SOIL MECHANICS IA-EECQ 3171

BACHELOR OF ENGINEERING IN CIVIL ENGINEERING

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Definition

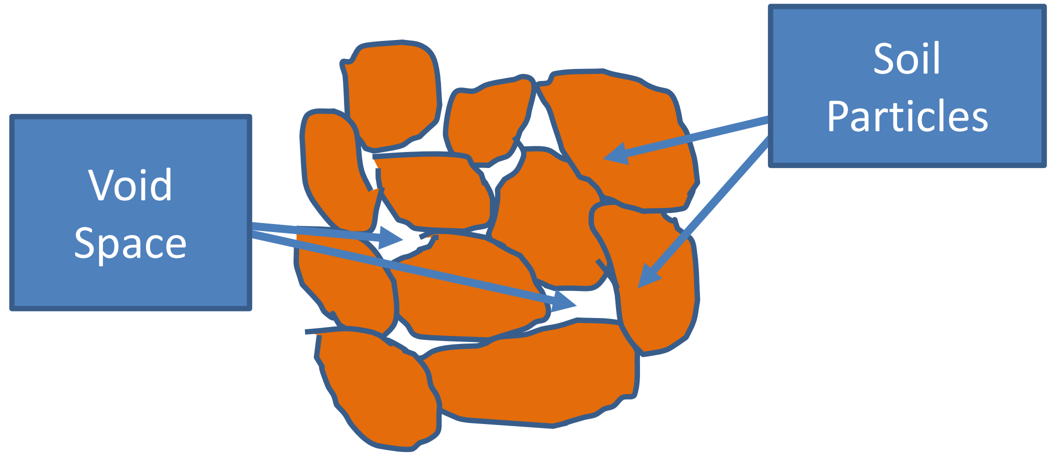
- Soil comes from Latin word **Solum**
- **To Agricultural Scientist**: Soil is the loose material on the earth's crust consisting of disintegrated rock mixed with organic matter which supports plant life
- **To a Civil Engineer**: Soil is the loose unconsolidated inorganic material on the earth's crust produced by the integration of rocks overlying hard rock with or without organic matter.
- **Soil Mechanics** therefore is the study of engineering behavior of soil when it is used either as a construction material or as a foundation material **(Karl Von Terzaghi- Father of Soil Mechanics)**

Field of Application of Soil Mechanics

- Foundations
- Underground and earth retaining structures
- Pavement design
- Excavations, embankments and dams

Soil Composition

- Soil is a complex system
- A mass of soil is composed of
  - Soil particles or soil grains
  - Void spaces (Water & air)
- A soil mass is represented in a phase
- A phase is any homogeneous part of the system different from other parts of the system separated from them by abrupt transition



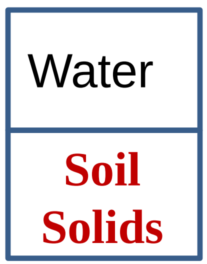
- (a) A soil mass

- (b) A 3-phase diagram

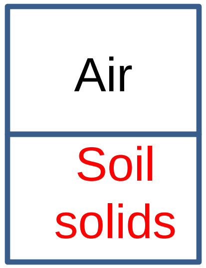
Soil Composition

- When the voids spaces are completely filled with water, the soil is said to be fully saturated
- When the void spaces are completely filled with air, the soil is said to be dry.
- In both cases, the phase representation becomes a 2-phase diagram

- Fully saturated 2-pase diagram

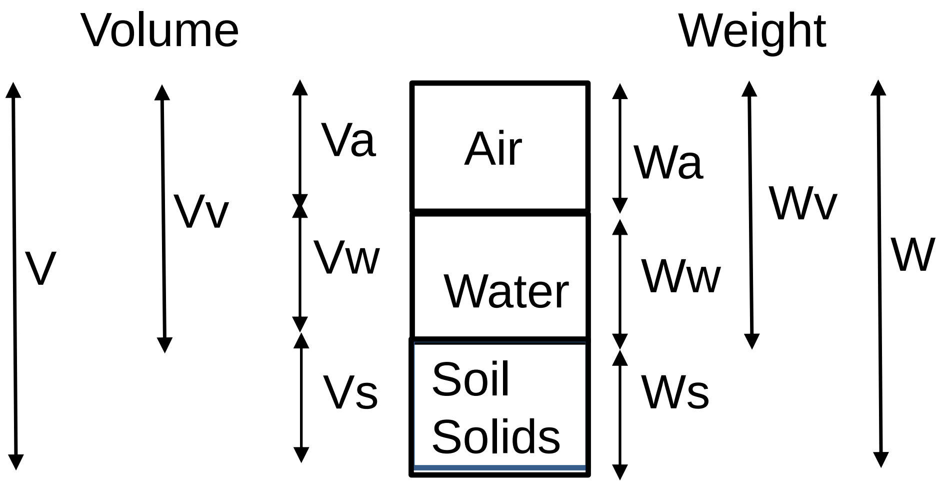


- A dry soil 2-pase diagram



Basic Terminologies

- The basic terminologies consist of a number of quantities based on soil as a 3-phase system. That is, a partially saturated soil.



Va=Vol. of air

Vw=Vol. of water

Vv=Volume of voids

Vs=Vol. of solids

V=Total vol. of soil mass

Vv=Vw+Va

Wa=Wt. of air

Ww=Wt. of water

Wv=Wt. of voids

Ws=Wt. of solids

W= Total Wt. of soil mass

Wv=Ww+Wa

Basic Terminologies

- **Porosity, n** is the ratio of volume of voids to the total volume of the soil mass. Expressed as a percentage. n= $\frac{V_v}{V}$x100
- **Void ratio, e** is the ratio of the volume of voids to the volume of solids in the soil mass. Expressed as a decimal fraction. e= $\frac{V_v}{V_s}$
- **Degree of Saturation, Sr** is the ratio of the volume of water to the volume of voids. Expressed as a percentage. $S_r = \frac{V_w}{V_v}$x100
  - For a fully saturated soil, Vv = Vw, Sr = 1 =100%
  - For a dry soil, Vw = 0, Sr = 0
- **Percent Air voids, n_a** is the ratio of the volume of air voids to the total volume of the soil mass. Expressed as a percentage. $n_a = \frac{v_a}{V}$x100
- **Air content, A** is the ratio of the volume of the air in the voids to the total volume of voids. Expressed as a percentage. A= $\frac{V_a}{V_V}$x100

Basic Terminologies Cont'

- **Moisture Content, w also referred to as water content** is the ratio of the weight of water to the weight of solids (dry weight) of the soil mass. Expressed as a percentage. w= $\frac{W_w}{W_s}$x100
- **Bulk Unit weight, γ** is weight per unit volume of the soil mass.

$$\gamma = \frac{W}{V}, \quad W = W_w + W_s, \text{ and } \quad V = V_a + V_w + V_s$$

- **Unit weight of soil solids, $\boldsymbol{\gamma_s}$** is the weight of the soil solids per unit volume of solids alone. $\gamma_s = \frac{W_s}{V_s}$
- **Unit weight of water, $\boldsymbol{\gamma_w}$** is the weight of water per unit volume of water. $\gamma_w = \frac{W_w}{V_w}$. Unit wt. of water is 9.81kNm^{-3}, 1000kgm^{-3}, 1gcm^{-3}
- **Saturated unit weight, $\boldsymbol{\gamma_{sat}}$** is the bulk unit weight of the soil mass in the saturated condition. $\gamma_{sat} = (\frac{W}{V})_{sat}$

Basic Terminologies Cont'

- **Submerged unit weight,** $\boldsymbol{\gamma'}$ is the unit weight of the soil solids in the submerged condition.$\boldsymbol{\gamma'} = \frac{(W_s)_{sub}}{V}$. $(W_s)_{sub}$ is equal to the weight of solids in air minus the weight of water displaced by the solids
- $(W_s)_{sub} = W_s - V_s.\gamma_w$. Since the soil is submerged, the voids are filled with water.
- $V = V_w + V_s$,
- $(W_s)_{sub} = W_s - V_s.\gamma_w = W - W_w - V_s.\gamma_w = W - V_w.\gamma_w - V_s.\gamma_w$
- $(W_s)_{sub} = W - \gamma_w(V_w + V_s) = W - V\gamma_w$. Dividing both sides by V gives
- $\frac{(W_s)_{sub}}{V} = (\frac{W}{V})_{sat} - \gamma_w = \boldsymbol{\gamma_{sat}} - \gamma_w$
- **Dry Unit weight,** $\gamma_{\boldsymbol{d}}$ is the weight of soil solids per unit volume
- $\gamma_{\boldsymbol{d}} = \frac{\boldsymbol{W_s}}{\boldsymbol{V}}$

Basic Terminologies Cont’

- **Specific gravity of solids, $\boldsymbol{G_s}$** is the ratio of the unit weight of solids to the unit weight of water at standard temperature (4^{o}C). Or the ratio of the weight of solids to the weight of equal volume of water. It has no units
- $G_s = \frac{W_s}{V_s.\gamma_w} = \frac{\gamma_s}{\gamma_w}$

Relationships involving porosity, void ratio, degree of saturation, moisture content, percent air voids and air content

(1) If porosity n$= \frac{V_v}{V} = \frac{V-V_s}{V} = 1\text{-}\frac{V_s}{V} = 1 - \frac{W_s}{\gamma_s.V} = 1 - \frac{W_s}{G_s\gamma_w V}$

- Since $\gamma_s = \frac{W_s}{V_s} = G_s\gamma_w$ and $V_s = \frac{W_s}{\gamma_s}$
- This provides a practical approach for the determination of porosity, n

(2) Void ratio, e $= \frac{V_v}{V_s} = \frac{V-V_s}{V_s} = \frac{V}{V_s}\text{-}1 = \frac{V\gamma_s}{W_s}\text{-}1 = \frac{VG_s\gamma_w}{W_s}\text{-}1$

- This provides a practical approach for the determination of void ratio, e

(3) Relationship between void ratio, e and porosity, n

If n $= \frac{V_v}{V}$ and $\mathbf{e} = \frac{V_v}{V_s}$, & nV= V_v, then e $=\frac{nV}{V_s} = \frac{n(V_s+V_v)}{V_s}$ = n($\frac{V_s}{V_s}$+$\frac{V_v}{V_s}$)

e = n(1 + e) and n = ${}^{e}/_{1+e}$ and e = ${}^{n}/_{1-n}$

Relationships involving porosity, void ratio, degree of saturation, moisture content, percent air voids and air content Cont'

(4) **Air Content**, $A = \frac{V_a}{V_v}$ and $n = \frac{V_v}{V}$, $\rightarrow V_v = nV$ and substituting for V_v in A gives $A = \frac{V_a}{nV} \Rightarrow nA = \frac{V_a}{V} = n_a$

(5) **Moisture content**, $w = \frac{W_w}{W_s}$ and $S_r = \frac{V_w}{V_v}$, $e = \frac{V_v}{V_s} \Rightarrow eS_r = \frac{V_v}{V_s} x \frac{V_w}{V_v} = \frac{V_w}{V_s}$

$w = \frac{W_w}{W_s} = \frac{W_w}{V_s \gamma_s} = \frac{\gamma_w V_w}{V_s \gamma_s}$, $G_s = \frac{\gamma_s}{\gamma_w}$ and $\gamma_s = \frac{W_s}{V_s}$ then $w = \frac{\gamma_w}{\gamma_s} \text{x} \frac{V_w}{V_s} = \frac{eS_r}{G_s}$

For saturated condition, Sr = 1 then $w = \frac{e}{G_s}$ and $e = wG_s$

(6) **Percent air voids**, $n_a = \frac{V_a}{V} = \frac{V_v - V_w}{V_s + V_v} = \frac{\frac{V_v}{V_s} - \frac{V_w}{V_s}}{\frac{V_s}{V_s} + \frac{V_v}{V_s}} = \frac{e - \frac{V_w}{V_s}}{1+e}$ but $\frac{V_w}{V_s} = eS_r$

$n_a = \frac{e - eS_r}{1+e} = \frac{e(1-S_r)}{1+e} \Rightarrow n_a = n(1 - S_r)$

Relationships involving porosity, void ratio, degree of saturation, moisture content, percent air voids and air content Cont'

(7) Air content, $A = \frac{v_a}{V_v}$ and $S_r = \frac{V_w}{V_v}$

$A + S_r = \frac{V_a + V_w}{V_v} = \frac{V_v}{V_v} = 1$

$A = 1 - S_r$ and $\Rightarrow n_a = n(1 - S_r) = nA$

Relationships involving unit weights, grain specific gravity, void ratio and degree of saturation

(1) Bulk Unit Weight, $\gamma = \frac{W}{V} = \frac{W_s+W_w}{V_s+V_v} = \frac{W_s(1+\frac{W_w}{W_s})}{V_s(1+\frac{V_v}{V_s})} = \frac{W_s(1+w)}{V_s(1+e)}$

But $\frac{W_s}{V_s} = \gamma_s = \gamma_w G_s$. and $\gamma = \frac{\gamma_s(1+w)}{(1+e)}$ Therefore $\gamma = \frac{\gamma_w G_s(1+w)}{1+e} = \frac{\gamma_w\,(G_s+wG_s)}{1+e}$

But $wG_s = eS_r$.

Then, $\gamma = \frac{\gamma_w\,(G_s+eS_r)}{1+e}$

(2) **Saturated unit weight, $\boldsymbol{\gamma_{sat}}$** occurs when S_r= 1 (Fully saturated). Then

$$\gamma_{sat} = \frac{\gamma_w\,(G_s+e)}{1+e}$$

(3) **Dry unit weight, $\boldsymbol{\gamma_d}$** occurs when S_r= 0 (Fully dry). Then

$$\gamma_d = \frac{\gamma_w\,G_s}{\ldots}$$

Relationships involving unit weights, grain specific gravity, void ratio and degree of saturation

(4) **Submerged unit weight**, $\gamma' = \gamma_{sat} - \gamma_w = \frac{\gamma_w\,(G_s+e)}{1+e} - \gamma_w$

$$\gamma' = \frac{G_s\gamma_w + e\gamma_w - \gamma_w(1+e)}{1+e} = \frac{G_s\gamma_w + e\gamma_w - \gamma_w - e\gamma_w)}{1+e} = \frac{\gamma_w\,(G_s-1)}{1+e}$$

(5) **Bulk unit weight**, $\gamma = \frac{W}{V} = \frac{W_s+W_w}{V}$ But $w = \frac{W_w}{W_s} \Rightarrow W_w = wW_s$

$\gamma = \frac{W_s + wW_s}{V} = \frac{W_s(1+w)}{V}$ But $\gamma_d = \frac{W_s}{V}$

Therefore, $\gamma = \gamma_d(1+w)$

And $\gamma_d = \frac{\gamma}{(1+w)}$

$\gamma_d = \frac{\gamma}{(1+w)} = \gamma_d = \frac{\gamma}{(1+\frac{eS_r}{G_s})}$

since $w = \frac{eS_r}{G_s}$

Example 1

One cubic metre of wet soil weighs 19.80kN. If the specific gravity of soil particles is 2.70 and water content is 11%, find the void ratio, dry unit weight, and degree of saturation.

Solution

Bulk unit weight, $\gamma = \frac{W}{V} = \frac{19.8}{1} = 19.80kNm^{-3}$ and

water content, w = 11% = 0.11

$Dry\ unit\ weight, \gamma_d = \frac{\gamma}{(1+w)} = \frac{19.8}{(1+0.11)} = 17.84kNm^{-3}$

If Gs = 2.70 and unit weight of water, $\gamma_w = 9.81kNm^{-3}$ then from

Dry unit weight, $\gamma_d = \frac{\gamma_w G_s}{1+e} = 17.84 = \frac{2.7x9.81}{1+e}$ ⇒void ratio, e = 0.485

Degree of saturation, $S_r = \frac{w\ G_s}{e} = \frac{0.11x\ 2.7}{0.485}x100 = 61.24\%$

Example 2

The porosity of a soil sample is 35% and the specific gravity of its particles is 2.7. Calculate its void ratio, dry unit weight, saturated unit weight and submerged unit weight.

Solution

Porosity, n = 35%, Void ratio, e = ${}^{n}/_{1-n}$ = ${}^{0.35}/_{1-0.35}$ = 0.54

If Gs = 2.7, then dry unit weight, $\gamma_d = \frac{\gamma_w\, G_s}{1+e} = \frac{9.81x2.7}{1+0.54} = 17.2kNm^{-3}$

Saturated unit weight, $\gamma_{sat} = \frac{\gamma_w\,(G_s+e)}{1+e} = \frac{9.81\,(2.7+0.54)}{1+0.54} = 20.64kNm^{-3}$

Submerged unit weight, $\gamma' = \gamma_{sat}$-γ_w = 20.64-9.81 = $10.83kNm^{-3}$

$\gamma' = \frac{\gamma_w\,(G_s-1)}{1+e} = \frac{9.81\,(2.7-1)}{1+0.54} = 10.83kNm^{-3}$

Example 3 (Assignment)

A dry soil has a void ratio of 0.65 and its grain specific gravity is 2.8. Water is added to the sample so that its degree of saturation is 60% without any change in void ratio. The sample is next placed below water. Determine:

1. Dry unit weight of the soil
2. The water content
3. The bulk unit weight
4. Saturated unit weight (without considering buoyancy) if the degree of saturation is 95% and 100%.

Particle Size Distribution

- Sometimes referred to as
  - particle gradation or gradation
  - Sieve analysis or sieving
  - Grain size distribution
- Simply means the separation of a soil into its different size fractions
- It can be done in two stages
  - Sieve analysis for coarse fraction
  - Sedimentation analysis or wet analysis for the fine fraction
- **Sieve analysis**
  - Screening process in which coarse fractions of the soil are separated by means of a nest of graded mesh or sieves
  - Sieve sizes are standardized by standard organizations such as British Standard Organization (BS) and American Society for Testing Materials (ASTM)

Particle Size Distribution Cont'

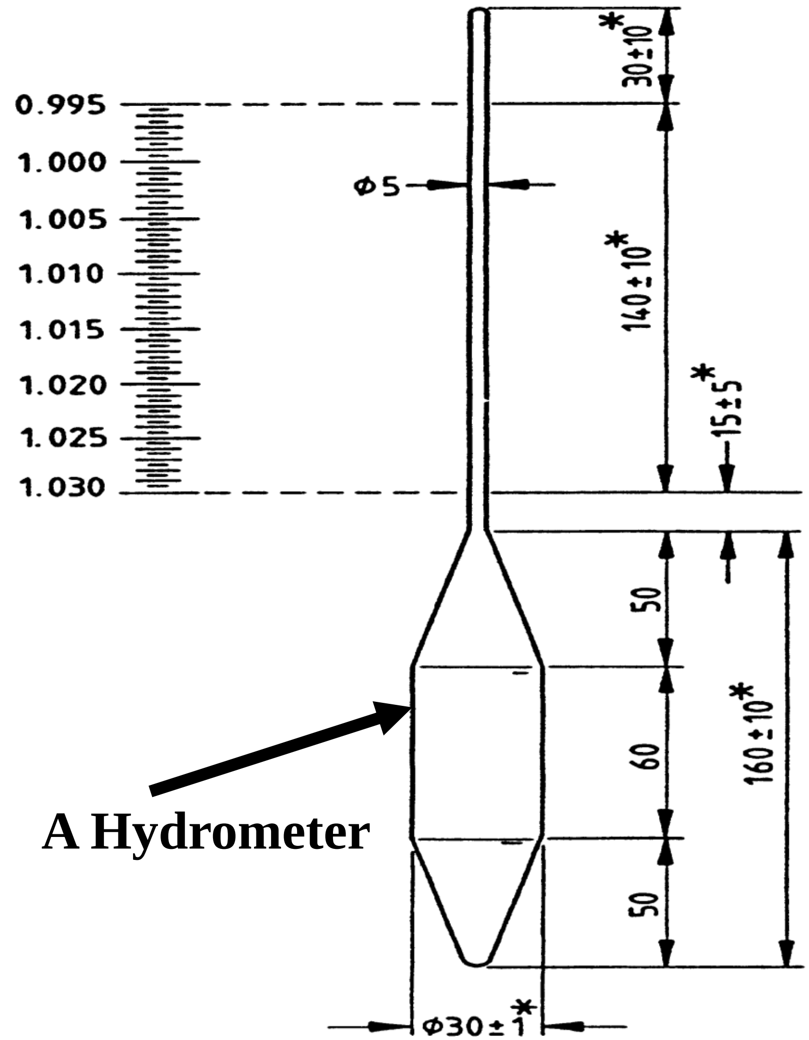
- **Sieve analysis:** The standard procedure is that a dry soil sample is
  - weighed
  - passed through a nest of sieves arranged from the largest aperture to the smallest
  - Soil retained in each sieve is weighed
  - Weight passing each sieve is obtained
  - Cumulative weight passing each sieve is computed
  - A semi-logarithmic graph is drawn
- **Sedimentation:**
  - Is used to determine the particle size distribution of fine-grained soil or the fines of a coarse-grained soil.
  - Is based on Stoke's law which states that the falling or settling velocity of spherical particles in a suspension is directly proportional to its size or diameter
  - That is, the larger the particle, the greater the settling velocity and vice versa.

Particle Size Distribution Cont’

- Types of sedimentation methods
  - Hydrometer method
  - Pipette Method
- **Hydrometer Method** – measures the specific gravity of the suspension by means of a hydrometer
  - The specific gravity depends on the mass of the particles in the suspension at the time of measurement
  - The weights of solids per milliliter in the suspension at the chosen depth at chosen instants are obtained indirectly by reading the specific gravity of the soil suspension
  - The particles will start settling down right from the start and hence the unit weight of the suspension will vary from top to bottom
  - Measurement of the unit weight of the suspension at a known depth at a particular time provides a point on the particle size distribution curve

Particle Size Distribution Cont'

- A soil sample for sedimentation analysis (Hydrometer method) must be deflocculated by adding sodium hexametaphosphate (2g per litre)
- Hydrogen peroxide is also added to oxidize any organic present.
- The soil sample is then poured into a glass jar and water is added to make it to 1-litre volume.
- Specific gravity of the suspension is then read at specific time intervals



A Hydrometer

NOTE. Calibrations in g/ml at 20 °C
All dimensions are in millimetres.
* See 4.1.3.1.1 of BS 1377 : Part 1 : 1990.

Particle Size Distribution Cont'

- **The Pipette Method**
- In this method, the sample is drawn at specified depth and at times corresponding to chosen particle sizes typically0.02, 0.006, 0.002 and 0.001mm
- The samples collected in weighing bottles are dried in an oven at 105-110°C for 24 hours
- The dry weight is then taken to the nearest 0.001g
- The specific gravity of 0.075 mm is determined
- The particle size distribution curve can then be completed

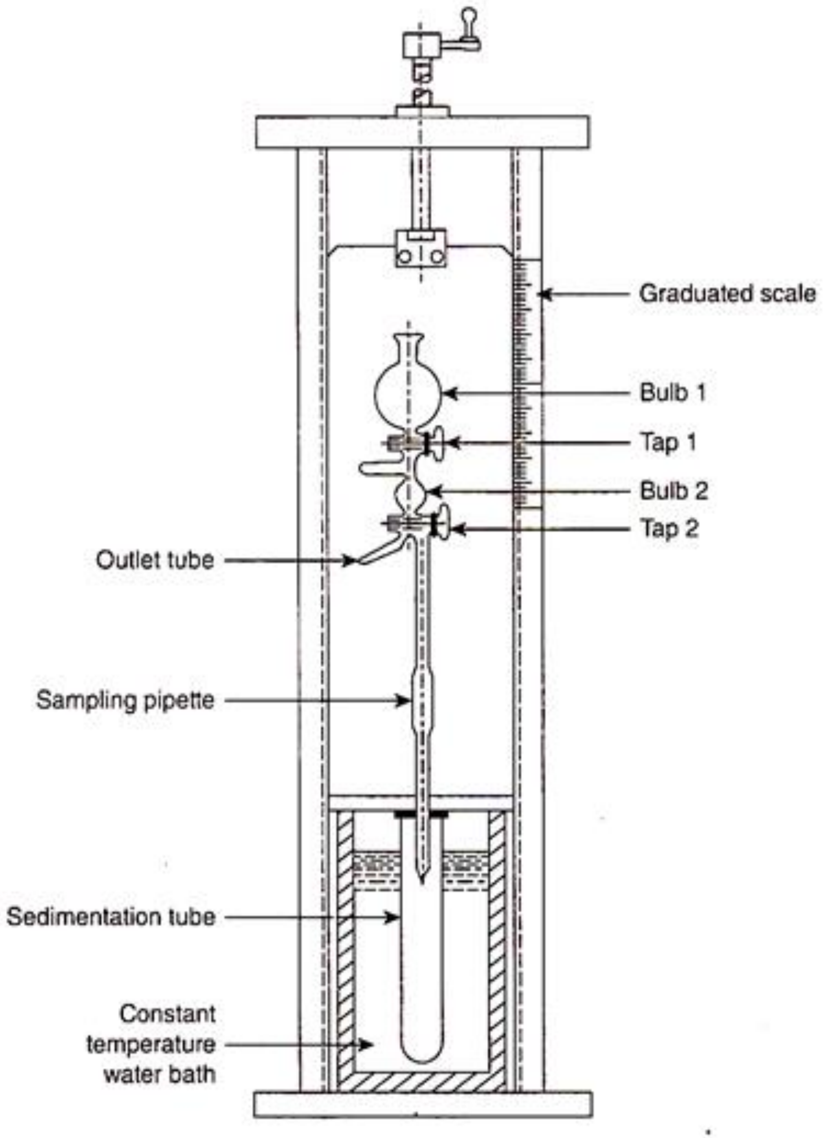
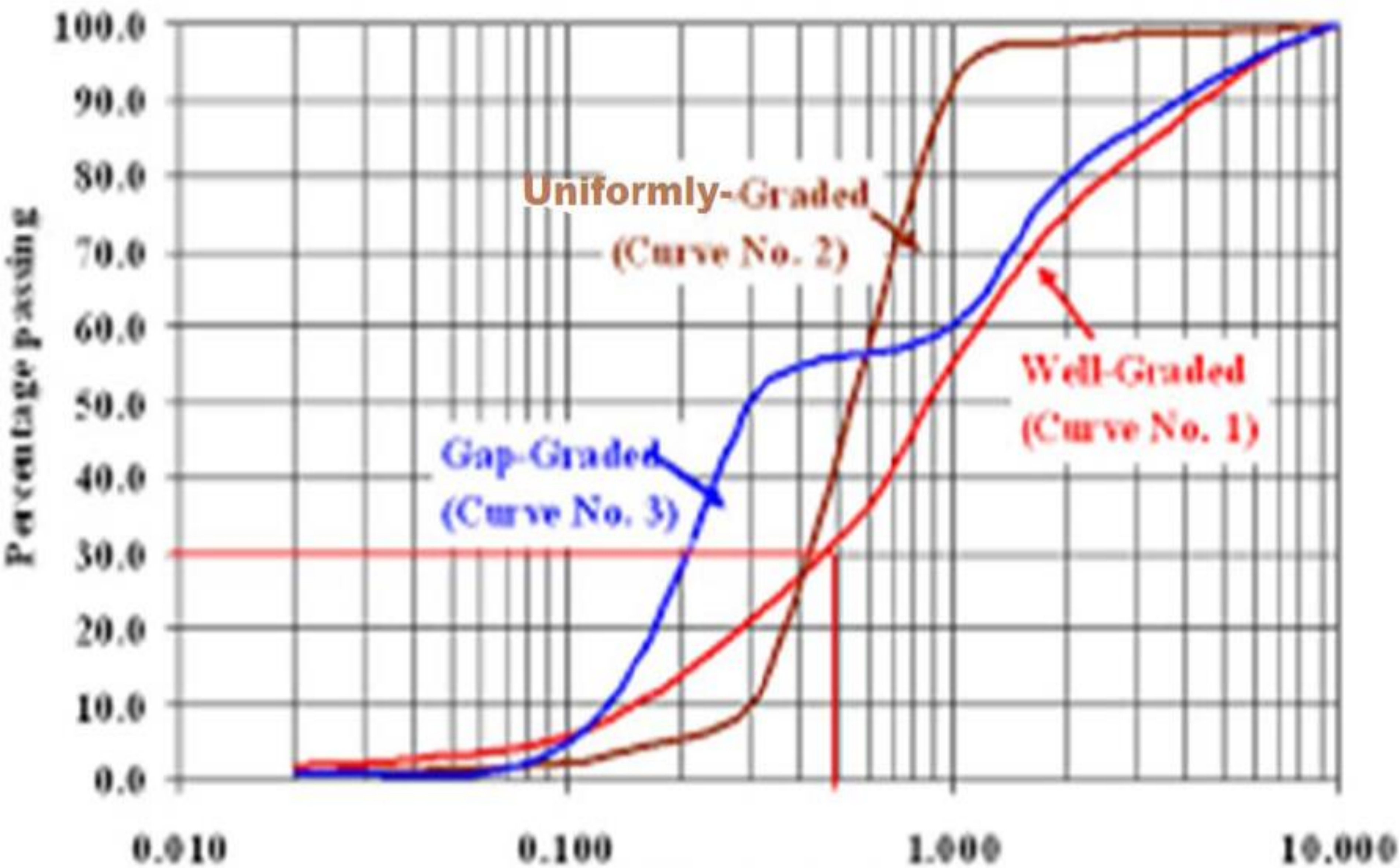


Figure 6.8 Pipette method apparatus.

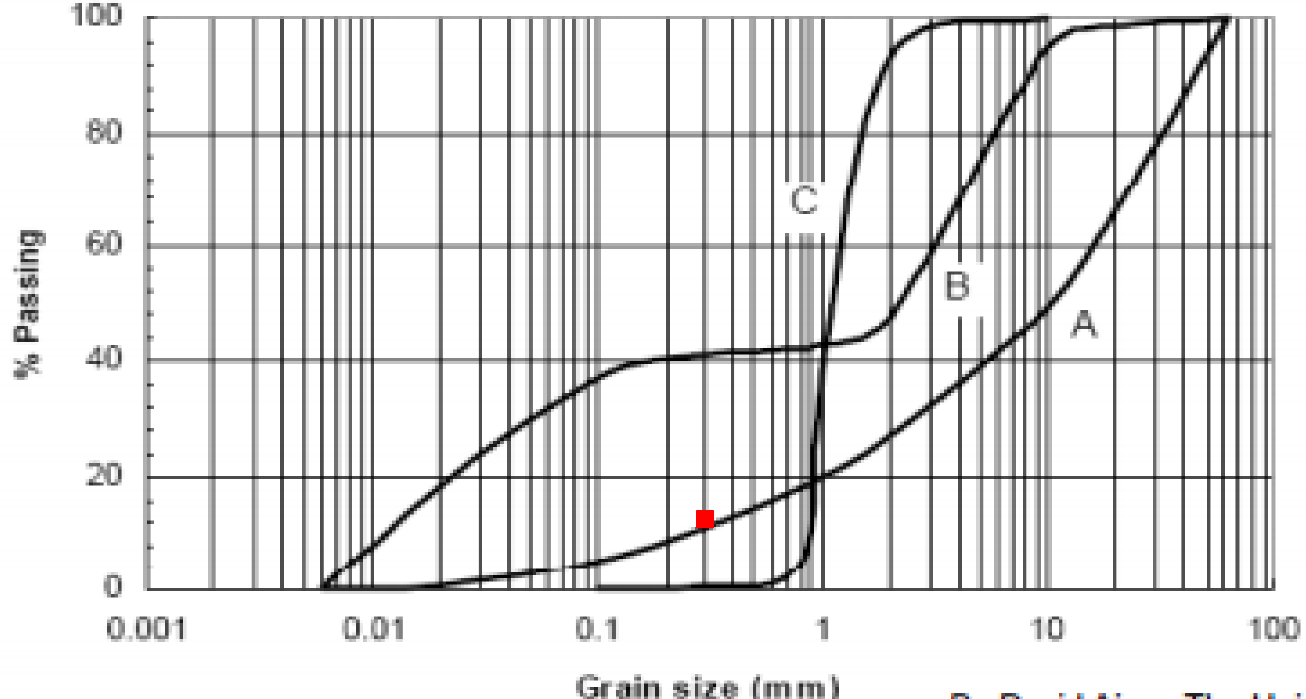
Particle Size Distribution Cont’

- Particle size distribution of a soil sample is presented as a curve on a semi-logarithmic plot,
  - the ordinate (y-axis) being the percentage by mass of particles smaller than the size given by the abscissa (x-axis)
  - the abscissa (x-axis) is particle size diameter in a logarithmic scale
- The shape of the curve will make us describe a soil as
  - **Well graded**- If there is no excess of particles in any size range and if no immediate particles are lacking and the curve is smooth and concave
  - **Poorly graded** – if a high proportion of the particles have
    - sizes within narrow limits (**Uniformly graded-single size particles**)
    - Particles of both large and small sizes are present but with a relatively low proportion of particles of intermediate size **(a gap-graded or step-graded) soil**

Gradation Curves



Gradation Curves 2



By David Airey, The University of Sydney

Soil A: Well Graded
Soil B: Gap Graded
Soil C: Uniform

Particle Size Distribution Cont'

- The following parameters may be read from the gradation curve
  - D_{10} – Is the size which 10% of the particles are smaller than, and corresponds to 10% by weight passing. It is also referred to as the effective size
  - D_{30} – Is the size which 30% of the particles are smaller than, and corresponds to 30% by weight passing
  - D_{60} – Is the size which 60% of the particles are smaller than, and corresponds to 60% by weight passing
- The general shape and slope of the gradation curve can be described by means of the
  - Coefficient of uniformity, $C_u = \frac{D_{60}}{D_{10}}$
  - Coefficient of curvature, C_v or $C_c = \frac{D_{30}^2}{D_{10}D_{60}}$
- For a well graded soil,
  - $C_u > 4$ for gravels and $C_u \geq 6$ for sands
  - Coefficient of curvature, C_v or C_c between 1 and 3

Particle Size Distribution Cont'

– NOTE

1. If the Coefficient of curvature, C_v or C_c is between 1 and 3, then the soil is considered to be well graded provided $C_u > 4$ for gravels and $C_u \geq 6$ for sands
2. These coefficients should be used only as guide as they do not yield correct results for all soil types

- Fineness Modulus, FM $= \frac{\sum \%cummulative\ retained}{100}$
    - For fine aggregates FM lies between 2 and 4
    - For coarse aggregates FM lies between 6.5 and 8

Typical Particle sizes

- BS 5930: 2015 Code of practice for ground investigations gives the basic soil types as:
  - Clay
  - Silt - Fine
    - Medium
    - Coarse
  - Sand - Fine
    - Medium
    - Coarse
  - Gravel-Fine
    - Medium
    - Coarse
  - Cobbles
  - Boulders

Soil Description Details

- Fine-grained soils are described as either silt or clay
- Terms such as silty clay should not be used
- For composite types of coarse soil, the predominant component is written in capital letters
- Fine-grained soils containing 35-65% coarse material are described as sandy and/or gravelly SILT (or CLAY)
- Deposits containing over 50% of boulders and cobbles are referred to as very coarse.
- Mixes of very coarse material with finer soils can be described by combining the descriptions of the two components e.g. COBBLES with some FINE MATERIAL (sand) ; gravelly SAND with occasional BOULDERS

Soil Description Details Cont'

- **Composite types of coarse soil**

– Slightly sandy GRAVEL	Upto 5% sand
– Sandy GRAVEL	5-20% sand
– Very sandy GRAVEL	Over 20% sand
– SAND and GRAVEL	About equal portions
– Very gravelly SAND	Over 20% gravel
– Gravelly SAND	5-20% gravel
– Slightly gravelly SAND	Upto 5% gravel
– Slightly silty SAND (and/or GRAVEL)	Upto 5% silt
– Silty SAND (and/or GRAVEL)	5-20% silt
– Very silty SAND (and/or GRAVEL)	Over 20% silt
– Slightly clayey SAND (and/or GRAVEL)	Upto 5% clay
– Clayey SAND (and/or GRAVEL)	5-20% clay
– Very clayey SAND (and/or GRAVEL)	Over 20% clay
– Slightly clayey gravelly SAND	Less than 5% clay+gravel
– Silty sandy GRAVEL	5-20% silt+sand

Particle Size Distribution Cont'

- Laboratory Work
  - Sieve Analysis

Consistency of Clay Soils

- Consistency of a soil refers to the resistance offered by a soil to forces that tend to deform or rupture the soil aggregates
- It represents the relative ease with which the soil may be deformed
- It is conventionally described as soft, medium stiff (or medium firm), stiff (or firm) or hard
- In the remoulded state, the consistency of a soil varies with the water content which tends to destroy the cohesion exhibited by the particles of such a soil
- As the water content is reduced from a soil from the stage of almost a suspension, the soil passes through various states of consistency
- Albert Atterberg, a Swedish soil scientist in 1911 distinguished the stages of consistency; that is liquid, plastic, semi-solid and solid states
- The water contents at which the soil passes from one of these states to the next have been arbitrarily designated as consistency limits or Atterberg limits (Liquid limit, plastic limit and shrinkage limit

Consistency of Clay Soils Cont'

- Plasticity of a fine-grained soil is the ability of a soil to undergo unrecoverable deformation without cracking or rupture or crumbling
- Depending on its water content soil may exist in Liquid, Plastic, Semi-solid and Solid states
- If the water content of a soil initially in the liquid state is gradually reduced, the state will change from liquid through plastic and semi-solid accompanied by gradual reduction in volume until the solid state is reached
- The water contents at which the transitions between states occur differ from soil to soil
- The upper and lower limits of the range of water content over which the soil exhibits plastic behavior are defined as liquid limit (LL) and plastic limit (PL)

Consistency of Clay Soils Cont'

- **The liquid limit (LL) -**Is the arbitrary limit of water content above which the soil moves from plastic state to liquid state.
  - Minimum moisture content at which the soil tends to flow as a liquid
- **The plastic limit (PL) -** Is the arbitrary limit of water content at which the soil tends to pass from the plastic state to the semi-solid state of consistency.
  - Minimum water content at which the change in shape of the soil is accompanied by visible cracks when worked upon
- **The Shrinkage Limit (SL)** – Is the arbitrary limit of water content at which the soil tends to pass from the semi-solid to the solid state.
  - It is the maximum moisture content at which the volume of the soil remains constant regardless of further drying.
- **Plasticity Index (PI)** – Is the range of water content within which the soil exhibits plastic properties. **PI = LL-PL**

Consistency of Clay Soils Cont'

- **Liquidity Index, I_L or LI** – This is also referred to as the water-plasticity ratio, and is the ratio of the difference between the natural water content and the plastic limit to the plasticity index.
  - $LI = \frac{w - PL}{PI}$
  - If LI > 1, the soil is in the liquid state
  - If LI < 0, the soil is in semi-solid state and is stiff

Plasticity Characteristics

Plasticity Index (PI)	**Plasticity**
0	Non-plastic
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	High Plasticity
>40	Very high plasticity

Source: Burmister, 1947

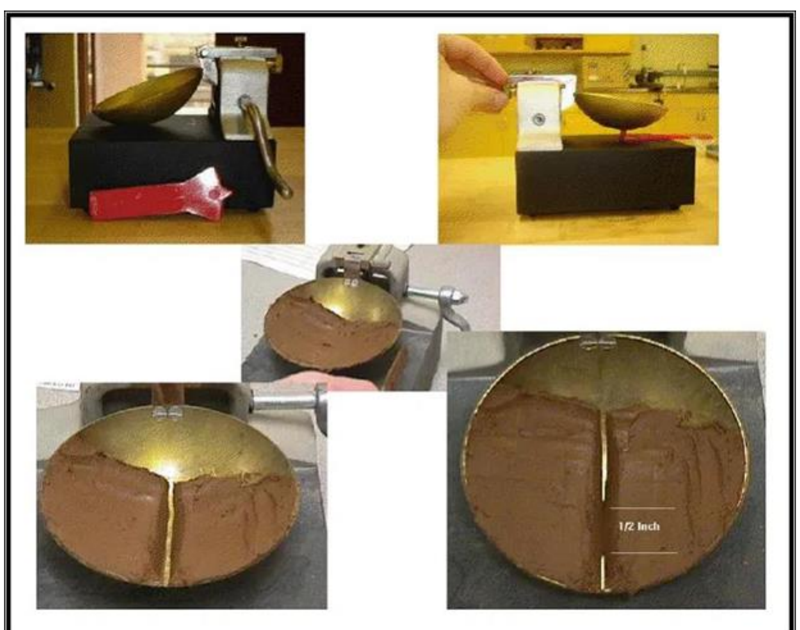
Laboratory methods for the determination of consistency limits

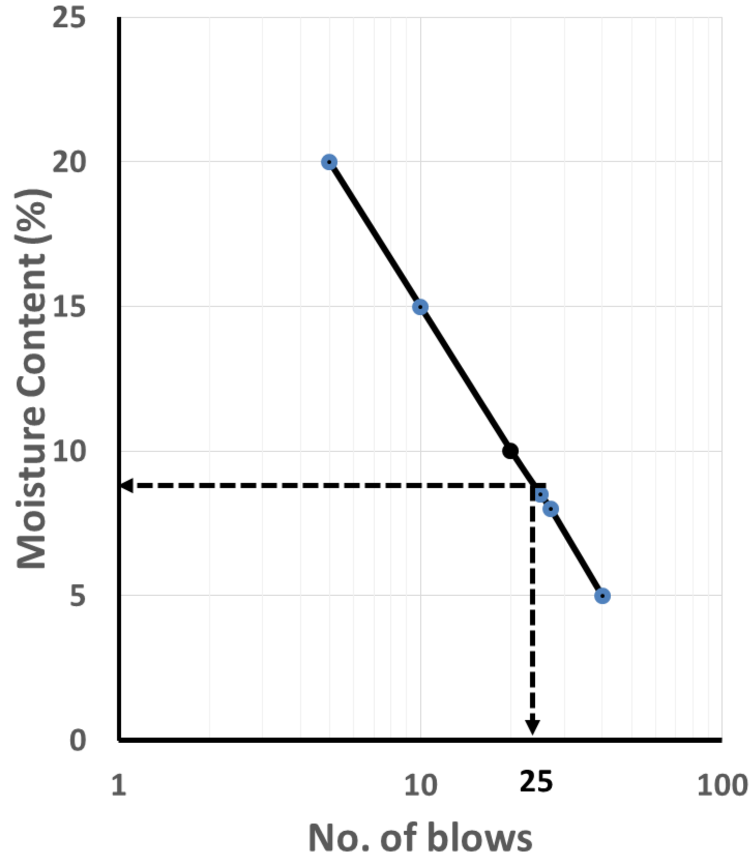
- The procedures for determining consistency limits are fully described in BS 1377 part 2, 1990
- **Sample preparation**
- The soil sample is dried sufficiently
- Crumbled and broken up using a mortar and rubber pestle
- Sieved through a 425µm (0.425mm) BS test sieve
- Material passing the sieve is used for the test
- **The liquid limit test**
  - May be done using
    - The Cassgrande apparatus-proposed by Arthur Cassagrande
    - The cone penetrometer apparatus

The Liquid Limit (LL)

- **The Cassagrande Method**
  - The soil sample passing 0.425mm BS test sieve is poured on a glass plate
  - The soil is homogeneously mixed with a measured quantity of distilled water using palate knives
  - The homogeneous mix is put on Cassagrande apparatus cup
  - A grooving tool is then used to cut a grove at the middle of the cup
  - The handle of the apparatus is then used to raise the cam up and then down onto the rubber base of the apparatus exerting a blow on the cup
  - The cranking is done at 2 rotations per second
  - As the blows continue, the middle of the cup closes
  - When the middle of the cup is closed about 13mm, the number of blows is recorded and a small amount of the wet soil is taken for moisture content determination
  - The amount of water for mixing is increased and the test is repeated 4 times
  - The results is then plotted in a semi-logarithmic graph (log x-axis), and the moisture content corresponding to 25 blows is taken as the liquid limit.

The Cassagrande Method





The Cone Penetrometer Method

- The apparatus is a Cone Penetrometer consisting of a stainless steel 30^o Cone and 35mm coned depth
- Soil is mixed with distilled water to form a thick homogeneous paste
- Some paste is placed in a cylindrical metallic cup 55mm internal diameter by 40mm deep and levelled off at the rim of the cup to give a smooth surface
- The cone is lowered so that it just touches the surface of the soil paste in the cup
- The cone is then released to penetrate the soil paste for 5 seconds, and the depth of penetration is noted
- A little paste is put in a moisture content tin and its moisture content is determined.
- The soil in the cup is then removed, a little more water is added and the test is repeated 4 times at different moisture contents

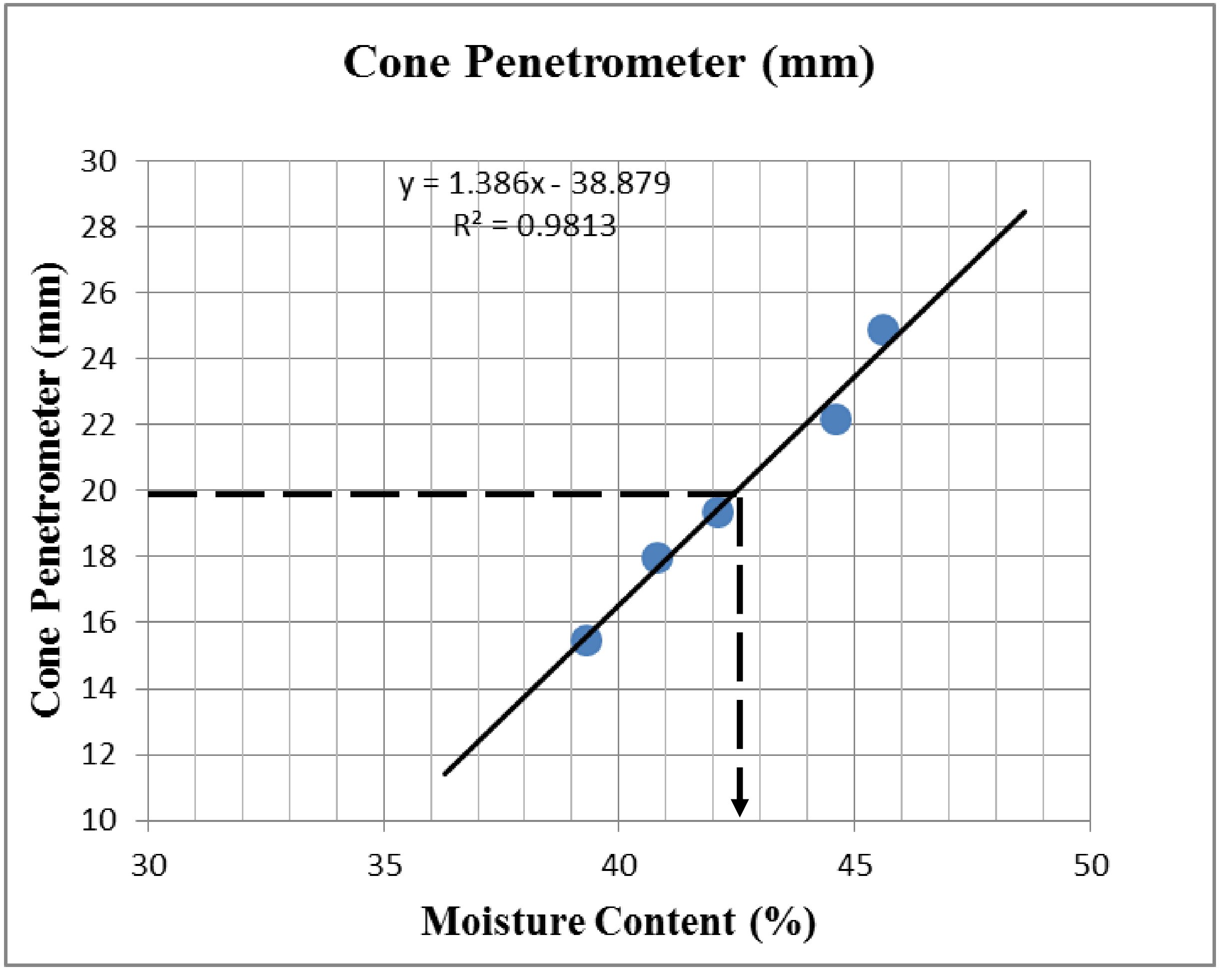
The Cone Penetrometer Method Cont’

- The penetration values should cover a range of approximately 15-25 mm (i.e from drier to wetter state of the soil)
- Moisture content is determined at each penetration test
- Cone penetration is plotted against moisture content and the best straight line fitting the plotted points is drawn
- The moisture content corresponding to 20 mm penetration is taken as the liquid limit (LL) of the soil sample.

The Cone Penetrometer Apparatus

The Cone Penetrometer Method Cont’

- Results of a Cone Penetrometer test



The Plastic Limit (PL) Test

- A soil with a moisture content on the dry side of the liquid limit is rolled with the palm of the hand on a glass plate till it begins to crumble at about 3 mm diameter.
- The pieces of crumbled soil is put in a moisture content tin and its moisture content is determined
- The moisture content test is done in pairs

The Plastic Limit (PL) Test Cont’

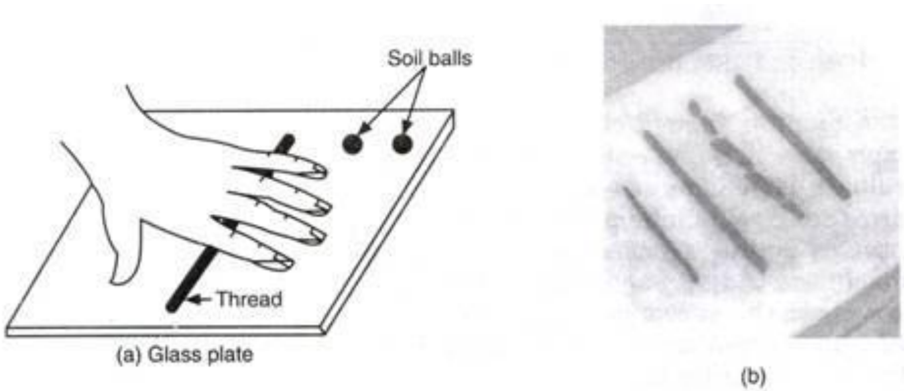


FIG. 3.17 (a) Plastic limit test (b) Cylinder rolling process

Shrinkage Limit (SL) Test

- The soil at a liquid limit moisture content is put in the shrinkage mould whose length is known
- It is then placed in the oven at 105^{o}C for 24 hrs, and its shrinkage limit is determined from
- $SL = \frac{Original\ Length - Length\ after\ oven\ drying}{Length\ after\ oven\ drying}$X100%
- Shrinkage limit can as well be done by weight of the sample. Thus
- $SL = \frac{Wet\ weight - weight\ after\ oven\ drying}{weight\ after\ oven\ drying}$X100%

Shrinkage Limit (SL) Test Cont'

Homogeneously mixed soil on a glass plate

Shrinkage Limit (SL) Test Cont’

(a) Shrinkage limit test mould

Sample after oven drying

(b) SL mould with sample

(d) Soil sample ready for measurement

Lab Work

- Determine atterberg limits
  - Liquid limit (LL)
  - Plastic limit (PL)
  - Plasticity Index (PI)
  - Shrinkage limit (SL)

End

Thank you