water content of the soil (ω, in percentage) is obtained from the relation –

ω = [(W2 – W1)/(W3 – W1)] x 100 ....(1)

where,

W1 is the weight of the container,

W2 is the weight of container + wet soil, and

W3 is the weight of container + dry soil.

Procedure

i. A clean dry non-corrodible container with lid is taken and its weight is determined (W1)
ii. The required quantity of a representative undisturbed soil sample, is taken and placed loosely in the container. The weight of the container with lid and wet soil is determined (W2).
iii. The container with wet soil is placed in the oven with its lid removed for 24 h, maintaining a temperature of 110 ± 5°C. The container now containing dry soil is then cooled in a desiccator with the lid closed.
iv. The weight of dry soil with the container and lid (W3) is determined. The water content is determined from Eq. as given in preceding slide

Note: A temperature more than 110 ± 5°C should not be used as it breaks the crystal structure of the soil and causes evaporation of structural water, which has properties completely different from normal water and is considered a part of soil solids.

2. Sand Bath Method

i. A clean dry non-corrodible container with lid is taken and its weight is determined (W1).

ii. The required quantity of a representative undisturbed soil sample, is taken and placed loosely in the container. The weight of the container with lid and wet soil is determined (W2).

iii. The container with wet soil is placed on a sand bath and is heated until all the water has evaporated. This takes about 0.5 to 1 h. The soil is mixed using a palette knife to ensure soil at the bottom is not overheated. Care should be taken to ensure that the sandbath is not too hot and does not exceed the temperature 110 ± 5 °C. The container now containing dry soil is then cooled in a desiccator with the lid closed.

iv. The weight of dry soil with the container and lid (W3) is determined. The water content is determined from the same equation

3. Alcohol Method:

The principle of water content determination in the alcohol method is the same as in the oven-drying method except that drying of wet soil is done with the help of methylated spirit.

i. A clean dry non-corrodible container with lid is taken and its weight is determined (W1).

ii. The required quantity of a representative undisturbed soil sample, is taken and placed loosely in the container. The weight of the container with lid and wet soil is determined (W2).

iii. The wet soil is mixed with a methylated spirit (1 mL/g of soil). The methylated spirit is worked well with the soil using a palette knife, and large lumps of soil, if any, are broken down.

iv. The wet soil with methylated spirit is then ignited. The contents are constantly stirred with a spatula or knife, care being taken to ensure that none of the soil is lost.

v. After methylated spirit completely burns away, the container (now with dry soil) is taken and cooled in a desiccator with the lid closed.

vi. The weight of the dry soil with the container and lid (W3) is determined. The water content is determined from Eq. (1).

4. Infrared Lamp Torsion Balance Method:

This method enables rapid determination of water content of soils by employing a device providing infrared lamp for drying and torsion balance for getting percentage of water on wet basis from a scale. The results obtained are convertible to water content on dry basis.

Procedure

i. About 25 g of a soil sample is taken. The lamp housing is raised and the soil is evenly distributed on the sample pan.

ii. The lamp housing is then lowered and the infrared lamp is switched on.

iii. A thermometer is inserted in its socket. The variac control knob is set between 95°C and 100°C. The soil sample now begins to lose water.

iv. When the thermometer indicates a temperature of 105°C, the variac knob is adjusted in such a manner that there is no further increase in temperature.

v. The drum scale is rotated by turning the drum drive knob until the pointer returns to the index. The percentage of water content is directly read from the scale. The final reading is taken when the pointer is steady on the drum scale, which indicates that the soil has dried to a constant mass.

vi. The water content read from the scale is based on the initial wet weight of soil (ω’).

5. Calcuim Carbide Method-

This is quick method but not accurate like drying oven method

Rapid moisture meter

1. Wet soi and CaC_2 is mixed in a closed container
2. Calcium Carbide reacts with free water in soil

$CaC_2 + H_2O = Ca(OH)_2 + C_2H_2$ (Acetylene Gas)

The water content is determined indirectly from the pressure of Acetylene Gas formed.

5. Pycnometer Method

This method may be used when the specific gravity of solids is known. This is a relatively quick method and is considered suitable for coarse-grained soils only.

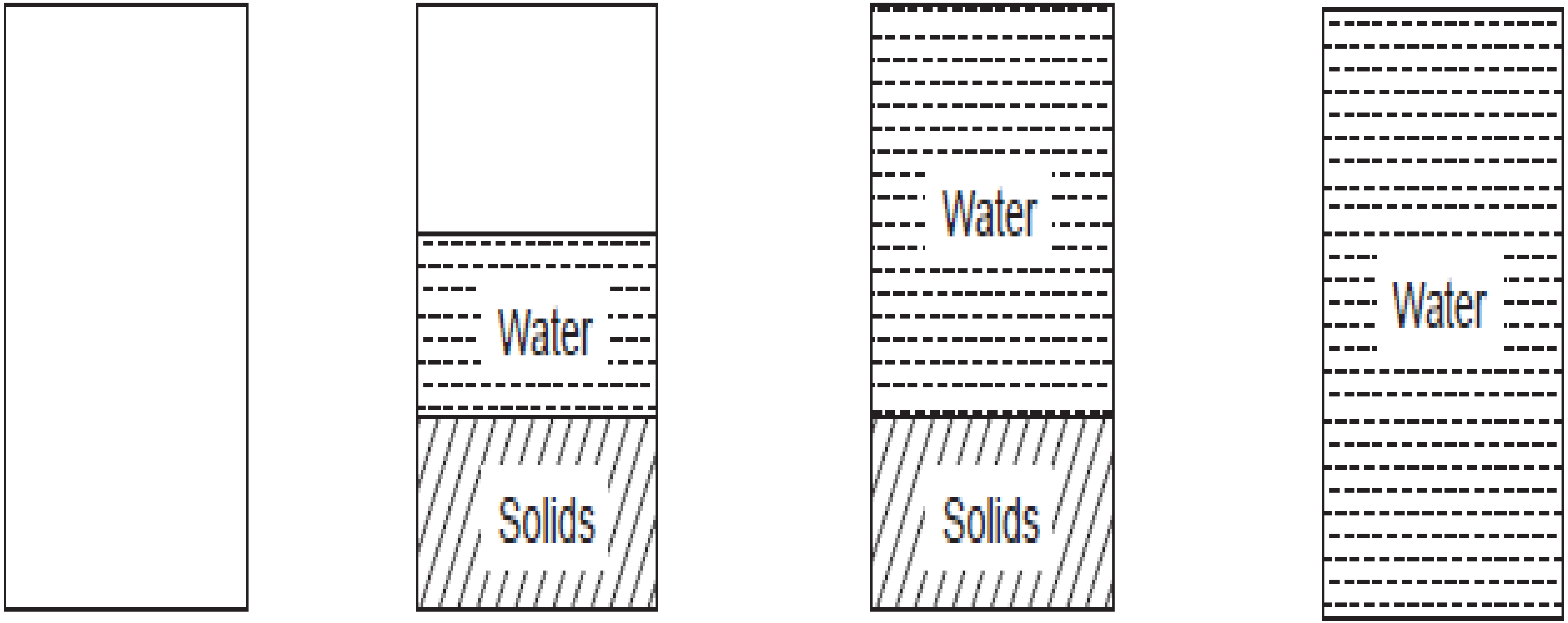
The following are the steps involved:

(*i) The weight of the empty pycnometer with its cap and washer is found* (*W1).*

(*ii) The wet soil sample is placed in the pycnometer (upto about 1/4 to 1/3 of the volume)*and its weight is obtained (*W2).*

(*iii) The pycnometer is gradually filled with water, stirring and mixing thoroughly with* a glass rod, such that water comes flush with the hole in the conical cap. The pycnometer is dried on the outside with a cloth and its weight is obtained (*W3).*

(*iv) The pycnometer is emptied and cleaned thoroughly; it is filled with water upto the* hole in the conical cap, and its weight is obtained (*W4).*



(a) Empty pycnometer wt. W_1

(b) Pycnometer + wet soil wt. W_2

(c) Pycnometer + wet soil + water wt. W_3

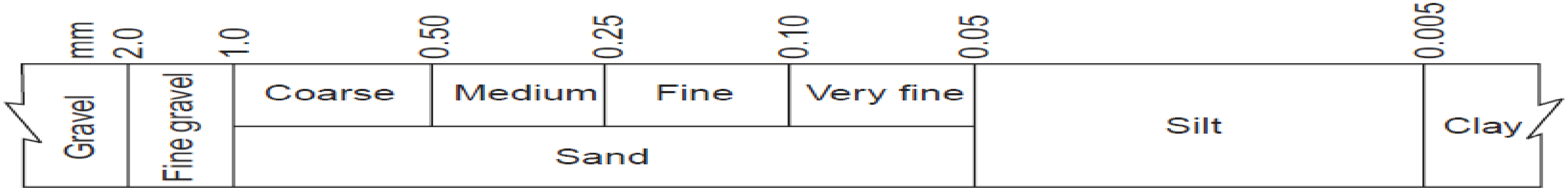
(d) Pycnometer + water wt. W_4

Purpose

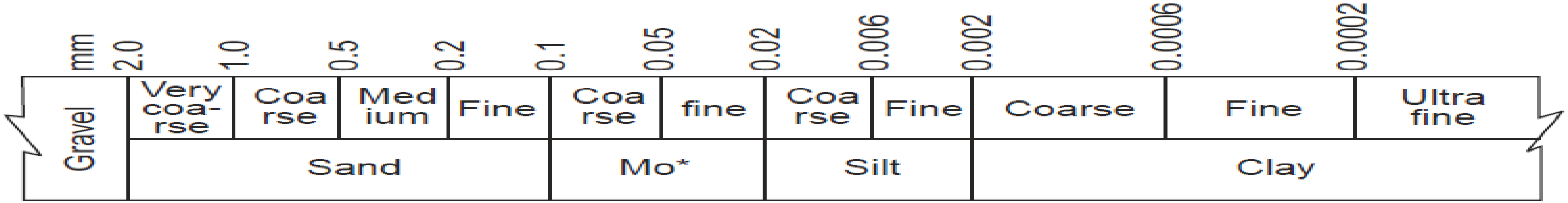
- Soils in nature rarely exist separately as gravel, sand, silt, clay or organic matter, but are usually found as mixtures with varying proportions of these components.

- Grouping of soils on the basis of certain definite principles would help the engineer to rate the performance of structures etc.

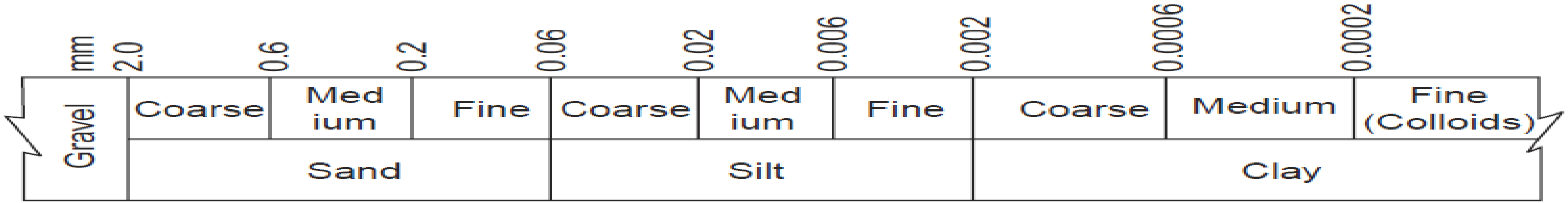
1. Grain Size Classification



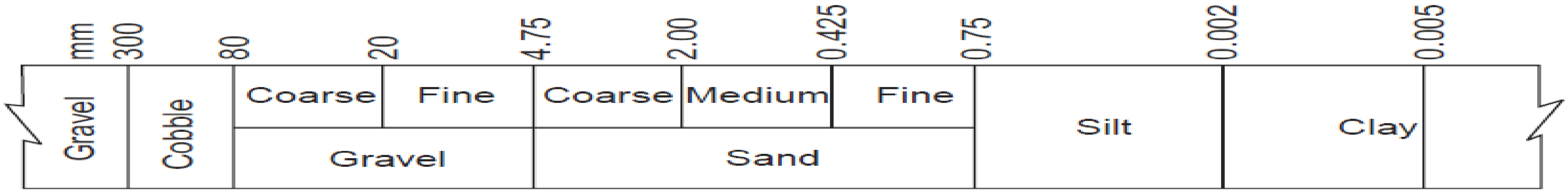
U.S.Bureau of soils and P.R.A. system of classification



International classification
(Mo* is a swedish term used for glacial silts or rock flour having little plasticity)



M.I.T. Classification

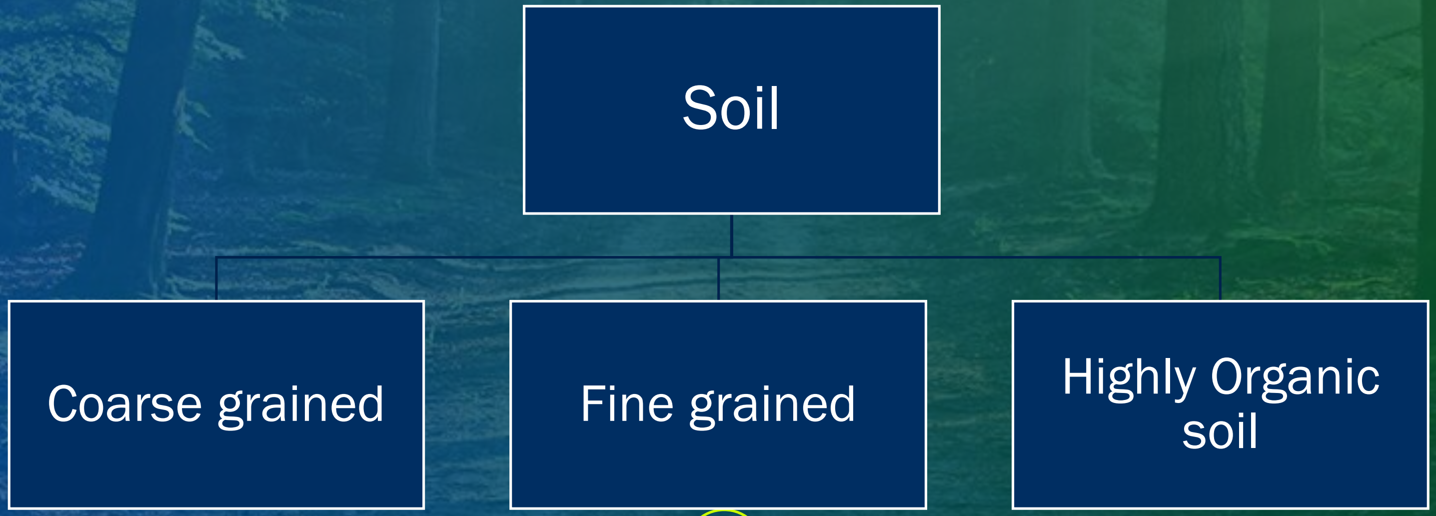


I.S. Classification (IS: 1498-1970)

Unified Soil Classification System/ I.S. Classification

- The Unified soil classification system was originally developed by A. Casagrande.
- Redesignated as the "Unified Soil Classification" in 1957 by Wagner.

- I.S. Classification (IS: 1498-1970) is similar with slight modification.



1. **Coarse-grained Soils**: *More than 50% of the total material by weight is larger than 75- μ IS* Sieve size.

2. Fine-grained Soils: *More than 50% of the total material by weight is smaller than 75- μ* IS Sieve size.

3. **Highly Organic Soils** *These soils contain large percentages of fibrous organic matter, such as peat etc*

Further Classified as

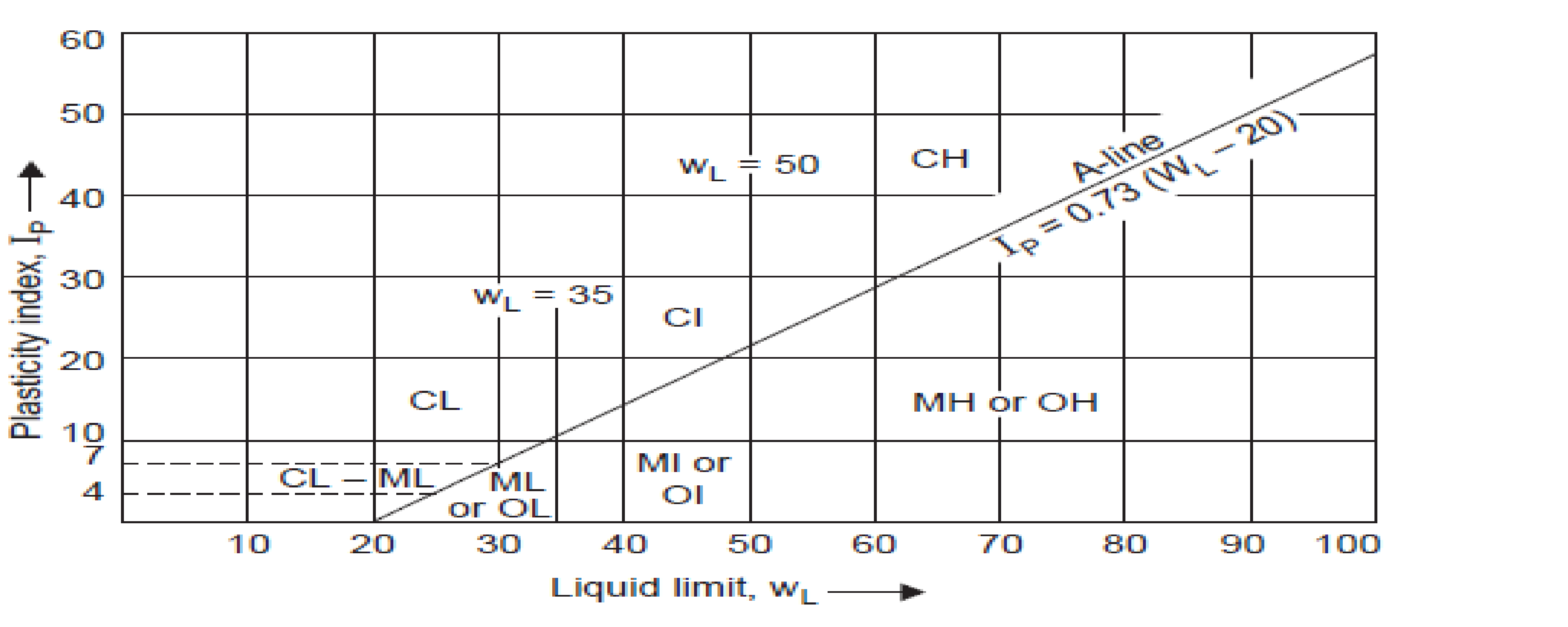
W = Well Graded
C = Well Graded with clay binders
P = Poorly Graded
M = Containing fine materials not covered in other group.

Fine-grained soils shall be divided into three sub-divisions:

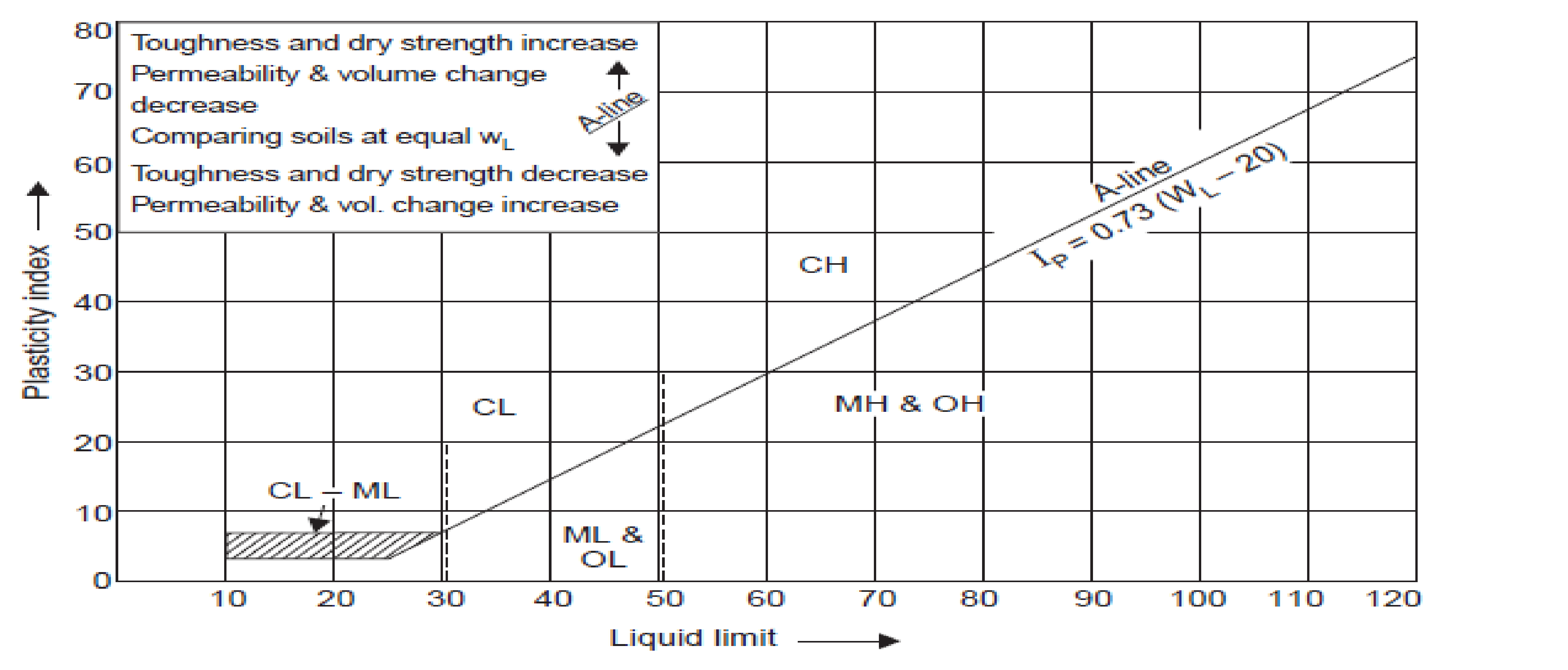
(a) Silts and clays of low compressibility : Liquid limit less than 35% (L).

(b) Silts and clays of medium compressibility : Liquid limit greater than 35% and less than 50% (I).

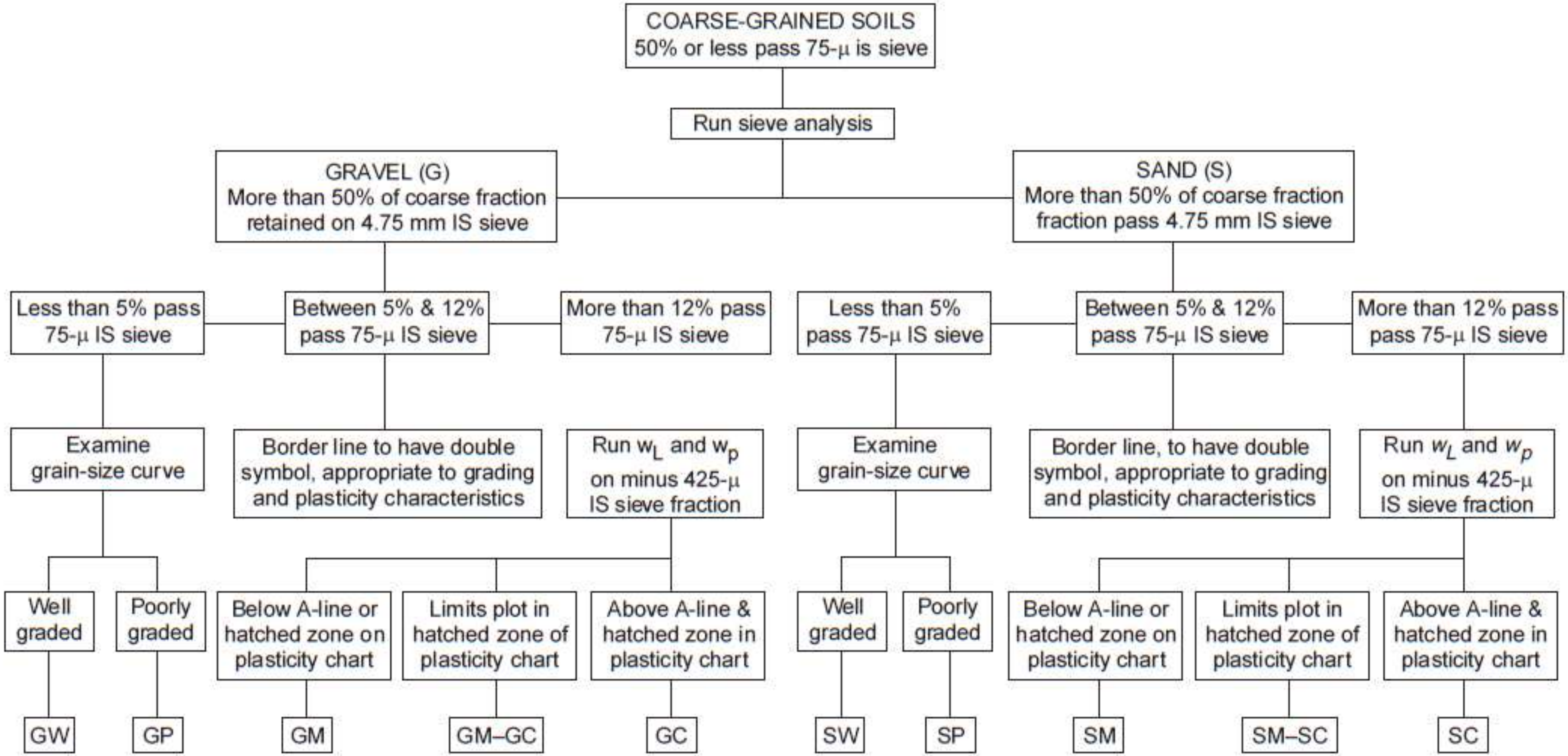
(c) Silts and clays of high compressibility: Liquid limit greater than 50 (H).



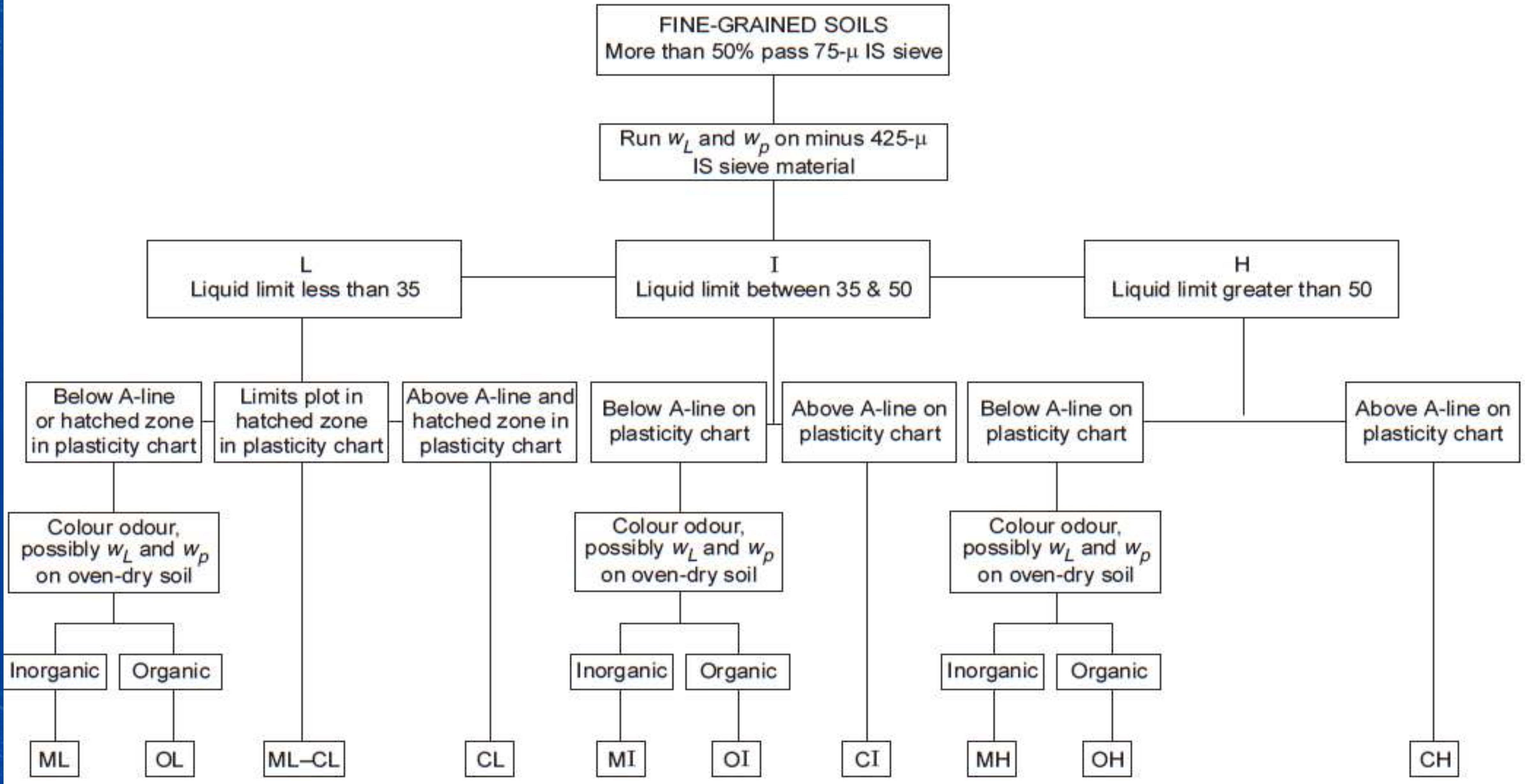
Plasticity chart (I.S. soil classification)



Plasticity chart (unified soil classification)



COARSE-GRAINED SOILS
50% or less pass 75-μ is sieve
Run sieve analysis
GRAVEL (G)
More than 50% of coarse fraction retained on 4.75 mm IS sieve
SAND (S)
More than 50% of coarse fraction fraction pass 4.75 mm IS sieve
Less than 5% pass 75-μ IS sieve
Between 5% & 12% pass 75-μ IS sieve
More than 12% pass 75-μ IS sieve
Less than 5% pass 75-μ IS sieve
Between 5% & 12% pass 75-μ IS sieve
More than 12% pass 75-μ IS sieve
Examine grain-size curve
Border line to have double symbol, appropriate to grading and plasticity characteristics
Run w_L and w_p on minus 425-μ IS sieve fraction
Examine grain-size curve
Border line, to have double symbol, appropriate to grading and plasticity characteristics
Run w_L and w_p on minus 425-μ IS sieve fraction
Well graded
Poorly graded
Below A-line or hatched zone on plasticity chart
Limits plot in hatched zone of plasticity chart
Above A-line & hatched zone in plasticity chart
Well graded
Poorly graded
Below A-line or hatched zone on plasticity chart
Limits plot in hatched zone of plasticity chart
Above A-line & hatched zone in plasticity chart
GW
GP
GM
GM–GC
GC
SW
SP
SM
SM–SC
SC


FINE-GRAINED SOILS
More than 50% pass 75-μ IS sieve
Run w_L and w_p on minus 425-μ IS sieve material
L
Liquid limit less than 35
I
Liquid limit between 35 & 50
H
Liquid limit greater than 50
Below A-line or hatched zone in plasticity chart
Limits plot in hatched zone in plasticity chart
Above A-line and hatched zone in plasticity chart
Below A-line on plasticity chart
Above A-line on plasticity chart
Below A-line on plasticity chart
Above A-line on plasticity chart
Colour odour, possibly w_L and w_p on oven-dry soil
Colour odour, possibly w_L and w_p on oven-dry soil
Colour odour, possibly w_L and w_p on oven-dry soil
Inorganic
Organic
Inorganic
Organic
Inorganic
Organic
ML
OL
ML–CL
CL
MI
OI
CI
MH
OH
CH

THANK YOU!

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