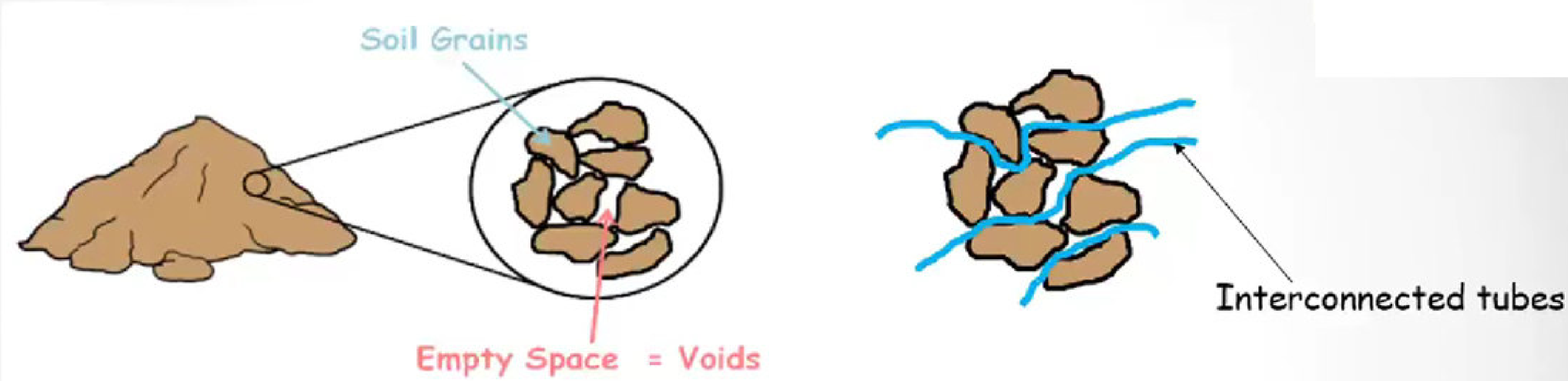
PERMEABILITY OF SOIL

PERMEABILITY OF SOIL



Whenever there is ***head difference*** between two points, ***water flows*** through these tubes.

Permeability is the property of the soil which permits flow of water through its inter-connecting voids.

Or

It is the ease with which water can flow through soil.

HYDRAULIC HEAD

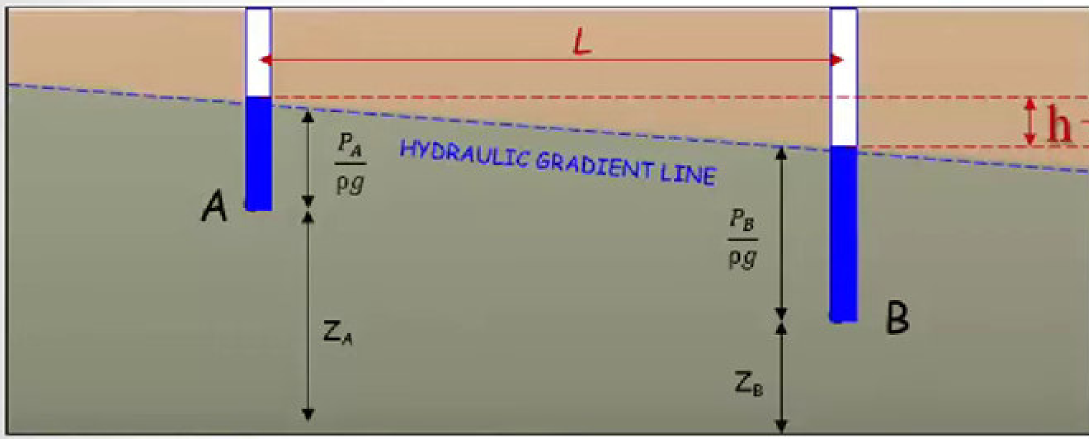
From Bernoulli's principle,

Total Head/Energy = Velocity head + Pressure head + Datum head

Negligible in flow through soil

So in soil Engineering,

Total Head/Energy = Pressure head + Datum head



h → *Head causing flow* → **HYDRAULIC HEAD**

Loss of head per unit Length ⟷ Hydraulic Gradient, i

Hydraulic Gradient, $i = \frac{h}{L}$

If, Head @ A, $h_A = \frac{P_A}{\rho g} + Z_A$ > Head @ B, $h_B = \frac{P_B}{\rho g} + Z_B$

- *Water Flows from A to B*

DARCY'S LAW


Henry Darcy

For Laminar flow conditions in a homogeneous soil, the **rate of flow (v)** is proportional to **hydraulic gradient (i).**

$$v \propto i$$

$$v = k\, i$$

COEFFICIENT OF PERMEABILITY

Velocity at unit hydraulic gradient

Unit m/s, cm/s, mm/s

If A is the area of cross section of soil,

Discharge of water through soil, $q = vA = kiA$

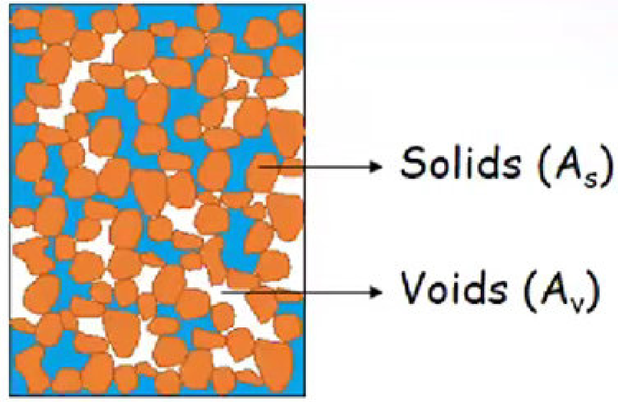
$$\boxed{v = ki} \qquad \boxed{q = kiA}$$

We have,

$q = v A$

Velocity of flow,

$$\boxed{v = \frac{q}{A}}$$



Total Area, $A = A_s + A_v$

DISCHARGE VELOCITY

- Velocity of flow corresponding to **total** cross sectional **area.**

$$v = \frac{q}{A}$$

- Velocity represented in Darcy's Equation
- Not actual velocity – **Superficial velocity**

SEEPAGE VELOCITY

- Velocity of flow corresponding to **area of voids.**

$$v_s = \frac{q}{A_v}$$

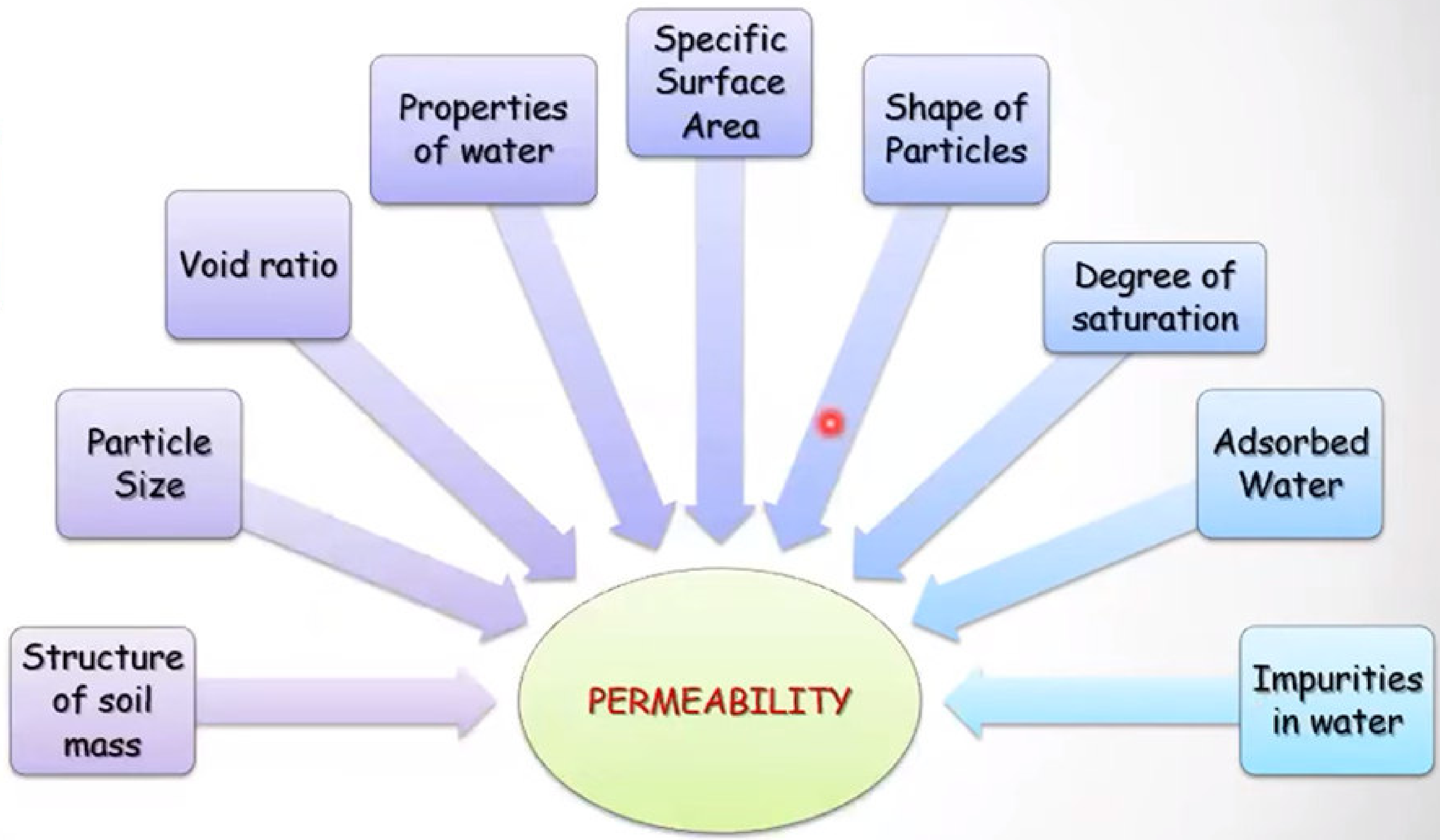
- Flow takes place only through voids
- Hence **actual velocity**

$$v_s = \frac{v}{n} \Rightarrow \textit{Seepage Velocity } (v_s) > \textit{Discharge Velocity } (v)$$

FACTORS AFFECTING PERMEABILITY

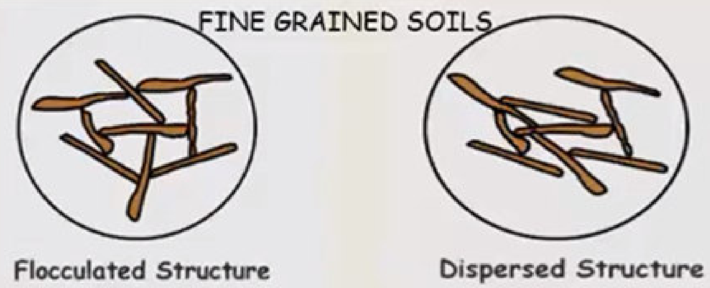
$$k = C\, D_{10}^{2}\, \frac{e^3}{1+e}\, \frac{\gamma_w}{\mu}$$

k	:	Coefficient of permeability
C	:	Constant depending on shape of conduit
D_{10}	:	Effective size
e	:	Void ratio
γ_w	:	Unit weight of water
μ	:	Viscosity of water



$$k = C\, D_{10}^2 \frac{e^3}{1+e} \frac{\gamma_w}{\mu}$$

1. STRUCTURE OF SOIL MASS



- Flocculated structure has more voids compared to dispersed structure.
- More the voids more the permeability.
- Hence soil with flocculated structure has more permeability
- Shrinkage cracks, fissures etc. influence permeability of soil.

$$k = C\,D_{10}^2 \frac{e^3}{1+e}\,\frac{\gamma_w}{\mu}$$

2. SIZE OF PARTICLES

- As size of particles increases, permeability also increases.

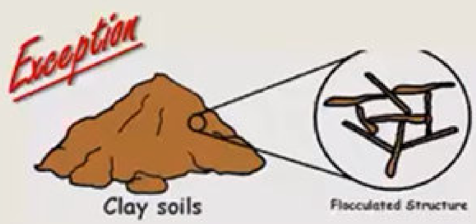
- Coarse grained soil has more voids connected and hence higher permeability.
- Fine grained soil has poorly connected voids and hence lesser permeability.

$$k = C\,D_{10}^2 \frac{e^3}{1+e} \frac{\gamma_w}{\mu}$$

3. VOID RATIO

$$\text{Void ratio} = \frac{\text{Volume of voids}}{\text{Volume of solids}}$$

- More the void ratio, more is the volume of voids.
- More the volume of voids, more is the permeability.
- Generally, permeability increases with increase in void ratio.



- Clayey soil has more void ratio.
- But the flow paths are smaller and poorly connected.
- So lesser permeability.

$$k = C\, D_{10}^2 \frac{e^3}{1+e} \frac{\gamma_w}{\mu}$$

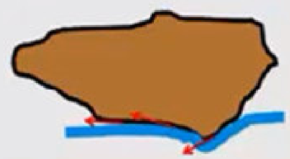
4. PROPERTIES OF WATER

- When viscosity of water decreases, permeability increases.
- Viscosity depends on temperature.

- Permeability increases with increase in temperature.

5. SPECIFIC SURFACE AREA

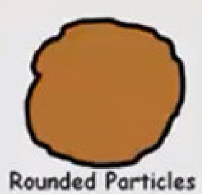
$$\text{Specific Surface Area (SSA)} = \frac{\text{Surface Area}}{\text{Volume of particle}}$$



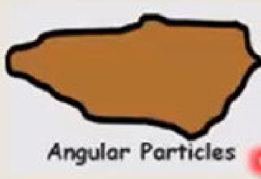
- Surface offers resistance to flow.
- More the resistance, lesser is the permeability.

- Fine grained soil has more specific surface area and hence less permeability.

6. SHAPE OF PARTICLES



- More surface area
- Higher flow resistance
- Lesser permeability



- Less surface area
- Lesser flow resistance
- More permeability

7. DEGREE OF SATURATION

- Partially saturated soil has air entrapped in its voids.
- Entrapped air blocks the flow passage.
- So, partially saturated has lesser permeability than fully saturated soil.

8. ADSORBED WATER

- Fine grained soil has adsorbed water
- Adsorbed water blocks the voids.
- Permeability decreases.

9. IMPURITIES IN WATER

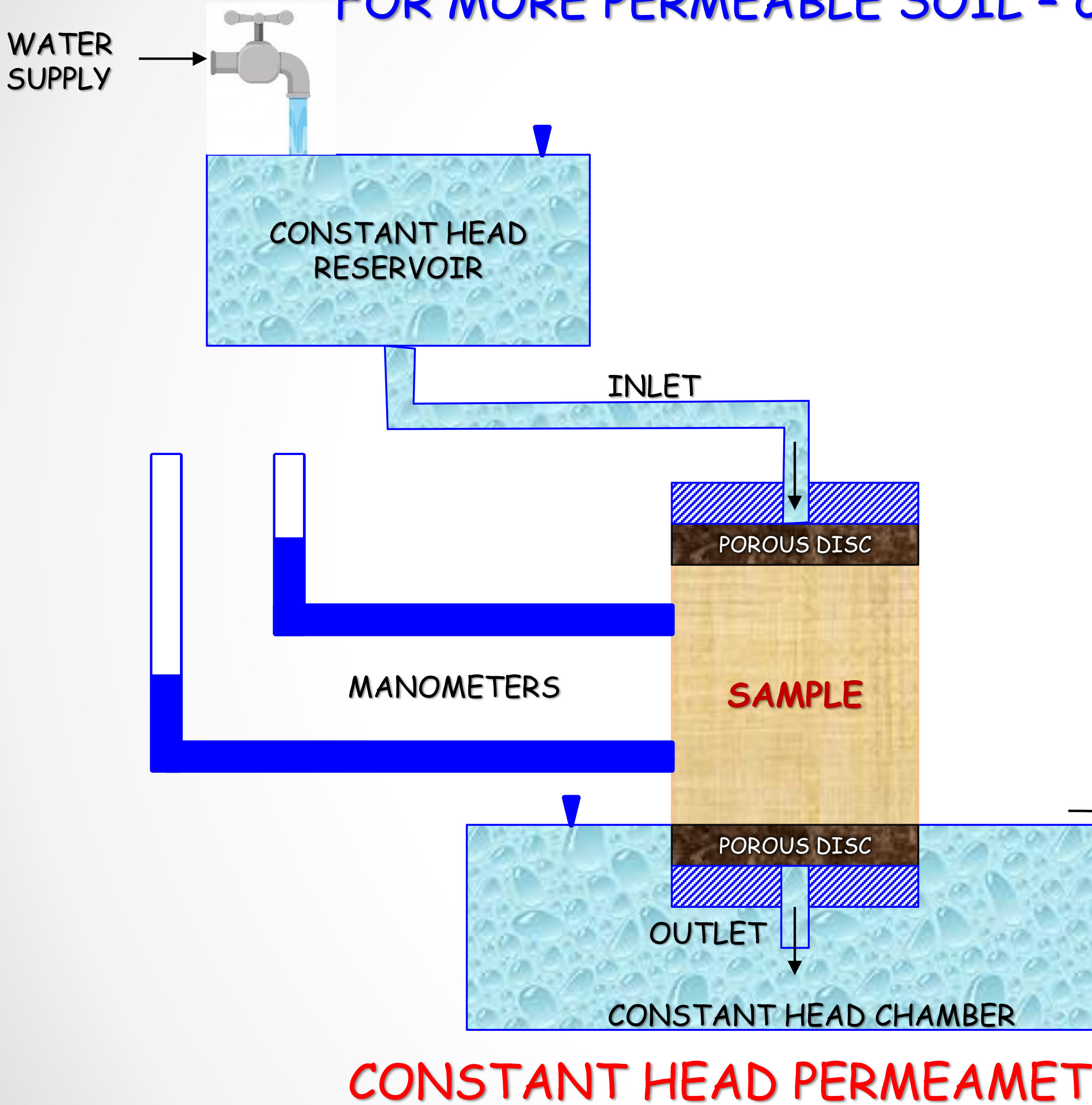
- Impurities in water and organic matter in soil blocks flow path.
- Hence permeability decreases.

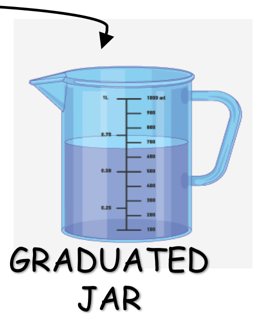
DETERMINATION OF COEFFICIENT OF PERMEABILITY

- METHODS
  - LABORATORY METHODS
    - CONSTANT HEAD PERMEABILITY TEST
    - VARIABLE HEAD PERMEABILITY TEST
    - HORIZONTAL CAPPILARITY TEST
  - FIELD METHODS
    - PUMPING OUT TEST
    - PUMPING IN TESTS
  - INDIRECT METHODS
    - COMPUTATION FROM GRAIN SIZE
    - COMPUTATION FROM CONSOLIDATION DATA

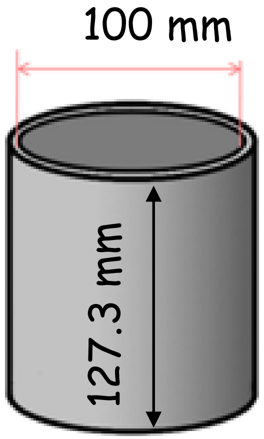
CONSTANT HEAD PERMEABILITY TEST

FOR MORE PERMEABLE SOIL – COARSE GRAINED SOIL





CONSTANT HEAD PERMEAMETER



Metallic Mould for Sample (1000 mL)

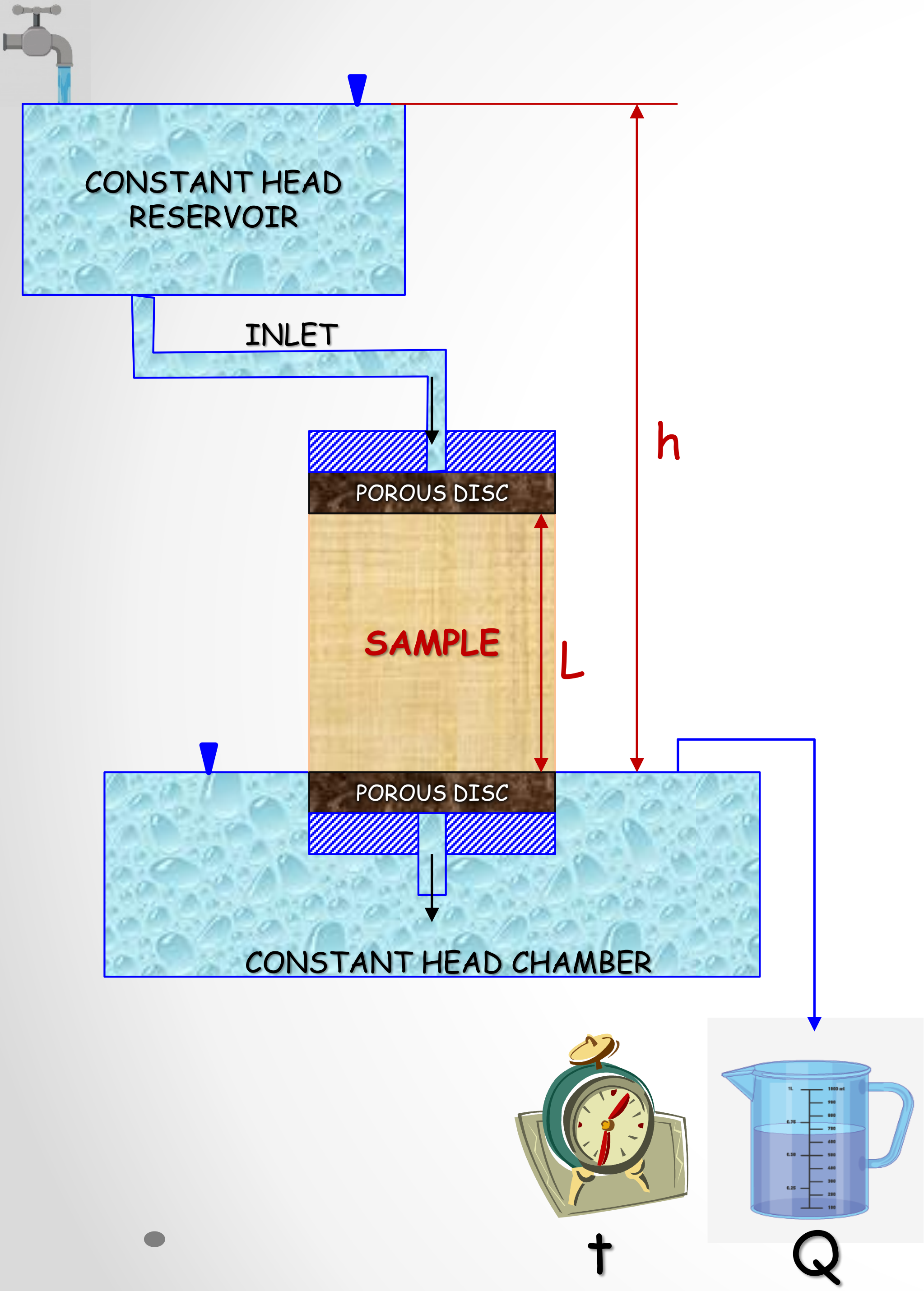
SAMPLE

1. Undisturbed.

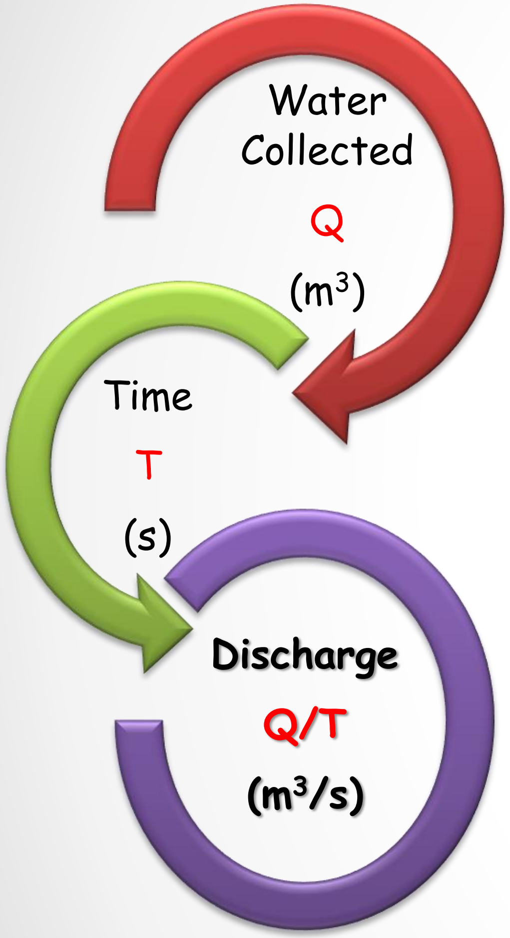
or

2. Compacted to field density

- Porous disc should have **porous stone** of permeability **ten times** than that of soil.



1. Soil **specimen of length 'L'** is kept in a mould between two porous discs.
2. Water is passed through the sample from a **reservoir** with **constant water level**.
3. The sample is placed in **a constant head chamber**.
4. Head difference **'h'** between reservoir and chamber **causes flow.**
5. The **overflow water** is collected in a **graduated cylinder.**
6. The quantity of water collected **Q'** in time **'t'** is noted.



From Darcy's Law,

$$\text{Discharge, } q = kiA$$

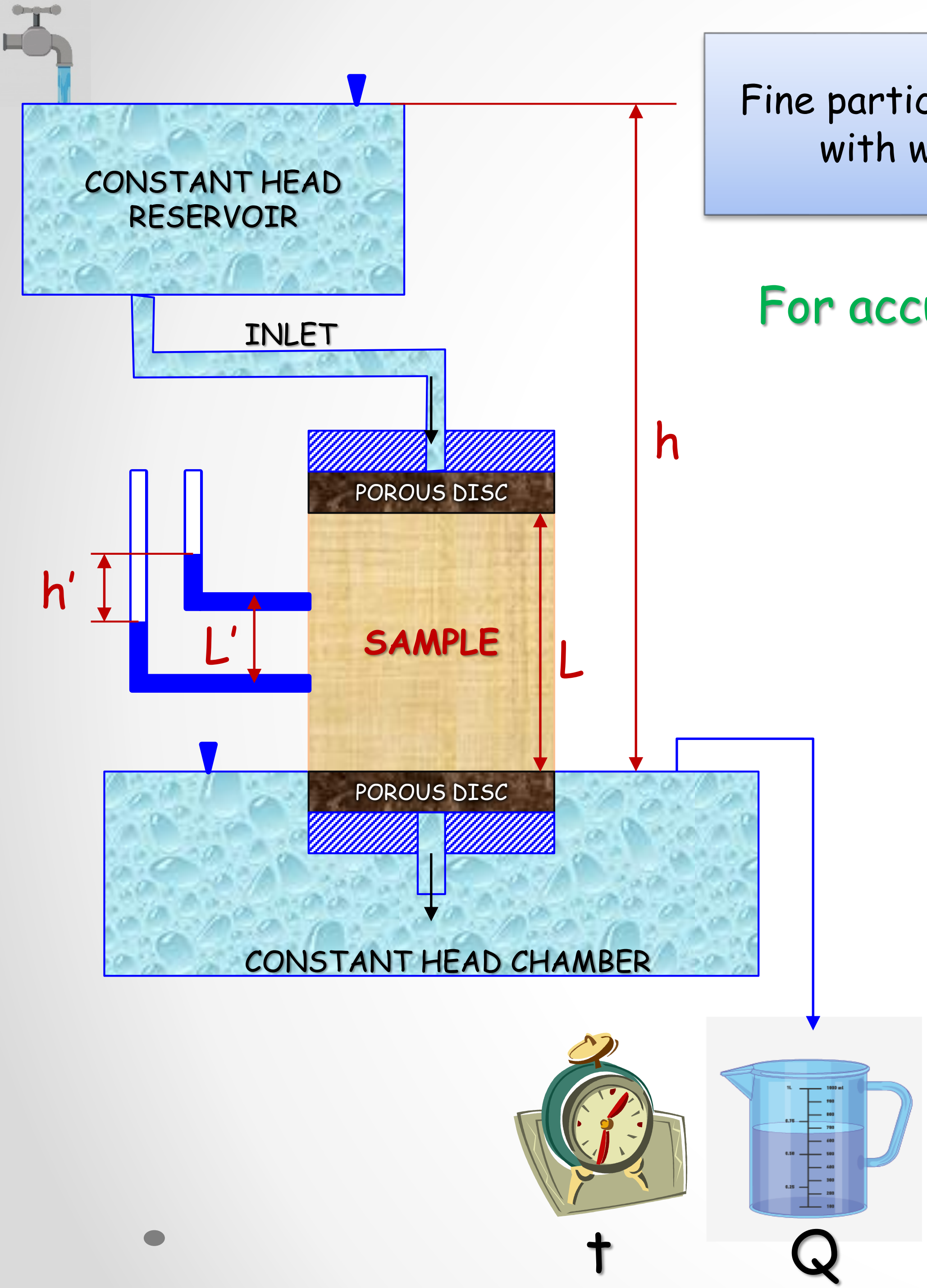
$$= k\frac{h}{L}A$$

$$\text{But, } q = \frac{Q}{T}$$

$$\frac{Q}{T} = k\frac{h}{L}A$$

$$\boxed{k = \frac{QL}{AhT}}$$

k	:	*Coefficient of permeability*
Q	:	*Quantity of water collected*
T	:	*Time for collecting water*
A	:	*Area of cross section of sample*
L	:	*Length of specimen*
h	:	*Head causing flow*



Fine particles flows with water → Settles at the ends of sample → Permeability different at ends

For accuracy permeability at centre is needed !!!

7
- Connect **two manometers at the middle** of the sample at a distance L'.

8
- The **loss of head** measured by manometer at the centre of sample is h'.

$$\text{Here, } i = \frac{h'}{L'}$$

$$\text{So, } \boxed{k = \frac{QL'}{Ah'T}}$$

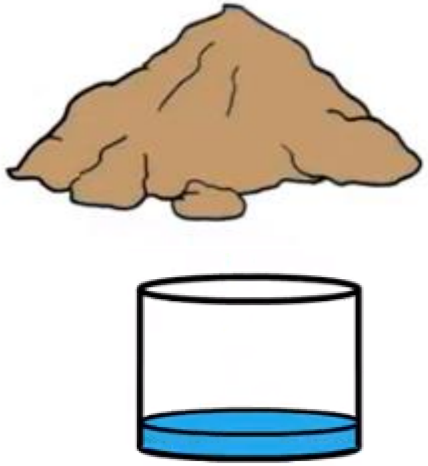
FALLING HEAD PERMEABILITY TEST

FOR LESS PERMEABLE SOIL – FINE GRAINED SOIL

COARSE GRAINED SOIL

- More interconnected voids
- Sufficient amount of water can be drained in small time

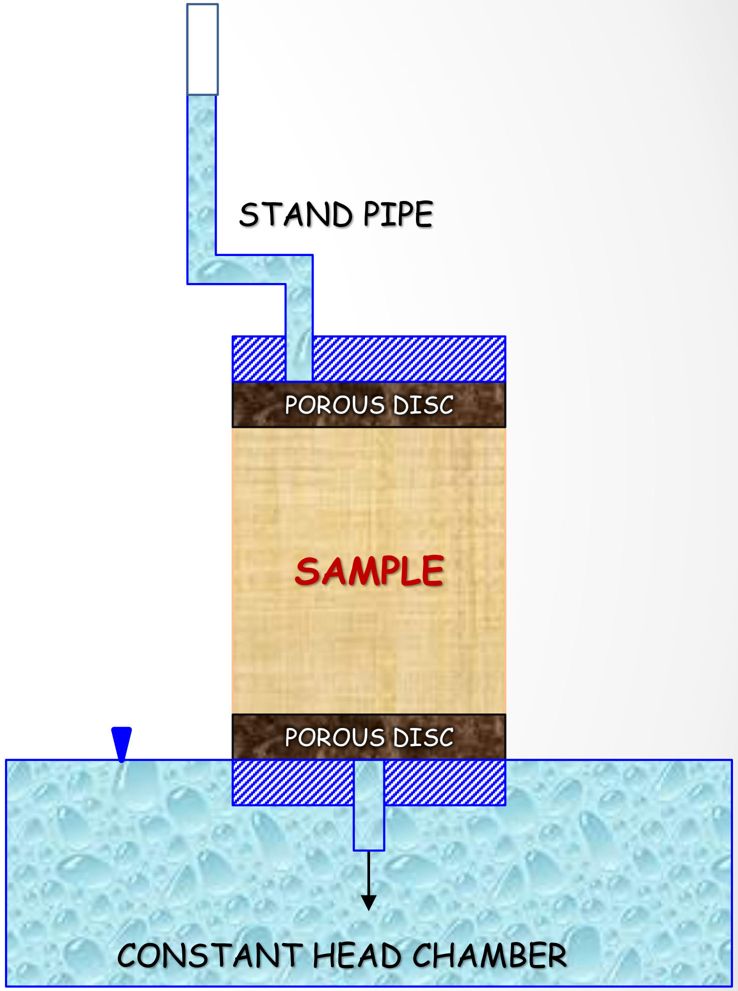
FINE GRAINED SOIL



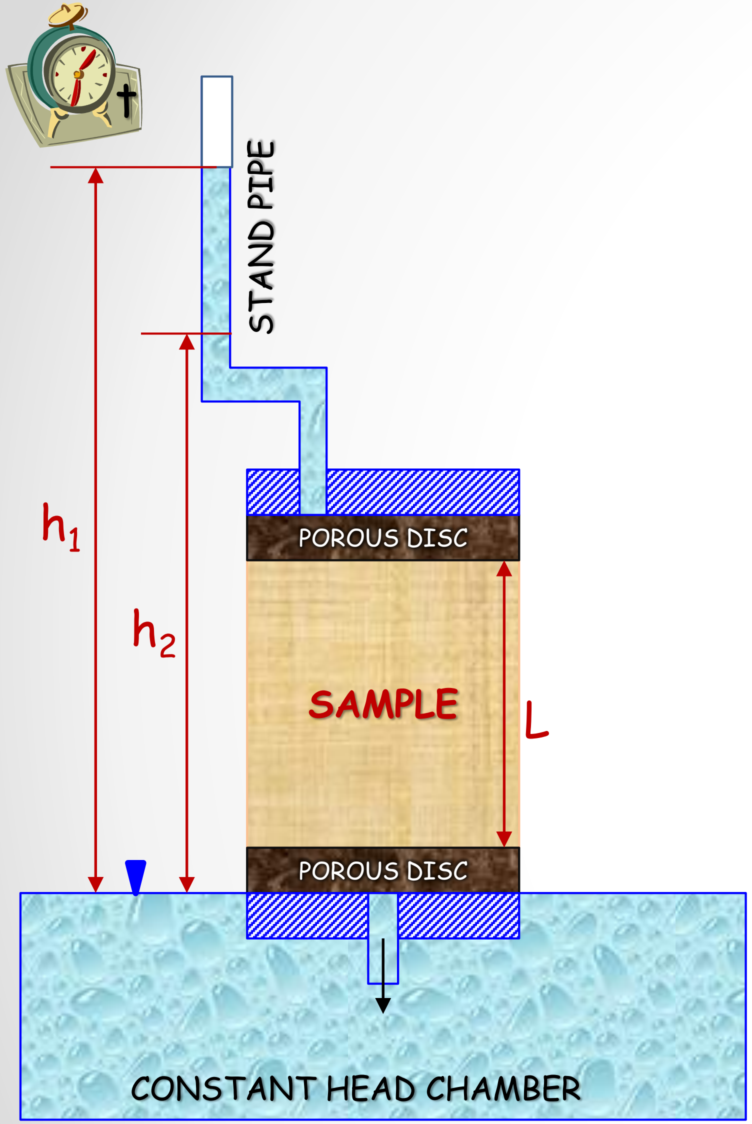
- Lesser interconnected voids
- Small amount water only can be drained

~~CONSTANT HEAD PERMEABILITY TEST~~

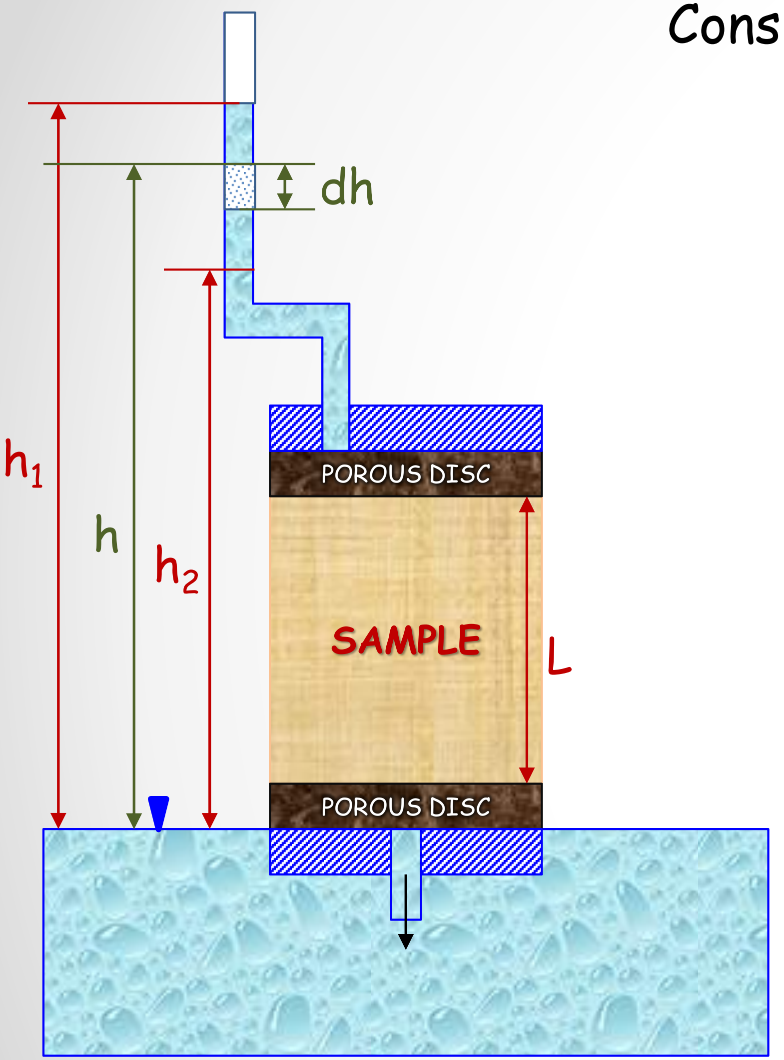
VARYING HEAD PERMEABILITY TEST



VARIYING HEAD PERMEAMETER



1. Soil specimen of length 'L' and area 'A' is kept in a mould between two porous discs. (Same as before)
2. A vertical stand pipe of area 'a' is fitted to top of sample.
3. The whole assembly is placed in a constant head chamber.
4. The soil is allowed get fully saturated.
5. The water in the stand pipe flows through the soil and overflows through the constant head chamber.
6. The water level in stand pipe falls from h_1 to h_2 in time t.



Consider an instant at which head is ‘h’.

- At an infinitely small time dt head falls by dh,

Velocity of fall, $v = -\dfrac{dh}{dt}$

(- ve as head decreases with time)

- Now flow at this instant , $q = a*v = -a\dfrac{dh}{dt}$ ……………(1)

- From Darcy’s Law flow through soil,

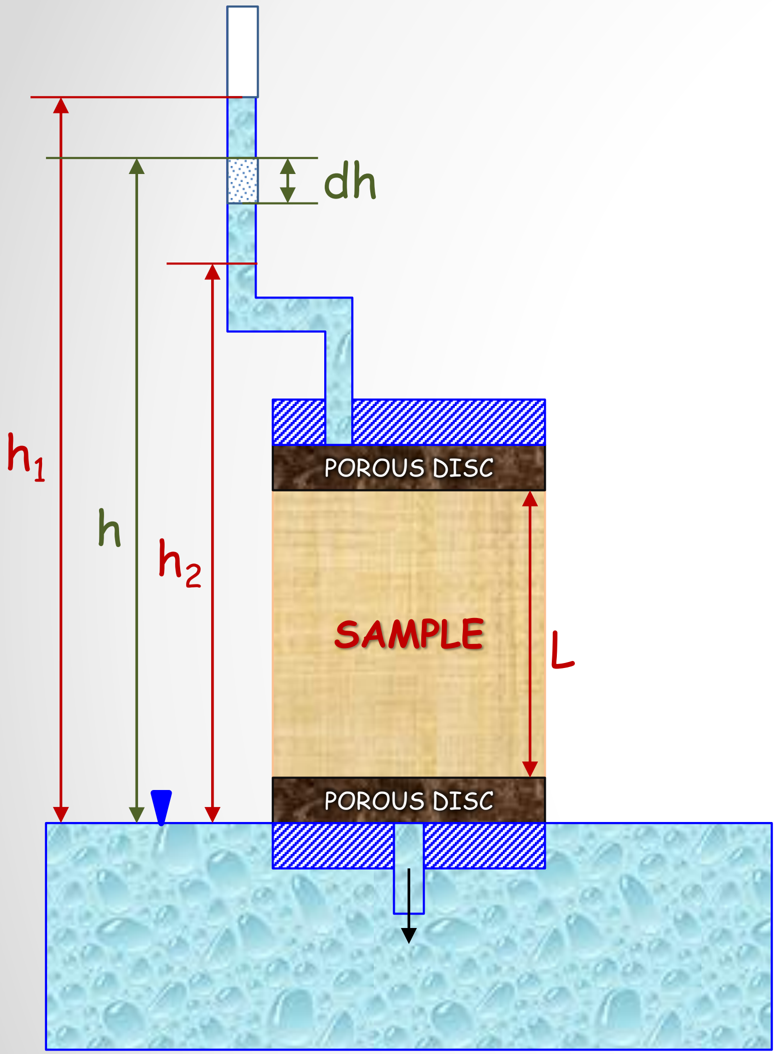
$$q = kiA = k\frac{h}{L}A \quad ………………(2)$$

(as i =h/L)

- Equating (1) and (2),

$$k\frac{h}{L}A = -a\frac{dh}{dt}$$

$$\frac{Ak}{aL}dt = -\frac{dh}{h}$$



$$\frac{Ak}{aL}\,dt = -\frac{dh}{h}$$

Head falls from h_1 to h_2 in time t ($t = t_1 - t_2$)

Integrate!!!

$$\frac{Ak}{aL}\int_{t1}^{t2} dt = -\int_{h1}^{h2}\frac{dh}{h}$$

$$\frac{Ak}{aL}\,[t]_{t_1}^{t_2} = -[\ln h]_{h_1}^{h_2}$$

$$\frac{Ak}{aL}\,(t_2 - t_1) = \ln\left(\frac{h_1}{h_2}\right)$$

Rearranging,

$$\boxed{k = \frac{aL}{At}\ln\left(\frac{h_1}{h_2}\right)}$$

$$\boxed{k = \frac{2.303\,aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)}$$

k	:	*Coefficient of permeability*
A	:	*Cross sectional area of the soil sample*
a	:	*Cross sectional area of stand pipe*
L	:	*Length of specimen*
t	:	*Time for head to fall from h_1 to h_2*
h_1	:	*Initial head*
h_2	:	*Final head*

1. In a constant head permeability test, following observations was taken.

Distance between manometer toppings = 100 mm
Difference of levels in manometer = 60 mm
Diameter of test sample = 100 mm
Quantity of water collected = 350 mL
Duration of the test = 270 s.

Calculate coefficient of permeability in cm/sec.

SOLUTION

Coefficient of permeability, $k = \frac{QL'}{Ah'T}$

$L' = 100 \text{ mm} = 10 \text{ cm}$

$d = 100 \text{ mm} = 10 \text{ cm}$

$A = \frac{\pi}{4} d^2 = \frac{\pi}{4} 10^2 = 78.54\ cm^2$

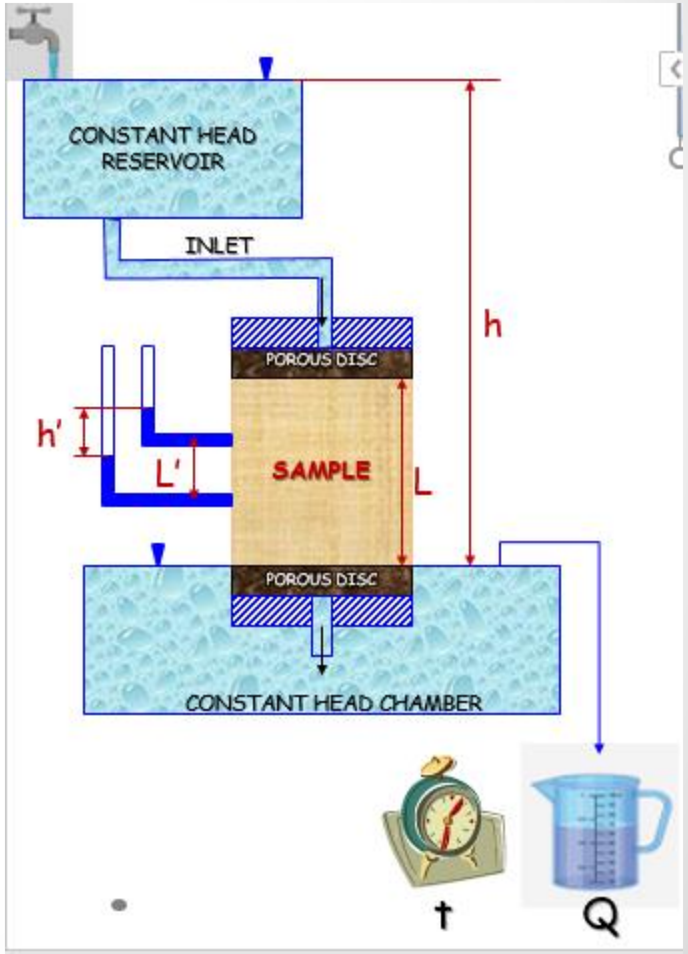
$h' = 60 \text{ mm} = 6 \text{ cm}$

$T = 270 \text{ s}$

$Q = 350 \text{ mL} = 350 \text{ cm}^3$

1000 L = 1 m^3 : 1 mL = 1 cm^3

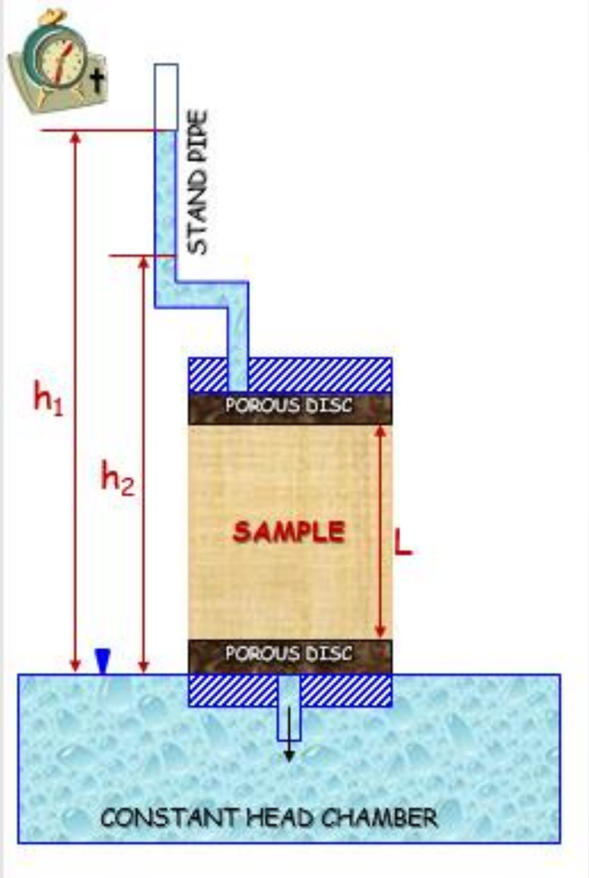
So, $k = \frac{350 \times 10}{78.54 \times 6 \times 270}$ = 0.0275 cm/s



2. The falling head permeability test was conducted on a soil sample 4 cm diameter and 18 cm length . The head fall from 1.0 m to 0.4 m in 20 minutes. If the cross sectional area of stand pipe was 1 cm^2, determine the coefficient of permeability.

SOLUTION

$$k = \frac{aL}{At} \ln\left(\frac{h_1}{h_2}\right)$$



a = 1 cm^2

L = 18 cm

d = 4 cm

$A = \frac{\pi}{4} d^2 = \frac{\pi}{4} 4^2 = 12.56\, cm^2$

t = 20 minutes

h_1 = 1 m

h_2 = 0.4 m

Coefficient of permeability, $k = \frac{1 \text{ x } 18}{12.56 \text{ x } 20} \ln\left(\frac{1}{0.4}\right)$

= 0.0657 cm/min

Example 6.15 The following data were recorded in a constant head permeability test:

Internal diameter of permeameter = 7.5 cm

Head lost over a sample length of 18 cm = 24.7 cm

Quantity of water collected in 60 seconds = 626 ml.

Porosity of the soil sample = 44%

Calculate the coefficient of permeability of the soil. Also, determine the discharge velocity and the seepage velocity during the test.

Solution:

Area of soil sample, $$A = \frac{\pi}{4}.d^2 = \frac{\pi}{4}\times(7.5)^2 = 44.18\text{ cm}^2$$

$$H = 24.7\text{ cm},\ L = 18\text{ cm},\ t = 60\text{ sec}$$

∴ Hydraulic gradient, $$i = \frac{H_L}{L} = \frac{24.7}{18} = 1.372$$

Discharge, $$Q = \frac{V}{t} = \frac{626}{60} = 10.433\text{ cm}^3\text{/s}$$

From Darcy's equation, $$Q = k.i.A$$

$$10.433 = k\times 1.372\times 44.18$$

$$k = 0.172\text{ cm/s}$$

Discharging velocity, $v = \frac{Q}{A} = \frac{10.433}{44.18} = 0.236 \text{ cm/s}$

Given, porosity of soil sample, $n = 0.44$

$\therefore$ Seepage velocity, $v_s = \frac{v}{n} = \frac{0.236}{0.44} = 0.537 \text{ cm/s}$

Example 6.16 In a falling head permeability test, the head causing fall was initially 90 cm, and it drops 6 cm in 15 minutes. How much time is required for the head to fall to 45 cm.

Solution:

We know, the coefficient of permeability under falling head permeability test is given by

$$k = 2.303\frac{aL}{At}\log_{10}\frac{h_1}{h_2}$$

Here, $h_1 = 90$ cm,

$h_2 = 90 - 6 = 84$ cm

and $t_1 = 15$ minutes

Therefore
$$t = 2.303\frac{aL}{kA}\log_{10}\frac{h_1}{h_2}$$

or
$$\frac{2.303\,aL}{kA} = \frac{t}{\log_{10}\left(\frac{h_1}{h_2}\right)}$$

$$\Rightarrow \quad \frac{2.303\,aL}{kA} = \frac{15}{\log_{10}\left(\frac{90}{84}\right)} = 500.61 \text{ minutes} \quad \ldots\text{(i)}$$

Let 'T' be the time interval in which head falls from 90 cm to 45 cm.

Therefore,
$$T = \frac{2.303\,aL}{kA}\log_{10}\frac{h_1}{h_3} = 500.61\times\log_{10}\frac{90}{45}$$

$$= 150.70 \text{ minutes}$$

Example 6.17 A permeameter of 100 mm diameter with a sample length of 30 cm was used for constant head and falling head test. While conducting a constant head test, the loss of head was 120 cm for the soil sample and rate of flow was 3.2 cm^3/s. Find the coefficient of permeability. If a falling head test was performed on the same sample at the same void ratio, find the time taken for the head to fall from 98 cm to 50 cm. The diameter of stand pipe in the falling head test was 25 mm.

Solution:

Constant head test:

$$\text{Area of sample, } A = \pi\left(\frac{100^2}{4}\right) = 7854 \text{ mm}^2$$

$$\text{Hydraulic gradient, } i = \frac{h}{L} = \frac{120}{30} = 4$$

Using, $$q = k.\ i.\ A$$

Therefore, $$k = \frac{q}{i.A} = \frac{3.2\times10^3}{4\times7854} = 0.102 \text{ mm/s}$$

Falling head test

$$\text{Area of stand pipe, } a = \pi\left(\frac{25^2}{4}\right) = 490.9 \text{ mm}^2$$

$$\text{Using, } k = 2.303\frac{aL}{At}\log_{10}\frac{h_1}{h_2}$$

or

$$t = \frac{2.303\, aL}{kA}\log_{10}\frac{h_1}{h_2}$$

$$t = \frac{2.303 \times 490.9 \times 300}{0.102 \times 7854}\log_{10}\left(\frac{98}{50}\right)$$

Q.1 In a falling head permeability test drop in head occurs from 60 m to 40 m in 10 minutes. The cross-sectional area of soil sample and stand pipe is 20 cm^2 and 2 cm^2 respectively. If the length of the soil sample is 15 cm then the permeability of soil sample in mm/sec is

(a) 1.01
(b) 0.12
(c) 0.01
(d) 0.001

Q.4 In a falling head permeability test, the time taken for the head to fall from 27 cm to 3 cm is

10 minutes. If the test is repeated with same initial head, i.e. 27 cm, what time would it take for the head to fall 9 cm

(a) 3 minutes
(b) 5 minutes
(c) 6 minutes
(d) 7.5 minutes

Q 1. A sand sample of 25 cm length was subjected to a constant head permeability test in a permeameter having an area of 30 m^2. A discharge of 100 cm^3 was obtained in a period of 1 minute under a head of 39 cm. Mass of dry sand in the sample was 1350 g. The specific gravity of the sand particles was 2.67.

Determine:

(i) the coefficient of permeability

(ii) the superficial velocity and

(iii) the seepage velocity

[Ans. 0.0356 cm/s, 0.056 cm/s, 0.0183 cm/s]

Q 2. Calculate the coefficient of permeability of a soil sample 8 cm in height and cross sectional area 60 cm^2. It is observed that in 12 minutes, 600 ml of water passed down under as effective constant head of 50 cm. On oven drying, the test specimen weight 750 gm. Taking $G_s = 2.70$, calculate the seepage velocity of water during the test.

[Ans. 2.22×10^{-3} cm/sec, 0.33 cm/sec.]

Q 3. A falling head permeability test was performed on a sand sample and the following data were recorded:

Cross-sectional area of permeameter = 100 cm^2; length of the soil sample = 15 cm; area of the stand pipe = 1cm^2; time taken for the head to fall from 150 cm to 50 cm = 8 min, temperature of water was 25°C. Dry mass of soil specimen = 2.2 kg and G_S = 2.68. Calculate the coefficient of permeability of the soil for a void ratio of 0.70 and standard temperature 20°C.

[Ans. 2×10^{-4} cm/s]

Q 4. The following data were recorded in a constant head permeability test:

Head lost over a sample length of 18 cm = 24.7 cm

Quantity of water collected in 60 seconds = 626 ml

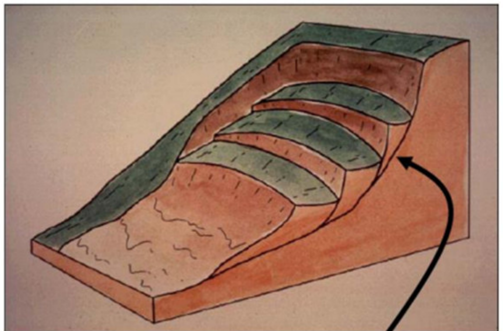
Internal diameter of permeability = 7.5 cm

Porosity of the soil sample = 44%

Calculate the coefficient of permeability of the soil. Also determine the discharge velocity and the seepage velocity during the test.

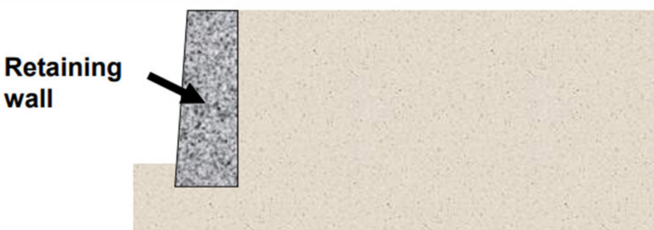
[Ans. [0.172 cm,s 0.236 cm/s, 0.537 cm/s]

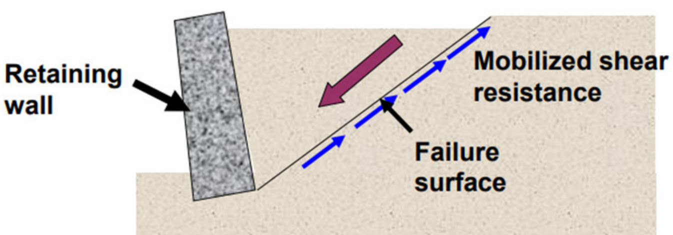
Shear Strength of Soil



Failure due to inadequate strength at shear interface

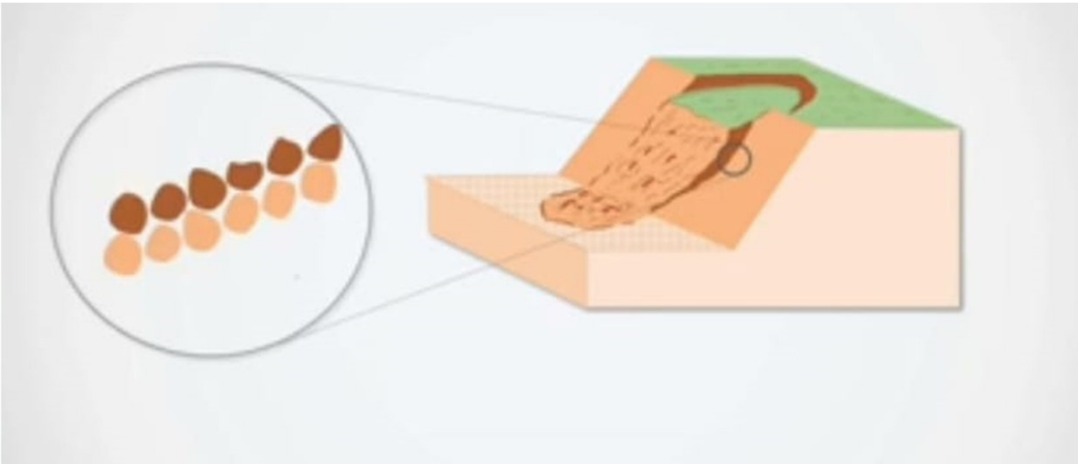
Failure of Retaining Walls

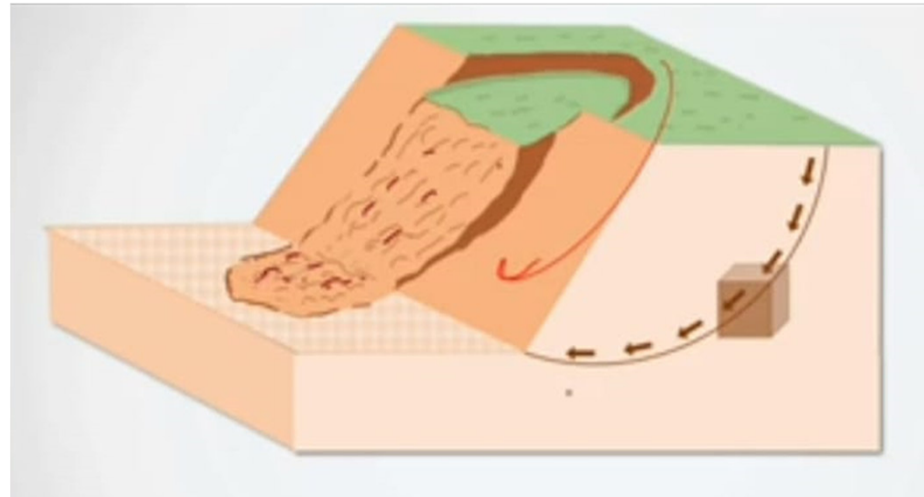


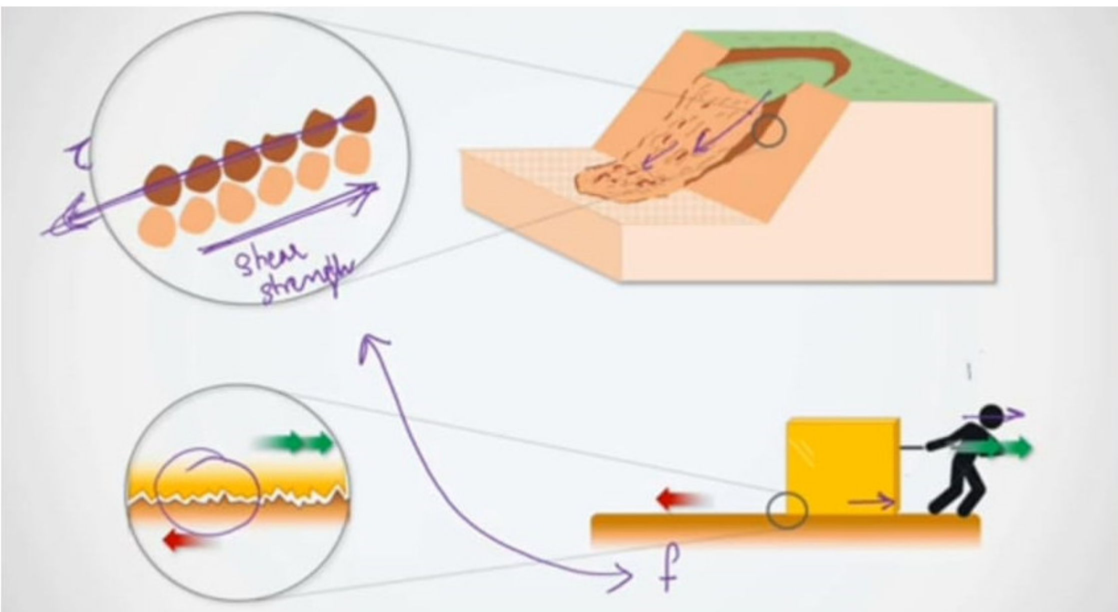


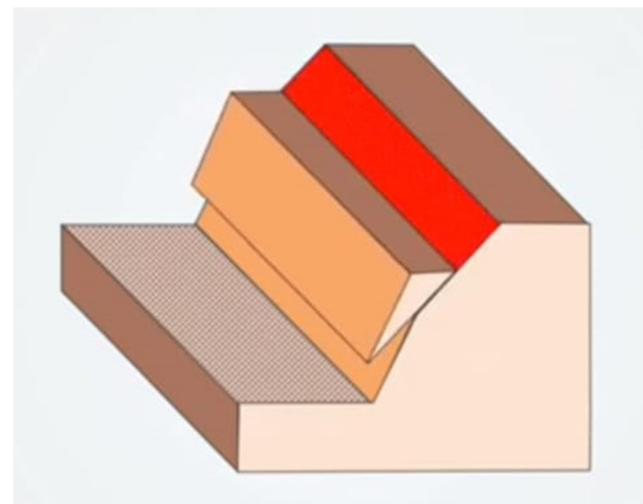
SLOPE FAILURE

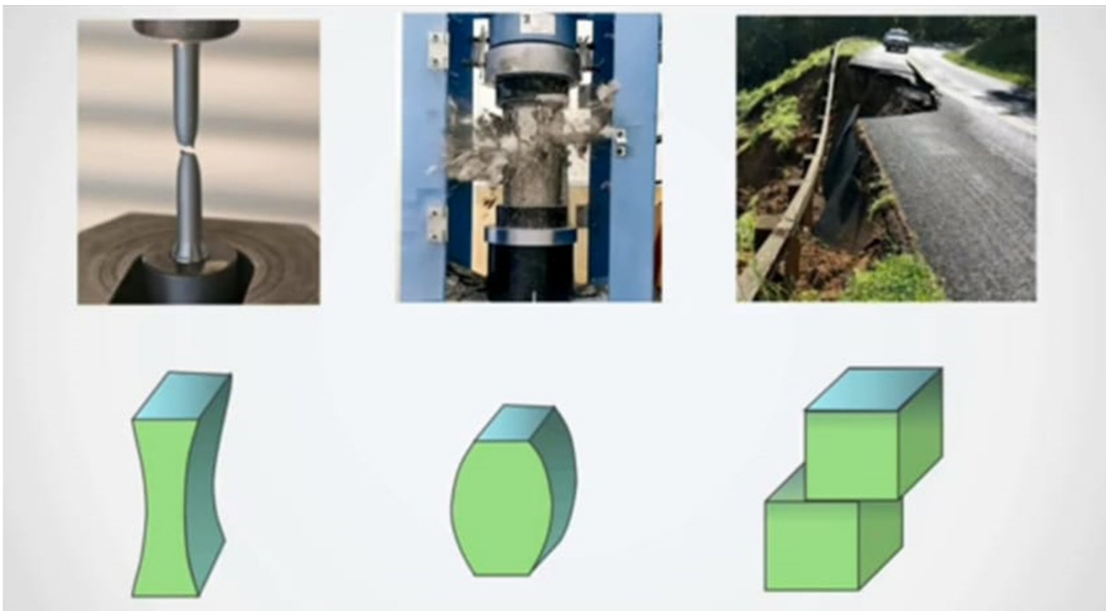

ver





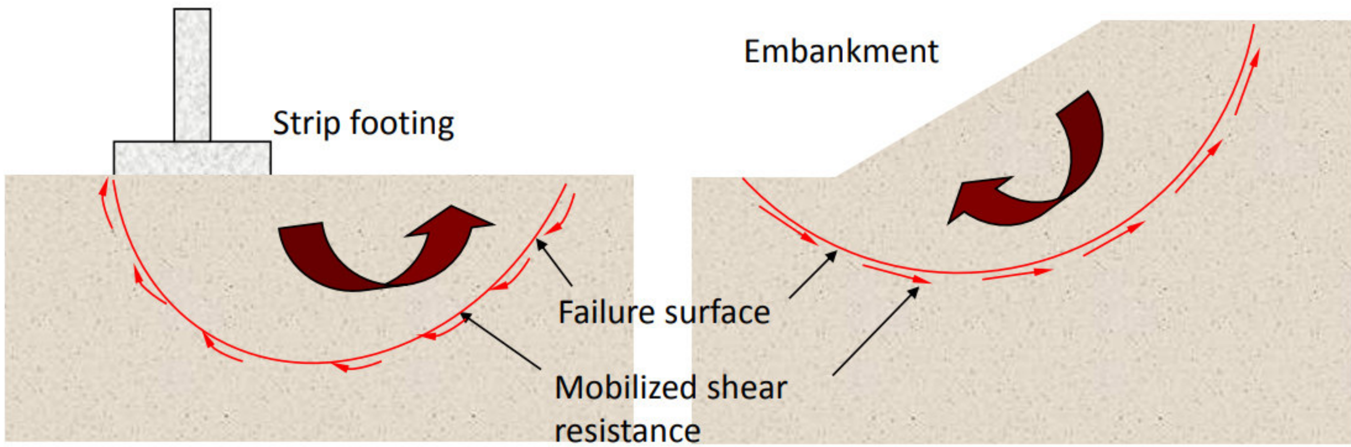

τ
shear strength
f





Shear failure of soils

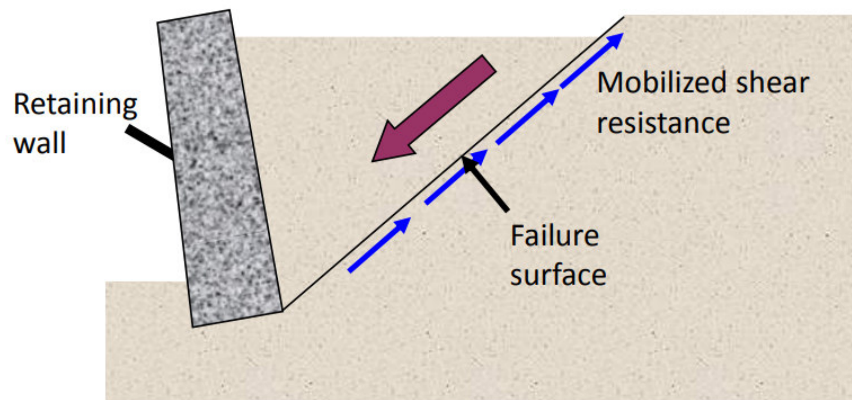
Soils generally fail in <u>shear</u>



At failure, shear stress along the failure surface (mobilized shear resistance) reaches the shear strength.

Shear failure of soils

Soils generally fail in <u>shear</u>



At failure, shear stress along the failure surface (mobilized shear resistance) reaches the shear strength.

What is shear strength of a soil?

- Shear strength is the maximum resistance to shear stresses before failure.
- The shear failure of a soil mass occurs when the shear stresses induced due to the applied compressive loads exceed the strength of the soil.
- It is the maximum value of shear stress that can be mobilised within the soil mass.

- Soil derives it's shearing strength from the following

1. Resistance due to interlocking of particles
2. Frictional resistance between the individual soil grains.
3. Adhesion between soil particles or cohesion.

Significance of Shear Strength :

- Engineers must understand the nature of shearing resistance in order to analyze soil stability problems such as;
    - Bearing capacity
    - Slope stability
    - Lateral earth pressure on earth-retaining structure

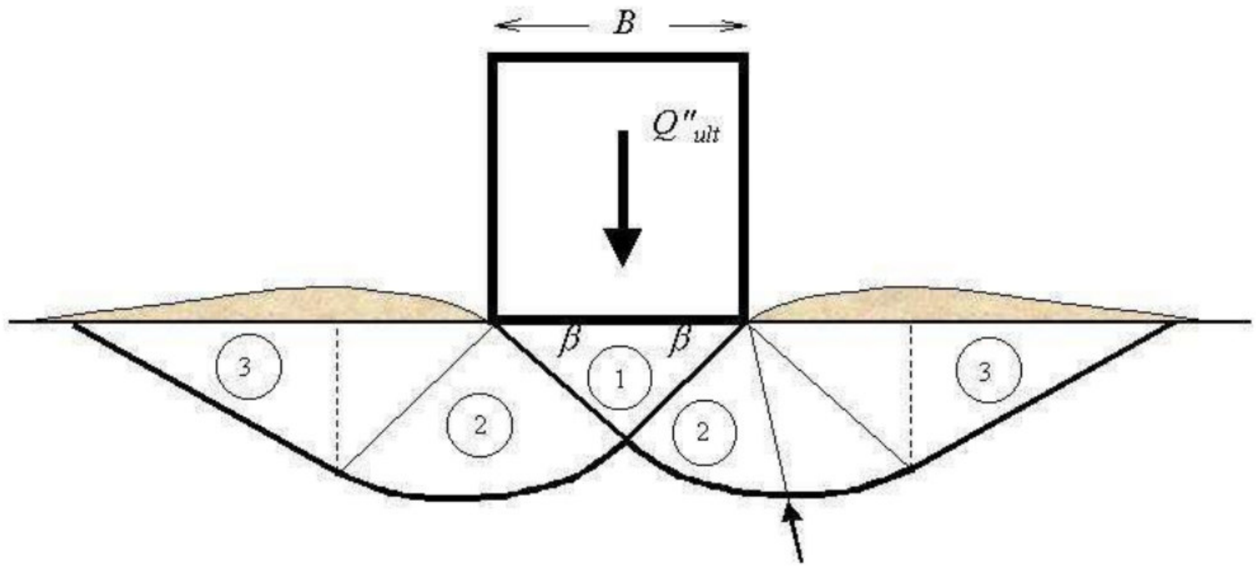
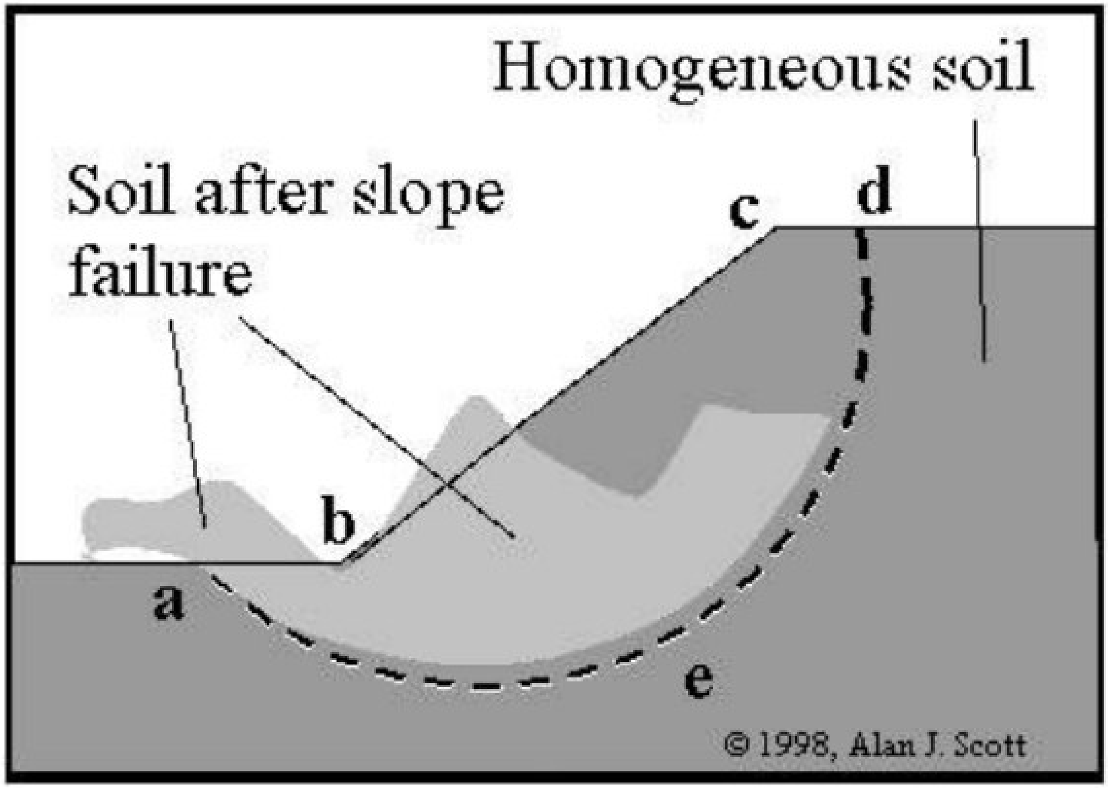


Fig: Shear Failure under Foundation Load



Slope Stability Failure as an Example of Shearing Along Internal Surface

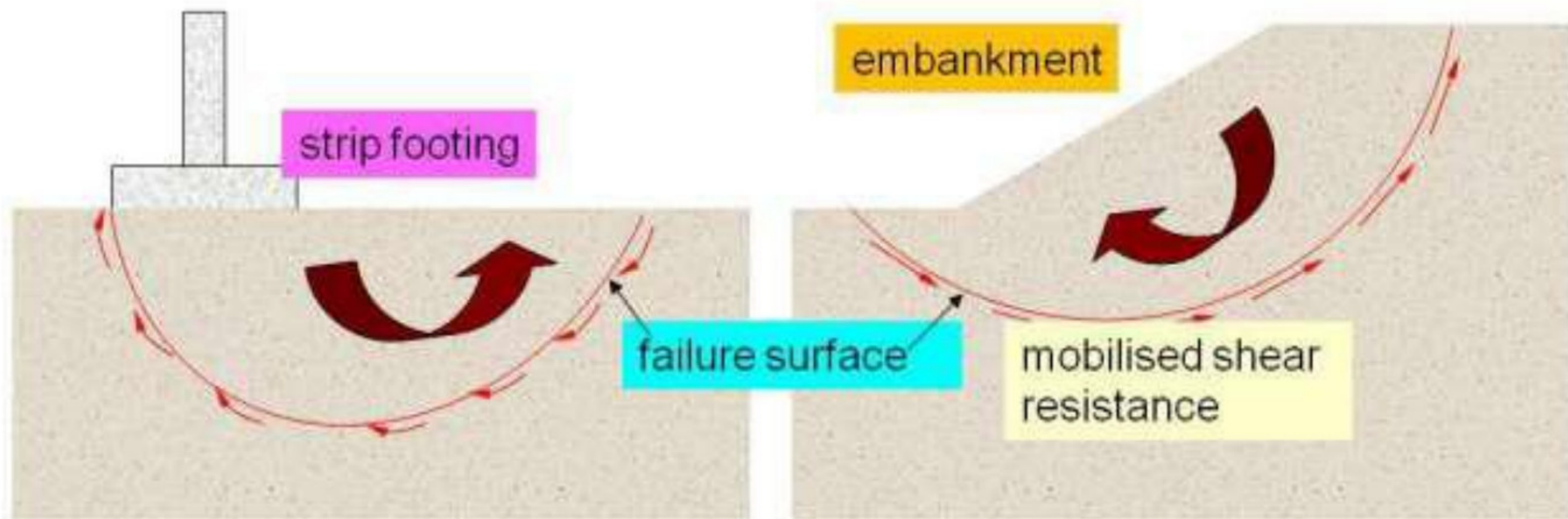


Fig. Shear Failure

At failure, shear stress along the failure surface reaches the shear Thus shear strength of soil is "The capacity of a soil to resist the internal and external forces which slide past each other"

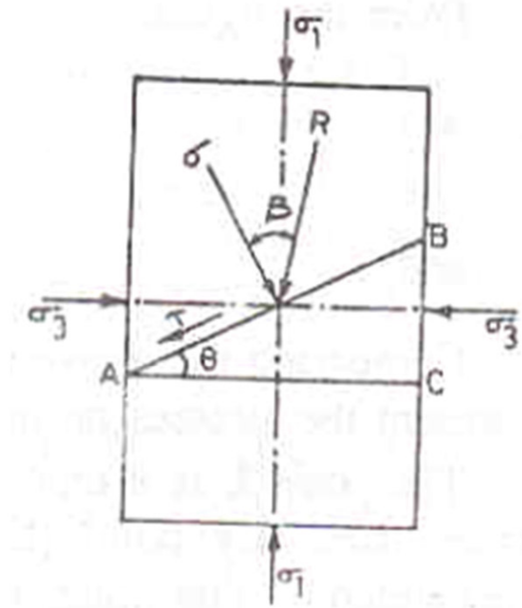
Stress system in soil mass

- Soil mass is subjected to a three dimensional stress system
- However in many soil engineering problems, the stresses in the third direction are not relevant and hence the stress system is considered to be two dimensional

Stress system in general (recap)

- At every point in a stressed body, there are three planes on which shear stress is zero – these planes are known as *principal planes*
- The plane with the maximum compressive stress (σ_1) = *major principal plane*
- The plane with the minimum compressive stress (σ_3) = *minor principal plane*
- The principal plane is subjected to a stress which has a value intermediate between σ_1 and σ_3 - known as *intermediate principal plane* – not much relevant
- In soil mechanics, tensile stresses rarely occur, and hence compressive stresses are taken as positive.

- If σ = normal stress on any plane AB
- τ = shear stress on that plane AB

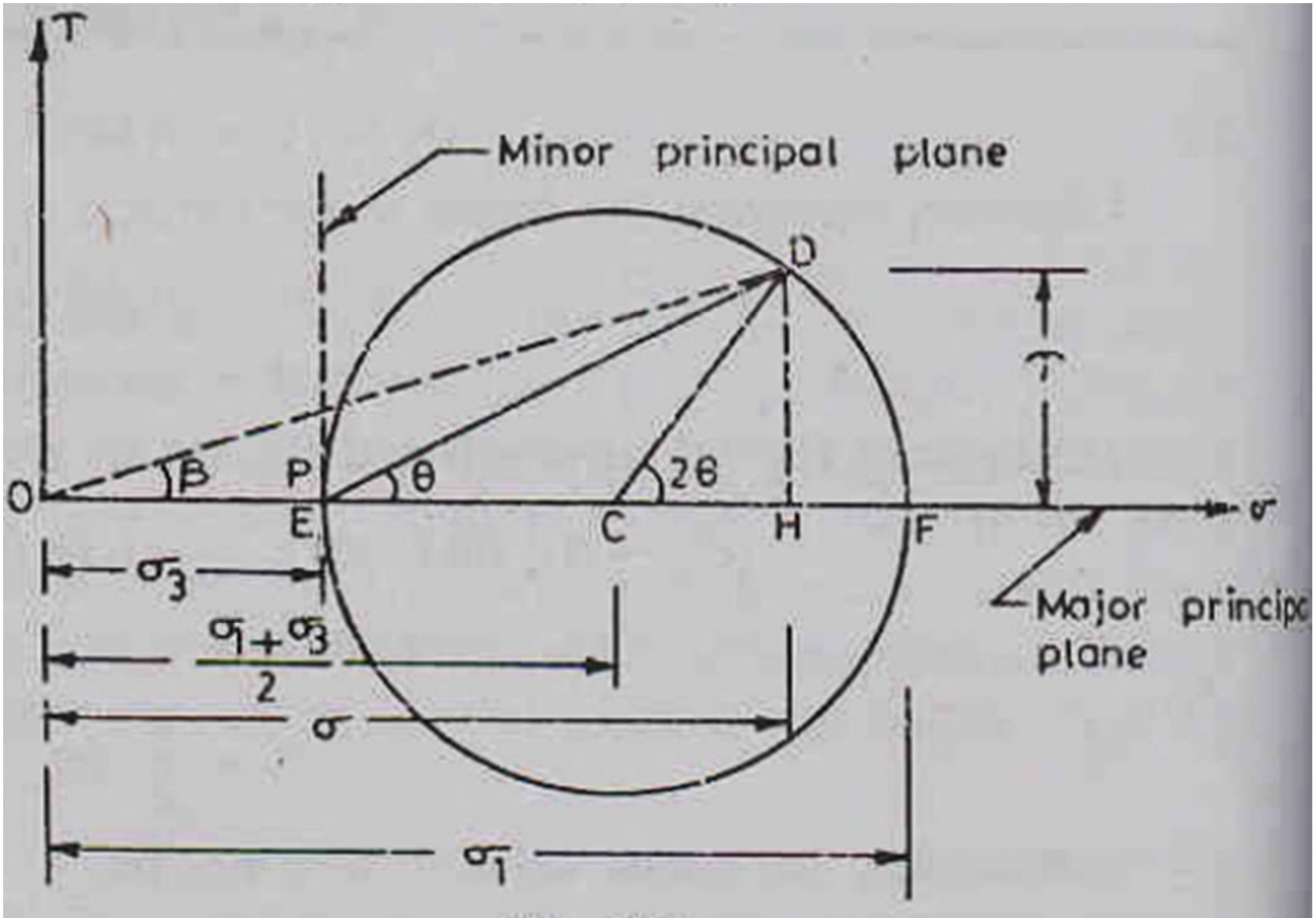


Eqs. give the stresses on the inclined plane *AB*, making an angle θ (measured counterclockwise) with the major principal plane *AC*.

$$\tau = \frac{1}{2}(\sigma_1 - \sigma_3)\sin 2\theta \qquad \sigma = \frac{(\sigma_1 + \sigma_3)}{2} + \frac{(\sigma_1 - \sigma_3)}{2}\cos 2\theta$$

Mohr's Circle

- Developed by Otto Mohr (German scientist)
- Graphical method to the determination of stresses on a plane inclined to the principal planes.
- This graphical construction = Mohr's circle
- Normal stress – along horizontal axis
- Shear stress – along vertical axis


τ
Minor principal plane
D
τ
β
P
θ
2θ
O
E
C
H
F
σ
Major principc
plane
σ3
(σ1+σ3)/2
σ
σ1

- Point E – minor principal stress
- Point F – major principal stress
- Circle drawn with C as the centre and EF as diameter = Mohr's circle
- Each point on the circle gives the normal and shear stresses on that particular plane.

- Point D on the circle gives the stresses on a plane (say AB) inclined at an angle θ to the major principle plane.
- Point E = Pole (P) or the origin of the planes (OP)
- The line OD represents the magnitude of the resultant stress on the inclined plane AB
- β = the angle of obliquity of the resultant with the normal of the plane AB

13.6. IMPORTANT CHARACTERISTICS OF MOHR'S CIRCLE

The following important characteristics of Mohr's circle should be carefully noted, as these are required for further study.

(1) The maximum shear stress τ_{max} is numerically equal to $(\sigma_1 - \sigma_3)/2$ and it occurs on a plane inclined at 45° to the principal planes (Fig. 13.5).

(2) Point D on the Mohr circle represents the stresses (σ, τ) on a plane make an angle θ with the major principal plane.

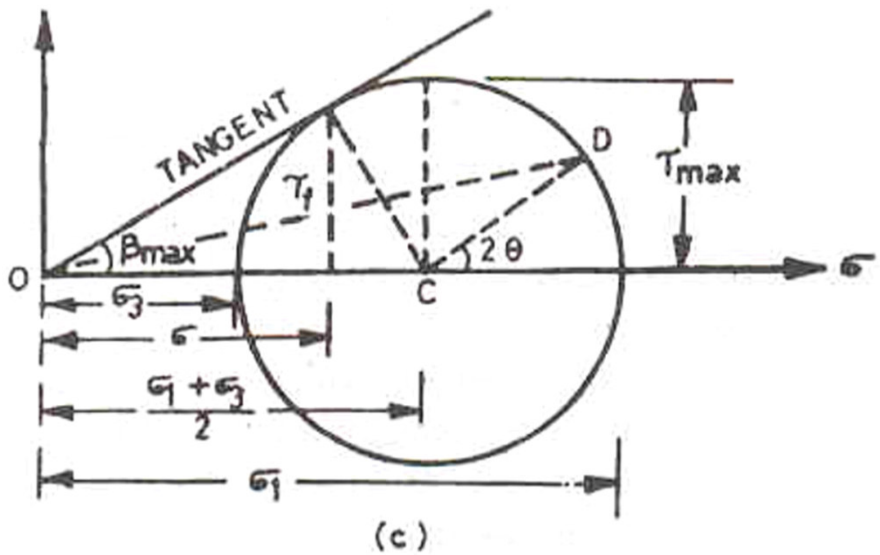


Fig. 13.5. Characteristics of Mohr's Circle.

Mohr – Coulomb theory

- The failure of soil is essentially by shear, but the shear stresses at failure depend upon the normal stresses on the potential failure plane.
- According to Mohr, the failure is caused by a critical combination of the normal and shear stresses.

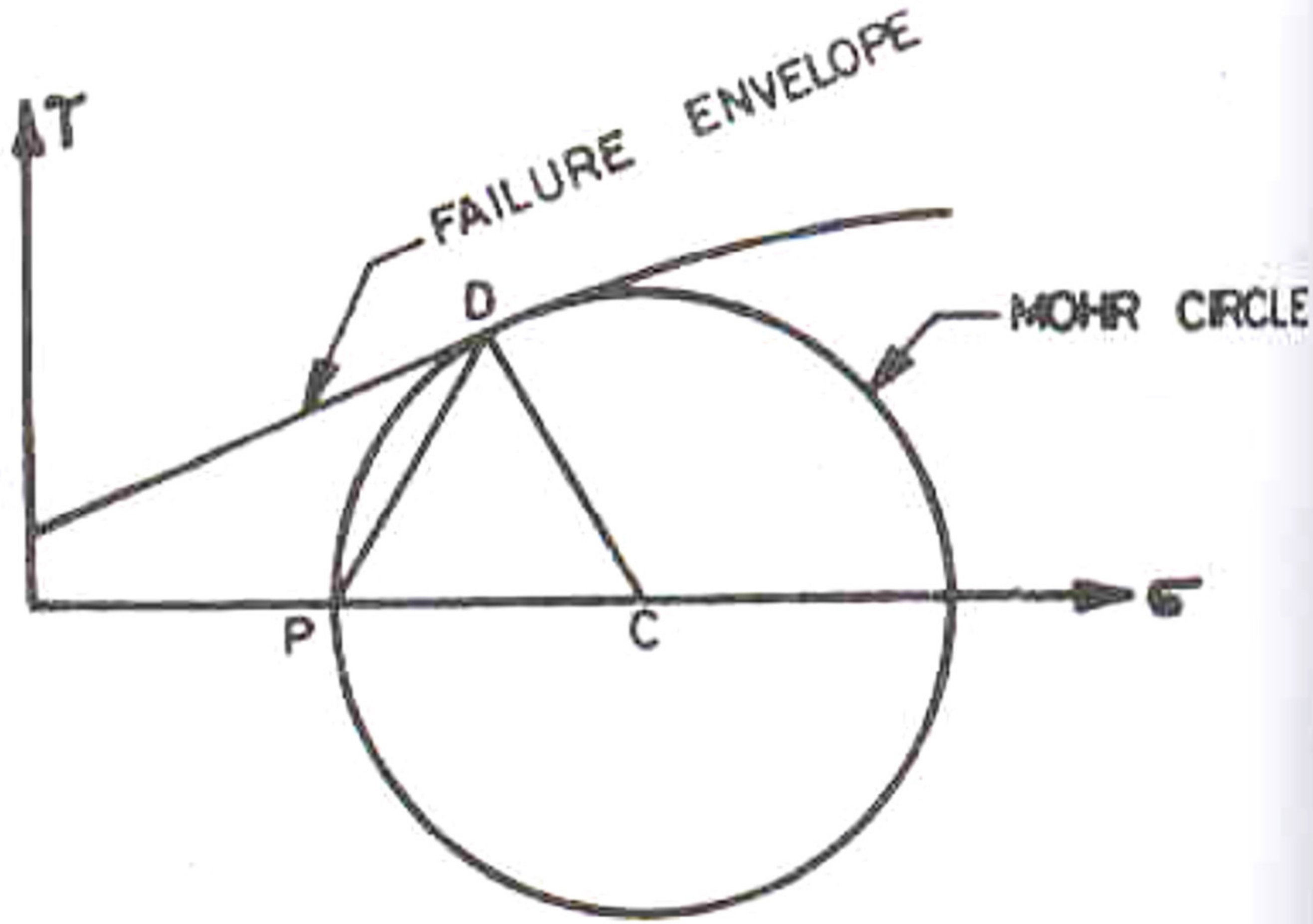
The soil fails when the shear stress (τ_f) on the failure plane at failure is a unique function of the normal stress (σ) acting on that plane.

$$\tau_f = f(\sigma)$$

Since the shear stress on the failure plane at failure is defined as the shear strength (s), the above equation can be written as

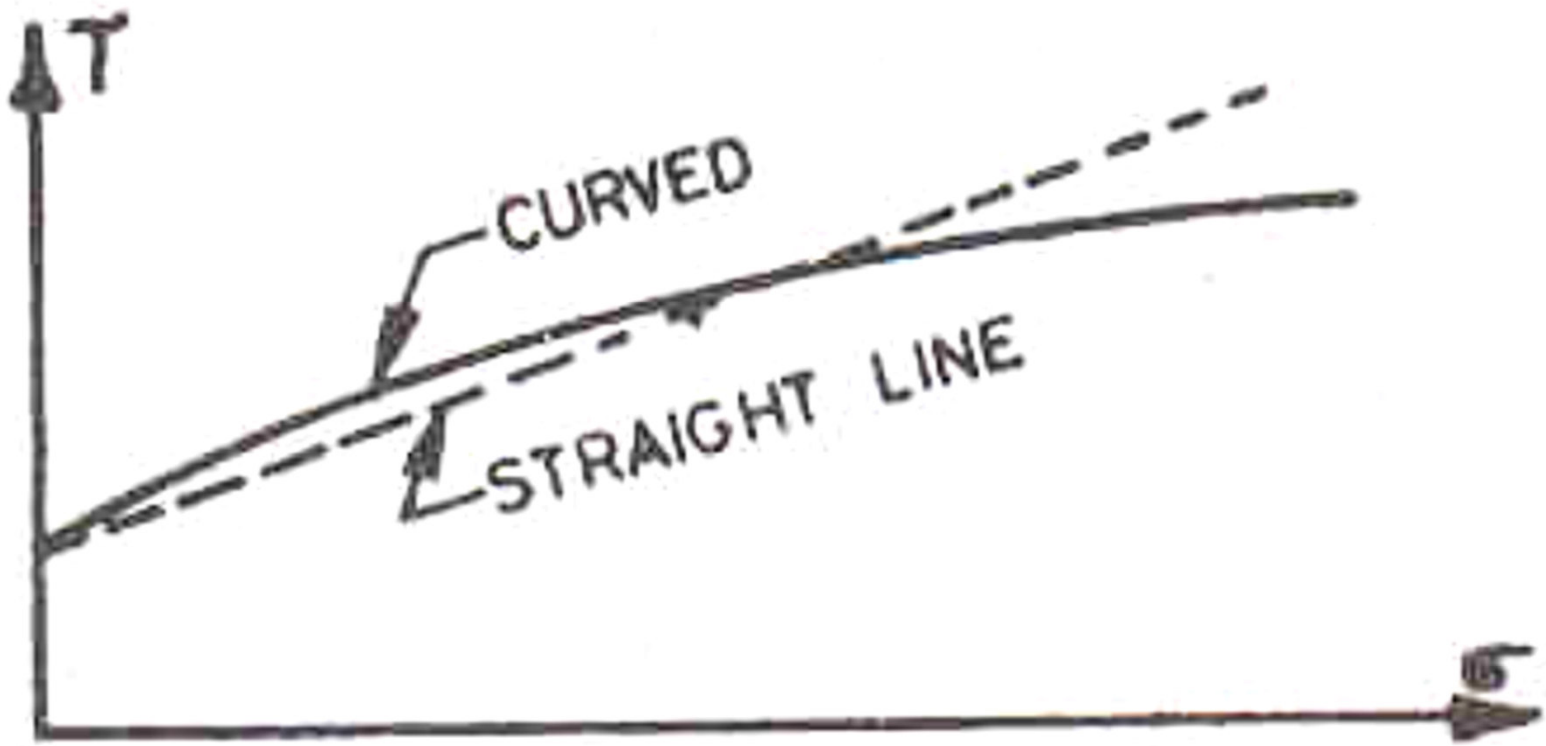
$$s = f(\sigma) \qquad \ldots(13.11)$$

- The curve defined by eqn 13.11 is known as the Mohr envelope.
- There is a unique failure envelope for each material



(a)

- Failure of a material occurs when the Mohr's circle of stresses touches the Mohr envelope.
- At the point of contact (D) of the failure envelope and the Mohr circle, the critical combination of shear and normal stresses is reached and the failure occurs.
- The plane indicated by the line PD = the failure plane.



(b)

- Any Mohr's circle which does not cross the failure envelope and lies below the envelope – represents a (non failure) stable condition.
- The Mohr circle cannot cross the Mohr envelope , as failure would have already occurred as soon as the Mohr circle touched the envelope.

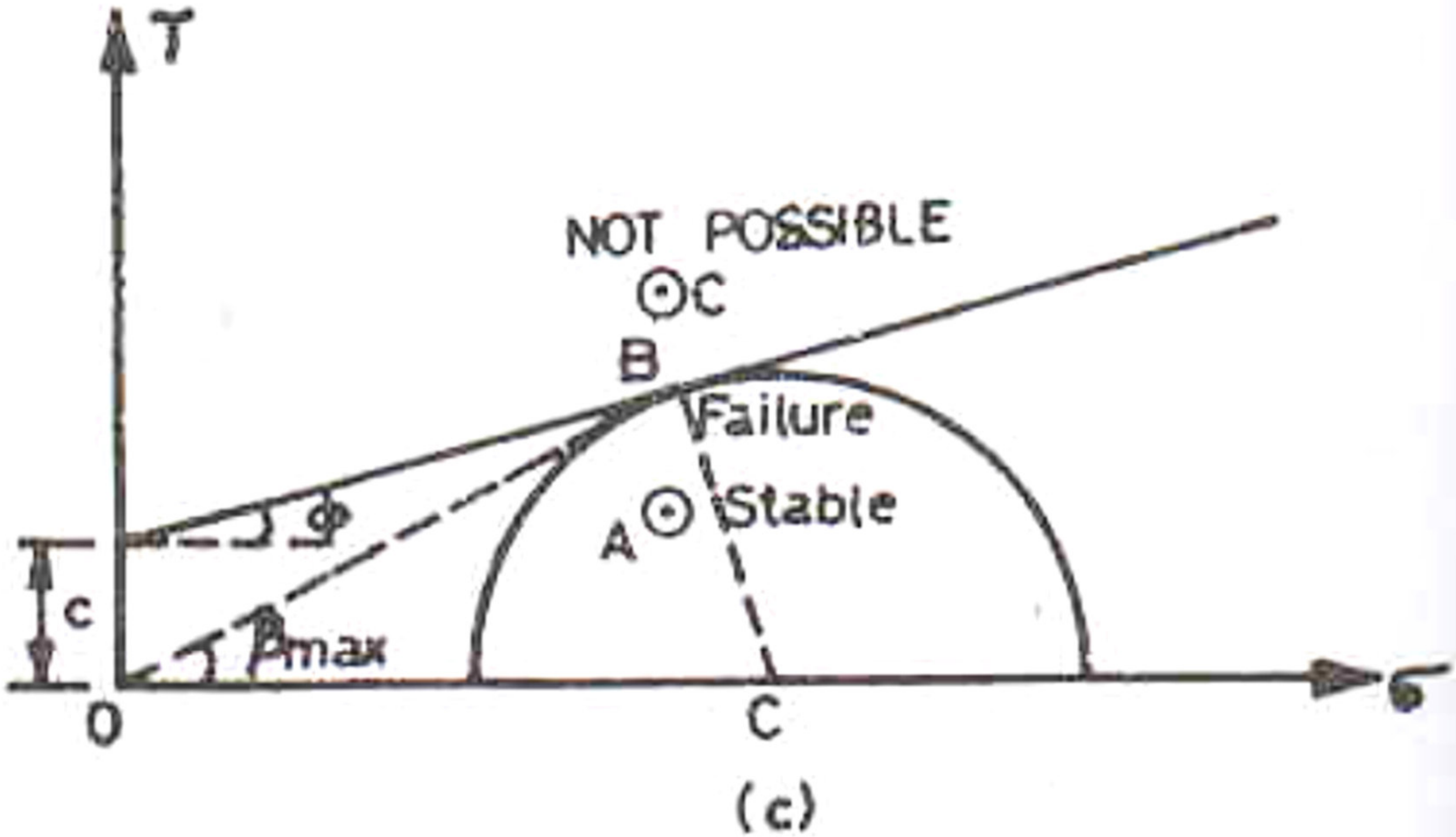


Fig. 13.6. Failure Envelopes.

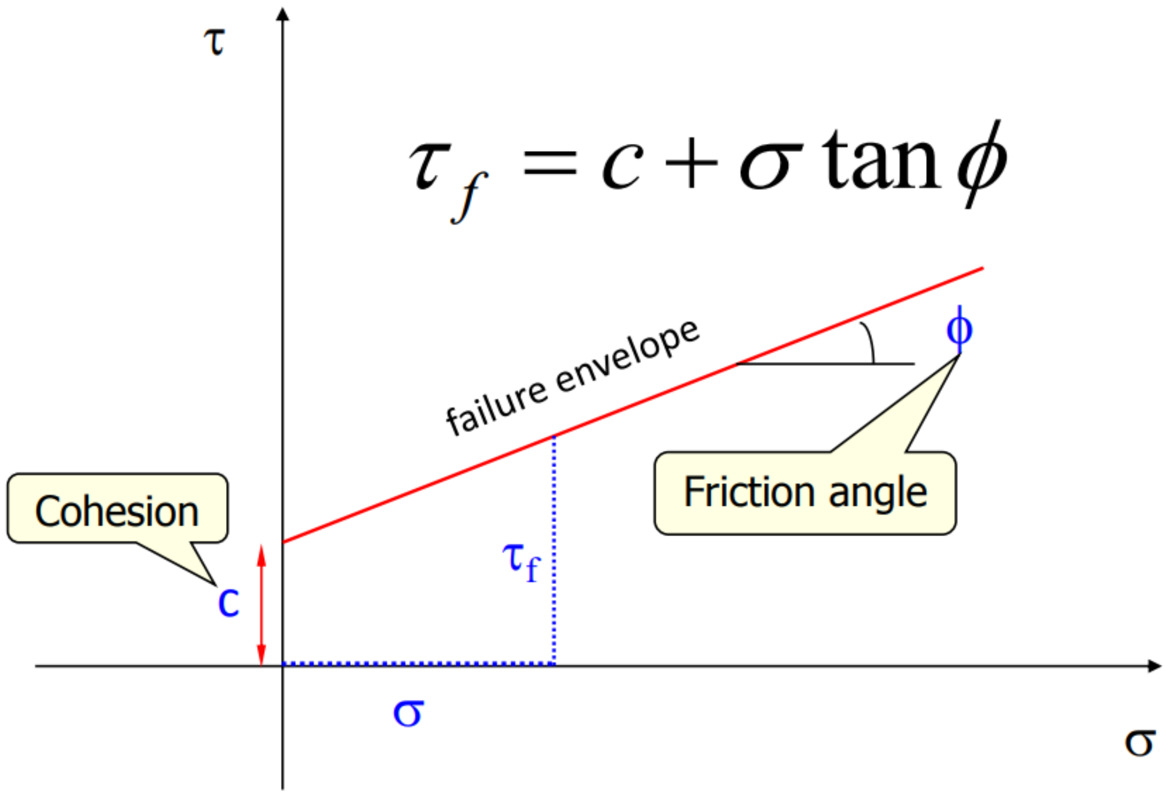
- The shear strength of a soil at a point on a particular plane was expressed by Coulomb as a linear function of the normal stress on that plane, as

$$\boxed{s = c + \sigma \tan \phi}$$

- C = Cohesion = intercept on the τ axis
- Ø = angle of internal friction = angle which the envelope makes with the σ axis

Mohr-Coulomb Failure Criterion

(in terms of total stresses)

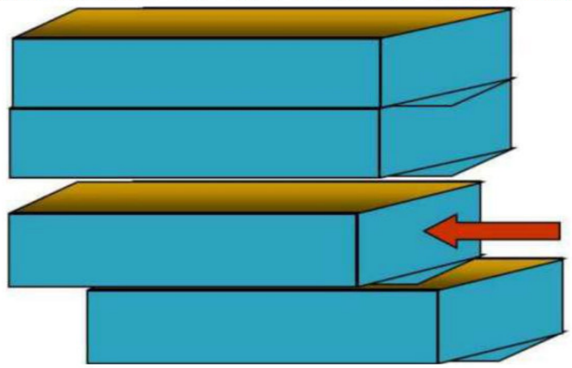


τ_f is the maximum shear stress the soil can take without failure, under normal stress of σ.

Cohesion and internal friction

- Cohesion = holds the particles of the soil together in a soil mass
- Independent of normal stress

Cohesion: Cohesion (C), is a measure of the forces that cement particles of soils



Cohesion and internal friction

- Angle ∅ = represents the frictional resistance between the particles
- Directly proportional to the normal stress

Internal Friction: Internal Friction angle (*f*), is the measure of the shear strength of soils due to friction.

Table Typical Values of Drained Angle of Friction for Sands and Silts

Soil type	ϕ' (deg)	$\mu=\tan\phi'$
Sand: Rounded grains		
Loose	27–30	0.51-0.58
Medium	30–35	0.58-0.70
Dense	35–38	0.70-0.78
Sand: Angular grains		
Loose	30–35	0.58-0.70
Medium	35–40	0.70-0.84
Dense	40–45	0.84-1.00
Gravel with some sand	34–48	0.67-1.11
Silts	26–35	0.49-0.70

Mohr-Coulomb shear failure criterion

Limitations of Mohr - Coulomb Theory

1. It neglects the effect of the intermediate principal stress (σ_2)
2. It approximates the curved failure envelope by a straight line, which may not give correct results.
3. When the Mohr envelope is curves, the actual obliquity of the failure plane is slightly smaller than the maximum obliquity. Therefore the angle of failure plane, as found, is not correct.
4. For some clayey soils, there is no fixed relationship between the normal and shear stresses on the plane of failure. The theory cannot be used for such soils.

Different Types of soil (based on shear strength)

1. Cohesionless soils
2. Purely cohesive soils
3. Cohesive – frictional soils

Cohesionless soils

- These soils do not have cohesion.
- $C = 0$
- These soils derive the shear strength from the intergranular friction.
- Also called frictional soils.
- Eg : Sands and gravels

Purely Cohesive soils

- Soils which exhibit cohesion but the angle of shearing resistance $\varnothing = 0$.
- Eg : Saturated clays and silts under undrained conditions
- Also called as $\varnothing = 0$ soils

Cohesive frictional soils

- They are composite soils having both C and Ø
- These are called c-Ø soils.
- Eg : Clayey sand, silty sand, sandy clay etc

DIFFERENT TYPES OF SHEAR TESTS AND DRAINAGE CONDITIONS

The following tests are used to measure the shear strength of the soil

1. Direct shear test
2. Triaxial compression test
3. Unconfined compression test
4. Vane shear test

Depending upon the drainage conditions, there are three types of tests

- Unconsolidated-Undrained condition
- Consolidated - Undrained condition
- Consolidated-Drained condition

Determination of shear strength parameters of soils (c, ϕ or c', ϕ')

Laboratory tests on specimens taken from representative undisturbed samples

Most common laboratory tests to determine the shear strength parameters are,

1. Direct shear test
2. Triaxial shear test
3. Vane shear test

Other laboratory tests include, torsional ring shear test, plane strain triaxial test, laboratory vane shear test, laboratory fall cone test

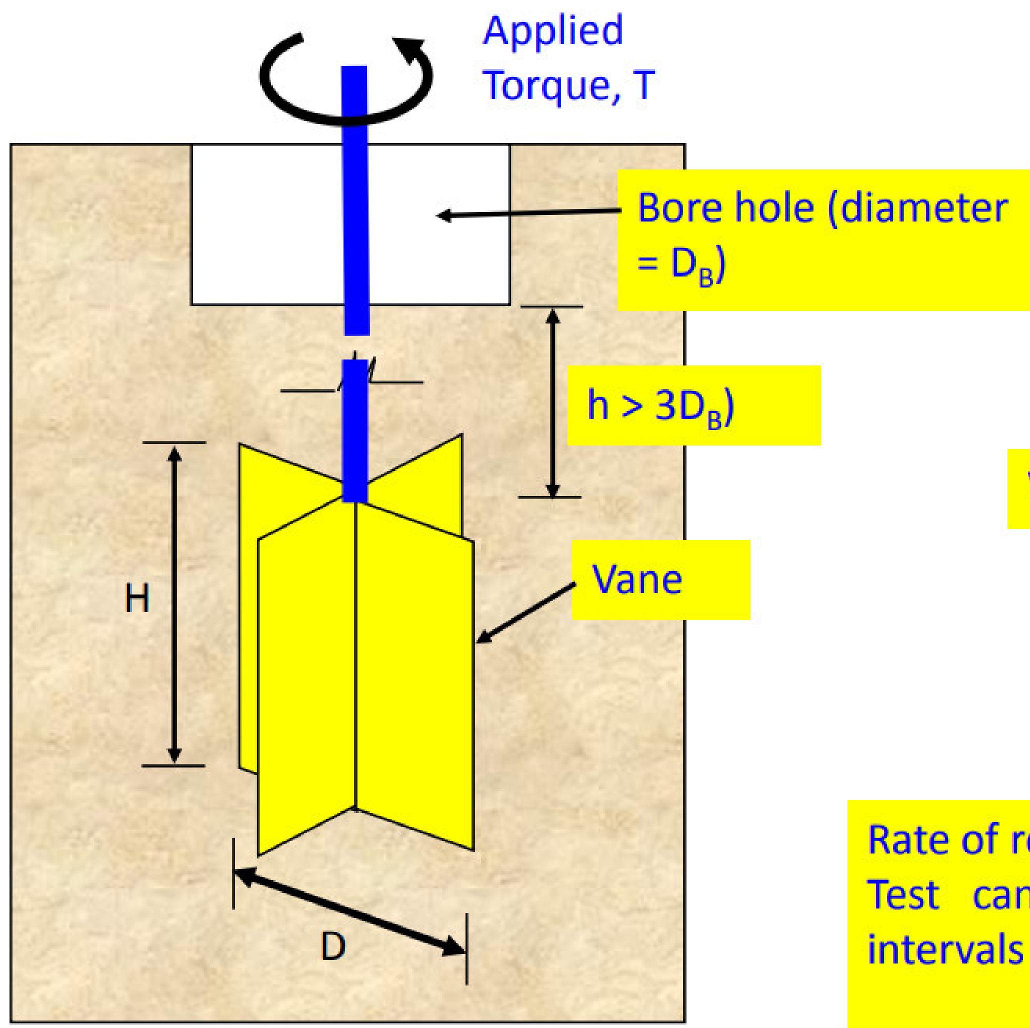
Field tests

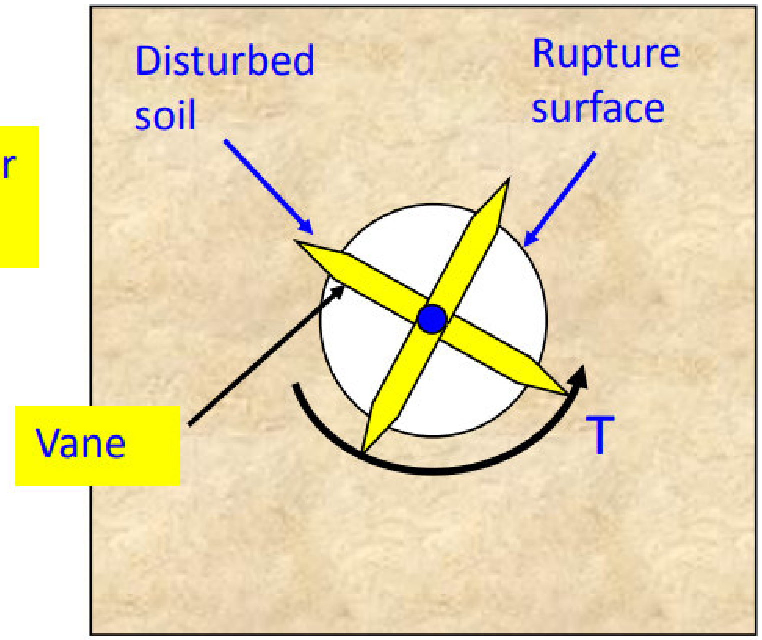
1. Vane shear test
2. Torvane
3. Pocket penetrometer
4. Fall cone
5. Pressuremeter
6. Static cone penetrometer
7. Standard penetration test

Vane Shear test

- Laboratory test
- Determine the undrained shear strength of soft clays
- Can also be conducted in the field on the soil at the bottom of a bore hole.
- Consists of a vertical steel rods having four thin stainless steel blades (Vanes) fixed at it's bottom end.

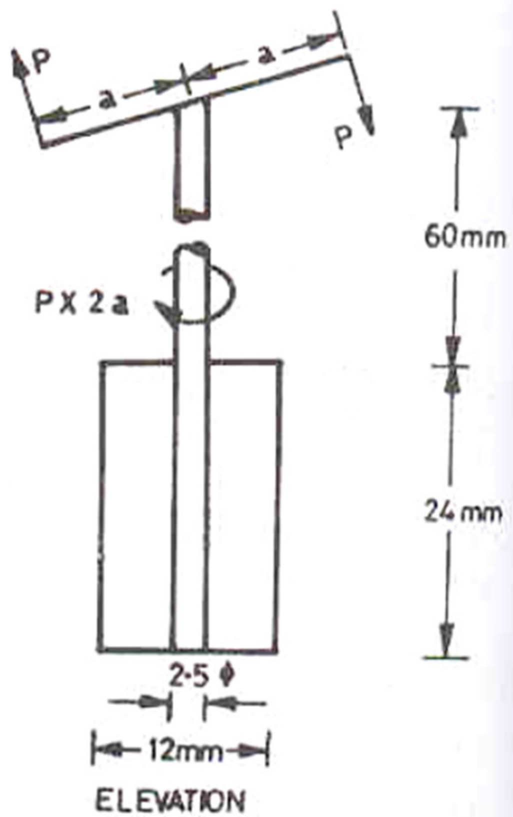
- IS 2720 – XXX -a980 recommends that the height of the vane should be equal to twice the overall diameter.
- Recommended diameter – 2.5mm
- Recommended length of the rod – 60mm.
- A specimen of size 38mm diameter and 75mm height is taken in a container which is fixed securely to the base.
- The vane is gradually lowered into the specimen till the top of the vane is at a depth of 10 to 20 mm below the top of the specimen.
- The readings of the strain indicator and torque indicator are taken.
- Torque is applied gradually to the upper end of the rod at the rate of about 6^0 per minute.
- Torque is continued till the soil fails in shear.





PLAN VIEW

Rate of rotation : $6^0 – 12^0$ per minute
Test can be conducted at 0.5 m vertical intervals



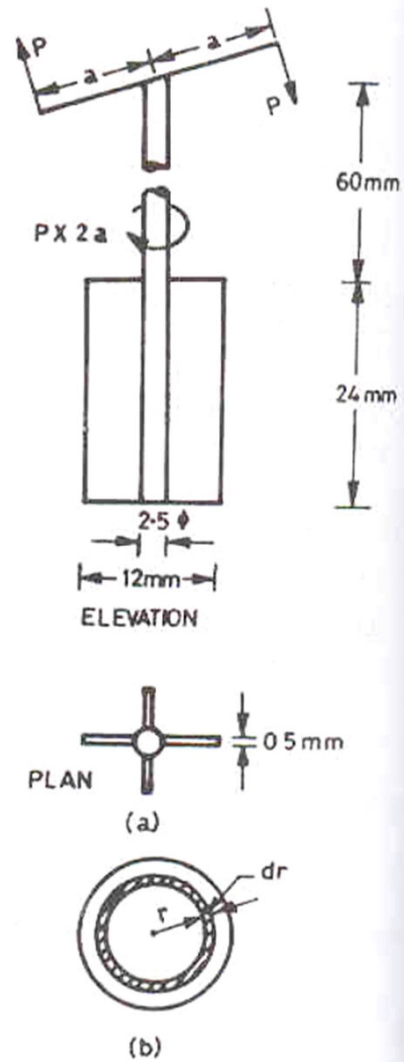


Fig. 13.30. Vane Shear Test.

- The shear strength of the soil is determined using the following formula

$$\boxed{s = \frac{T}{\pi (D^2 H/2 + D^3/6)}}$$

- Vane shear test can be used to determine the sensitivity of the soil.
- After the initial test, the vane is rotated rapidly through several revolutions such that the soil becomes unmoulded.
- The test is repeated ion the remoulded and soils and shear strength in remoulded state is found out

$$\boxed{\text{Sensitivity } (S_t) = \frac{(s) \text{ undisturbed}}{(s) \text{ remoulded}}}$$

- Merits of Vane shear test

1. The test is simple and quick
2. It is ideally suited for the determination of in-situ undrained shear strength of non-fissured, fully saturated clay.
3. The test can be conveniently used to determine the sensitivity of the soil.

- Demerits of Vane shear test

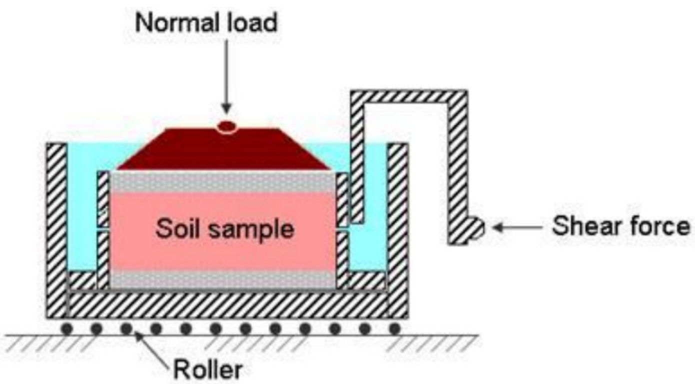
1. The test cannot be conducted in the fissured clay or the clay containing sand or silt laminations.
2. The test does not give accurate results when the failure envelope is not horizontal

Direct Shear Test

Direct Shear Test Apparatus

Apparatus

- The test is conducted in a soil specimen in a shear box which is split in to two halves along the horizontal plane at its middle.
- The size of the shear box is 60 x 60 x 50 mm. the box is divided horizontally such that the dividing plane passes through the centre.
- The two halves are held together by locking pins the box is also provided with gripper plates plain or perforated according to the testing conditions



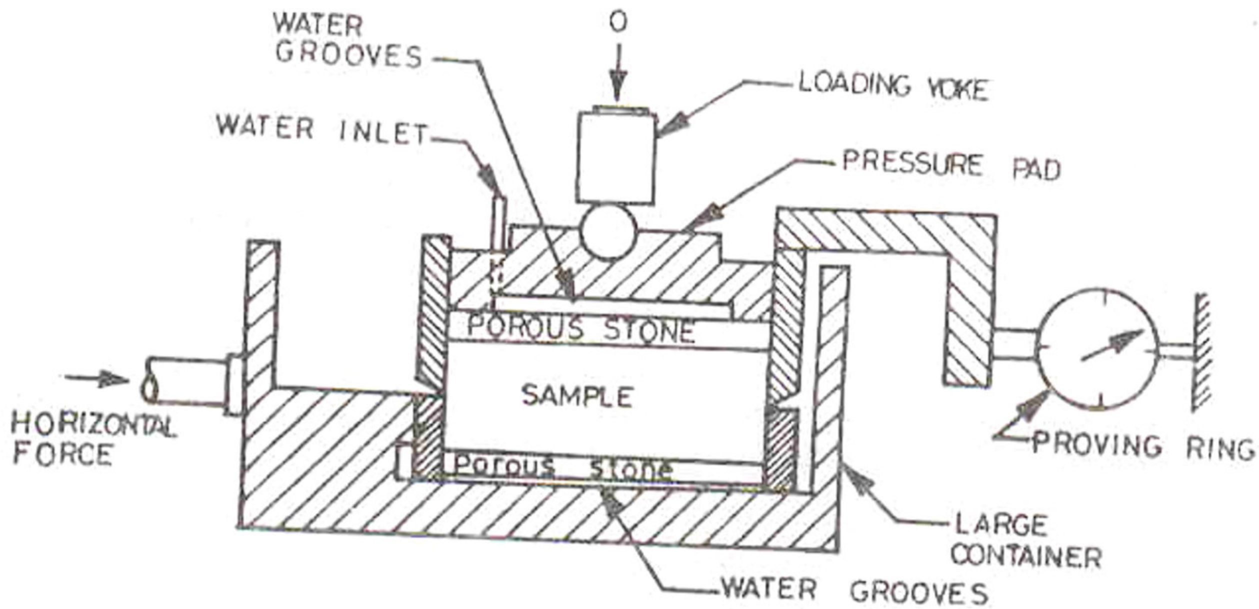


Fig. 13.7. Direct Shear Test.

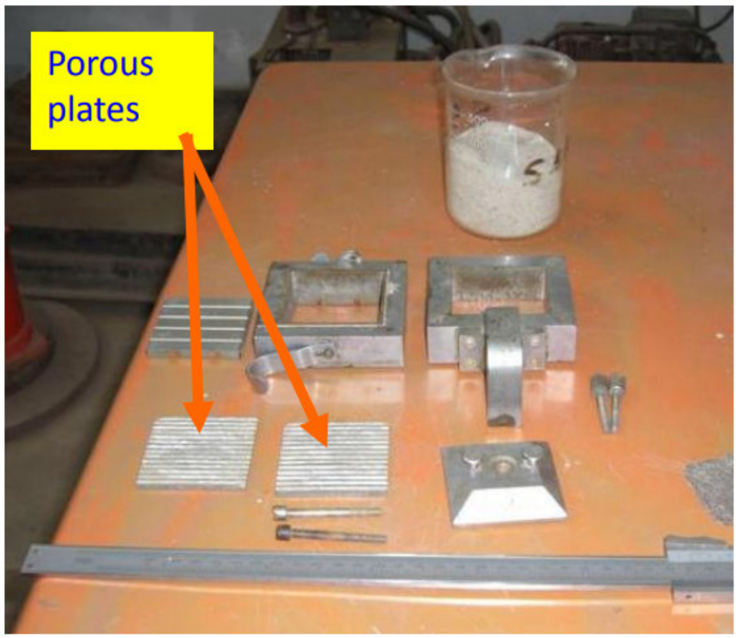
Test procedure

- Check the inner dimension of the soil container.
- Put the parts of the soil container together.
- Calculate the volume of the container. Weigh the container.
- Place the soil in smooth layers (approximately 10 mm thick). If a dense sample is desired tamp the soil.
- Weigh the soil container, the difference of these two is the weight of the soil. Calculate the density of the soil.
- Make the surface of the soil plane.
- Put the upper grating on stone and loading block on top of soil.

Direct shear test

Direct shear test is most suitable for consolidated drained tests specially on granular soils (e.g.: sand) or stiff clays

Preparation of a sand specimen



Components of the shear box

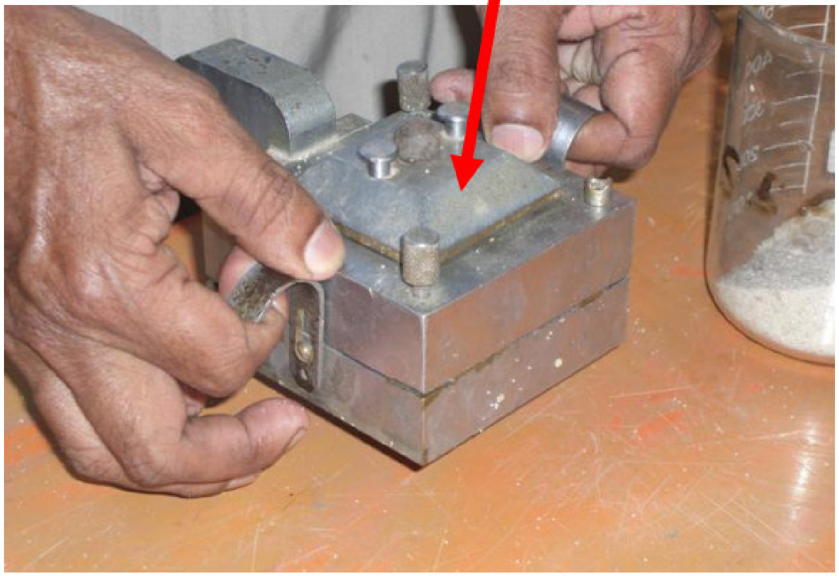
Preparation of a sand specimen

Direct shear test

Preparation of a sand specimen

Leveling the top surface of specimen

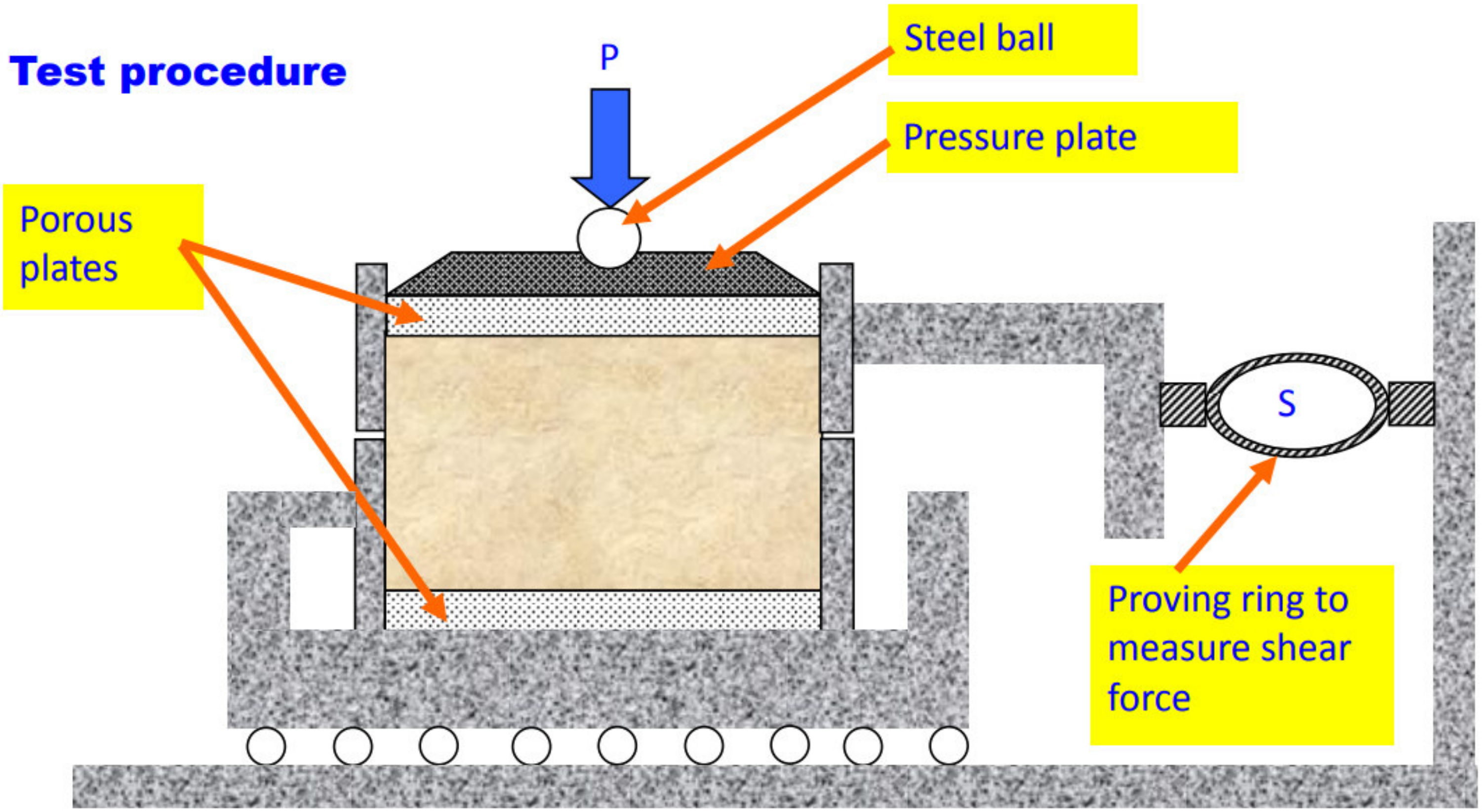
Pressure plate



Specimen preparation completed

Direct shear test

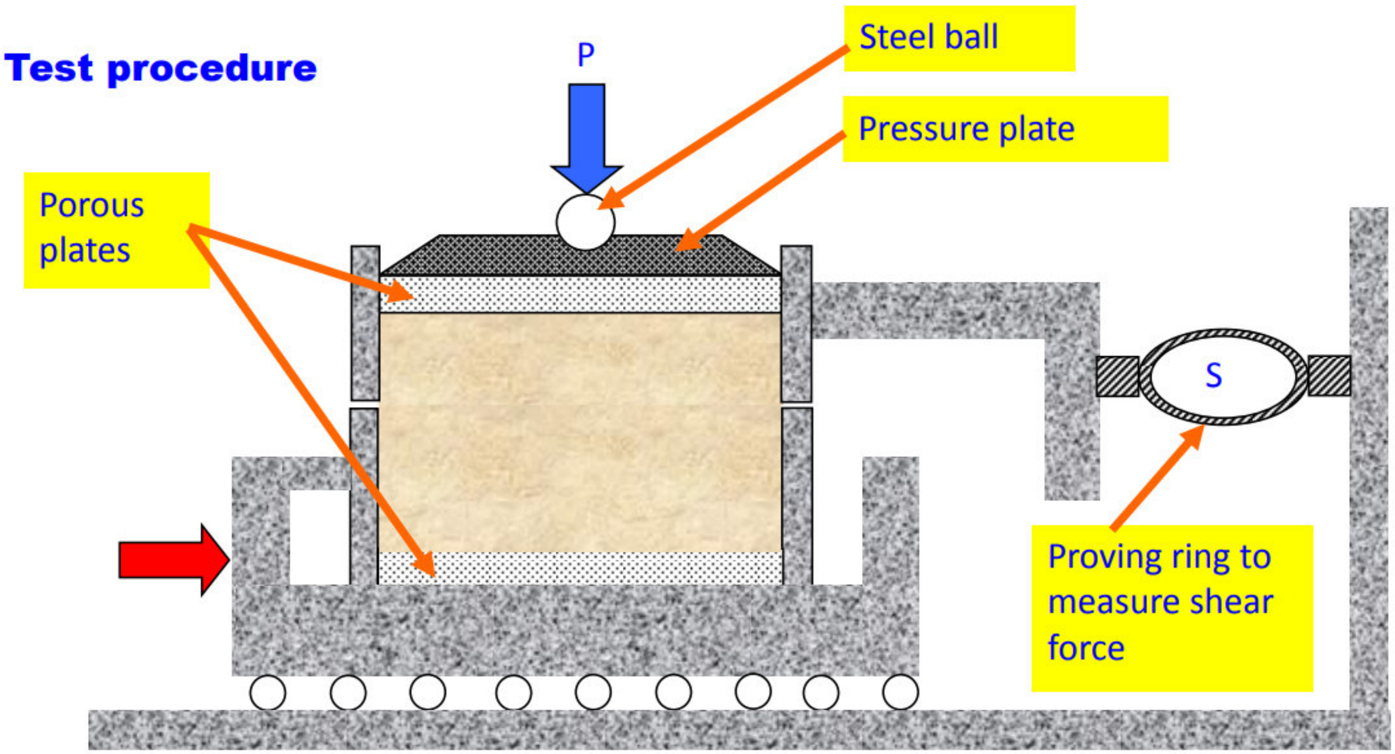
Test procedure



Step 1: Apply a vertical load to the specimen and wait for consolidation

Direct shear test

Test procedure



Step 1: Apply a vertical load to the specimen and wait for consolidation

Step 2: Lower box is subjected to a horizontal displacement at a constant rate

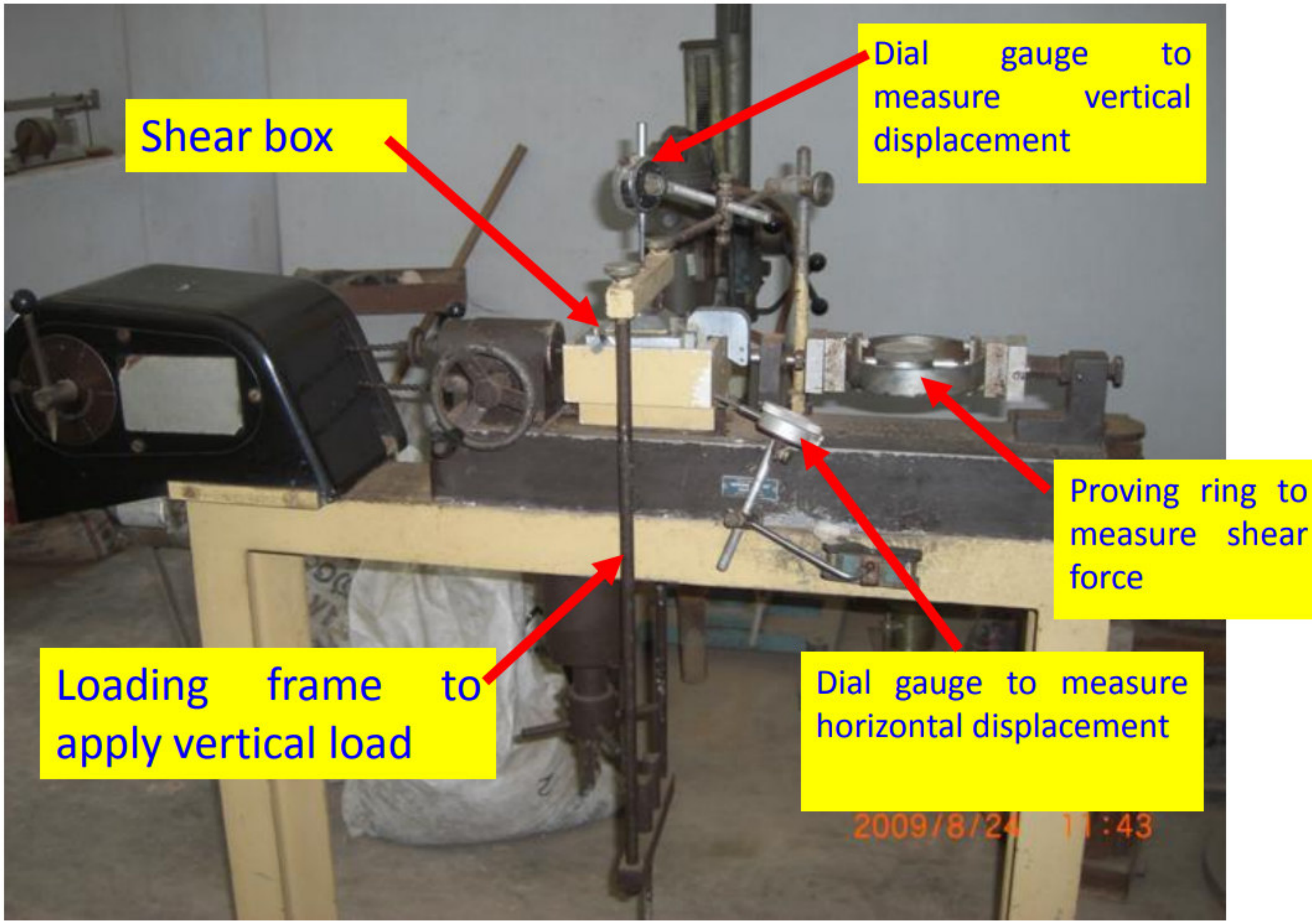
- Measure the thickness of soil specimen.
- Apply the desired normal load.
- Remove the shear pin.
- Attach the dial gauge which measures the change of volume.
- Record the initial reading of the dial gauge and calibration values.
- Before proceeding to test check all adjustments to see that there is no connection between two parts except sand/soil.
- Start the motor. Take the reading of the shear force and record the reading.
- Take volume change readings till failure.
- Add 5 kg normal stress 0.5 kg/cm2 and continue the experiment till failure
- Record carefully all the readings. Set the dial gauges zero, before starting the experiment

- As a vertical normal load is applied to the sample, shear stress is gradually applied horizontally, by causing the two halves of the box to move relative to each other.
- The shear load is measured together with the corresponding shear displacement.
- The change of thickness of the sample is also measured.
- A number of samples of the soil are tested each under different vertical loads and the value of shear stress at failure is plotted against the normal stress for each test. .
- From the stresses at failure, the failure envelope can be obtained.

Presentation of results:

- Stress – strain curve
- Failure envelope
- Mohr’s circle

Direct shear test



Direct shear test

Analysis of test results

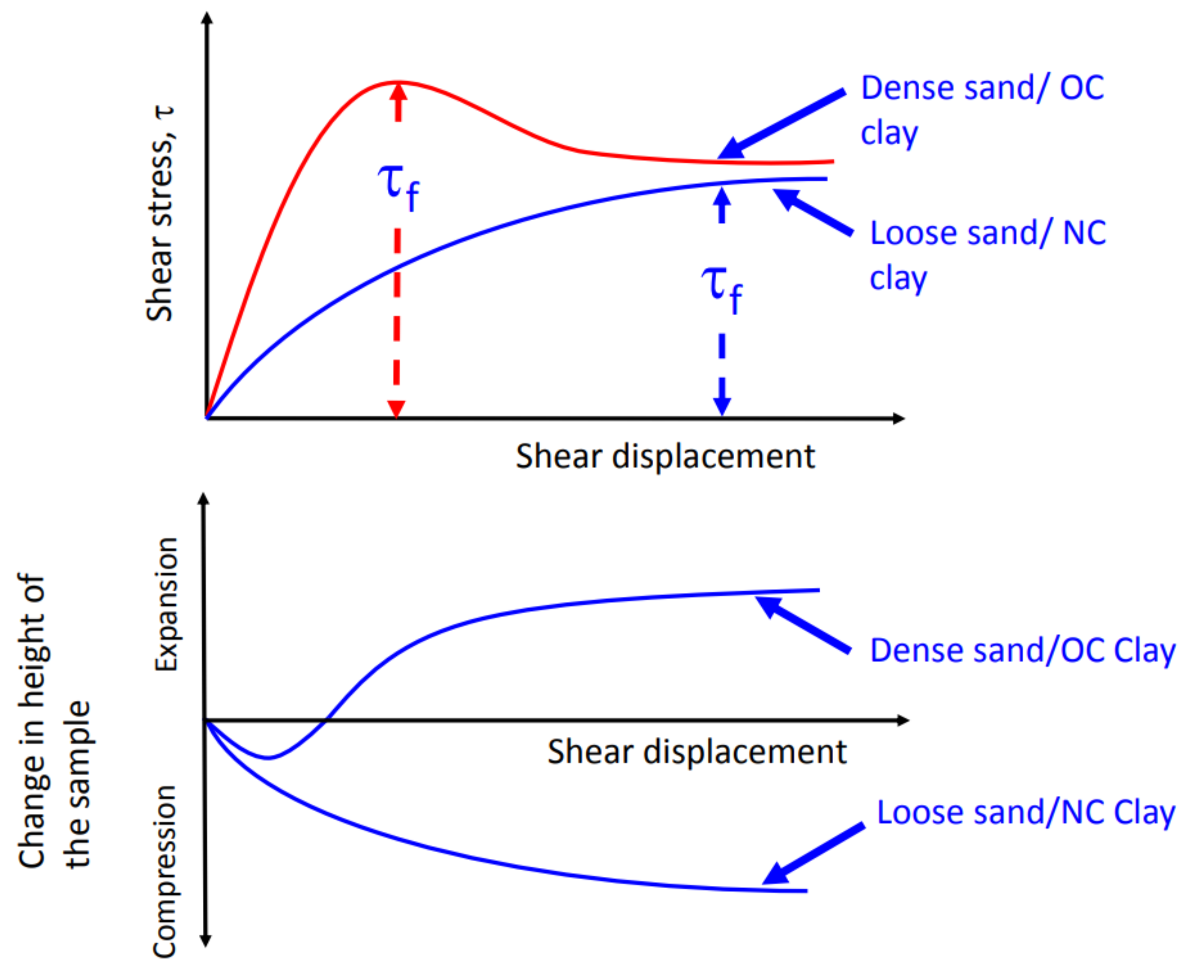
$$\sigma = \text{Normal stress} = \frac{\text{Normal force (P)}}{\text{Area of cross section of the sample}}$$

$$\tau = \text{Shear stress} = \frac{\text{Shear resistance developed at the sliding surface (S)}}{\text{Area of cross section of the sample}}$$

Note: Cross-sectional area of the sample changes with the horizontal displacement

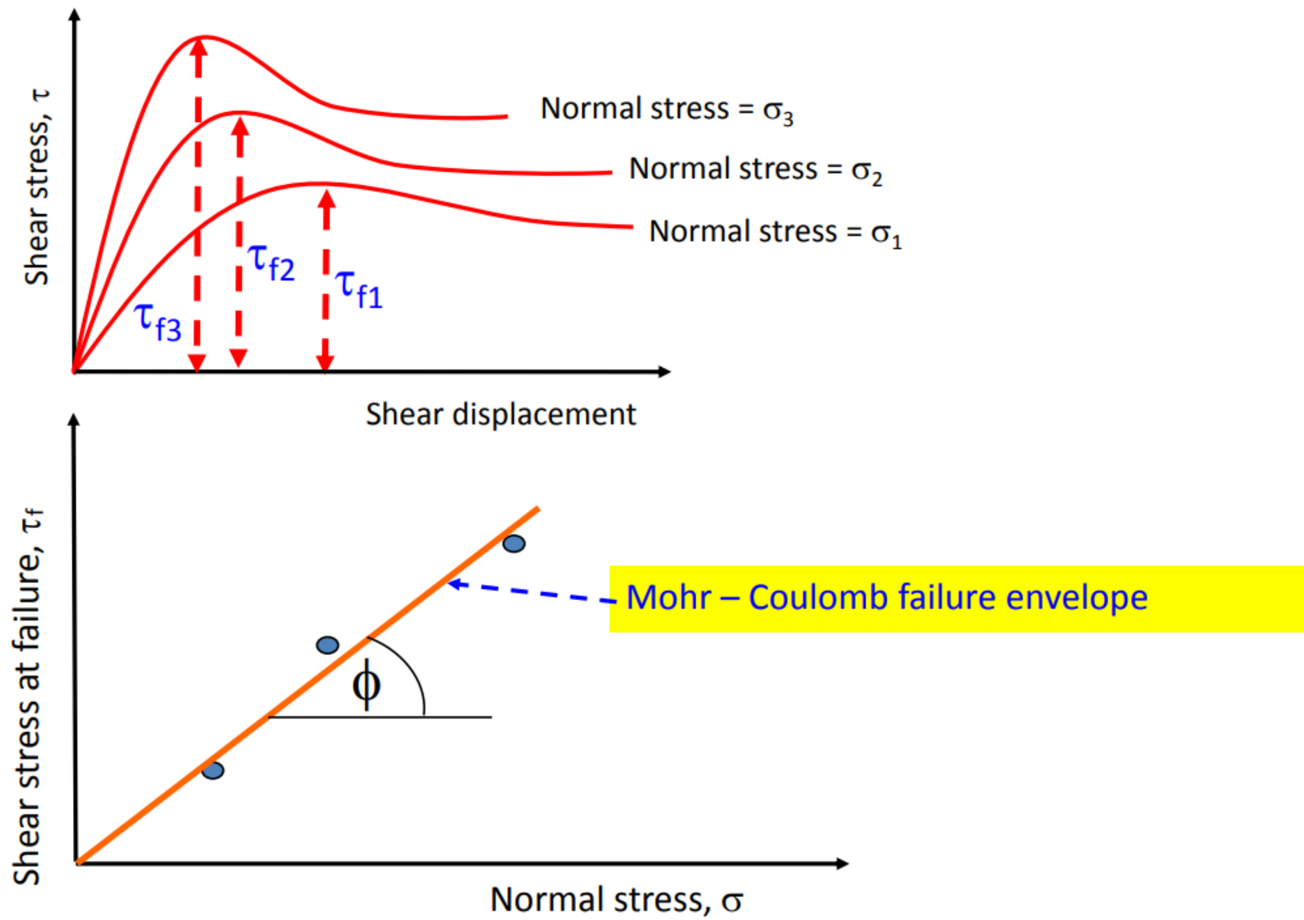
Direct shear tests on sands

Stress-strain relationship



Direct shear tests on sands

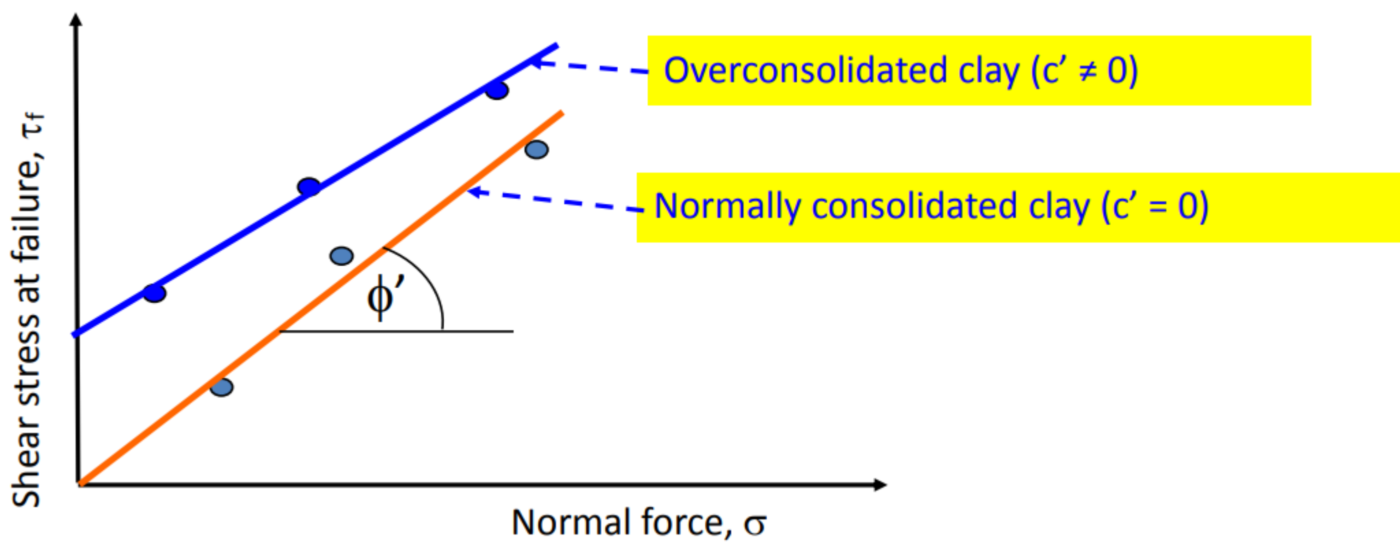
How to determine strength parameters c and ϕ



Direct shear tests on clays

In case of clay, horizontal displacement should be applied at a very slow rate to allow dissipation of pore water pressure (therefore, one test would take several days to finish)

Failure envelopes for clay from drained direct shear tests



Merits of direct shear test

- the sample preparation is easy
- as the thickness of the sample is very less, the drainage is quick
- it is ideally suited for conducting drained tests on cohesionless soils
- the apparatus is relatively cheap

Demerits of direct shear test

- the stress conditions are known only at failure
- the stress distribution on the failure plane is not uniform
- the area of shear gradually decreases as the test progresses
- the orientation of the failure plane is fixed
- control of drainage conditions is very difficult
- measurement of pore water pressure is not possible

Problems

Illustrative Example 13.9. *A shear vane of 7.5 cm diameter and 11.0 cm length was used to measure the shear strength of a soft clay. If a torque of 600 N-m was required to shear the soil, calculate the shear strength.*

The vane was then rotated rapidly to cause remoulding of the soil. The torque required in the remoulded state was 200 N-m. Determine the sensitivity of the soil.

Illustrative Example 13.9. *A shear vane of 7.5 cm diameter and 11.0 cm length was used to measure the shear strength of a soft clay. If a torque of 600 N-m was required to shear the soil, calculate the shear strength.*

The vane was then rotated rapidly to cause remoulding of the soil. The torque required in the remoulded state was 200 N-m. Determine the sensitivity of the soil.

Solution. From Eq. 13.27,

$$s = \frac{T}{\pi (D^2 H/2 + D^3/6)} = \frac{600 \times 10^{-3}}{\pi [(7.5)^2 \times 11.0/2 + (7.5)^3/6] \times 10^{-6}}$$

or

$$s = 503 \text{ kN/m}^2$$

In the remoulded state,

$$s_{rem} = \frac{200 \times 10^{-3}}{\pi [(7.5)^2 \times 11.0/2 + (7.5)^3/6] \times 10^{-6}} = 168 \text{ kN/m}^2$$

From Eq. 13.29, sensitivity $= \dfrac{503}{168} = 3.0$

13.7. A shear vane, 7.5 cm dia and 11.25 cm long, was pressed into soft clay at the bottom of a bore hole. Find the shear strength of the clay if the torque required for failure was 40 N-m. [Ans. 33 kN/m^2]