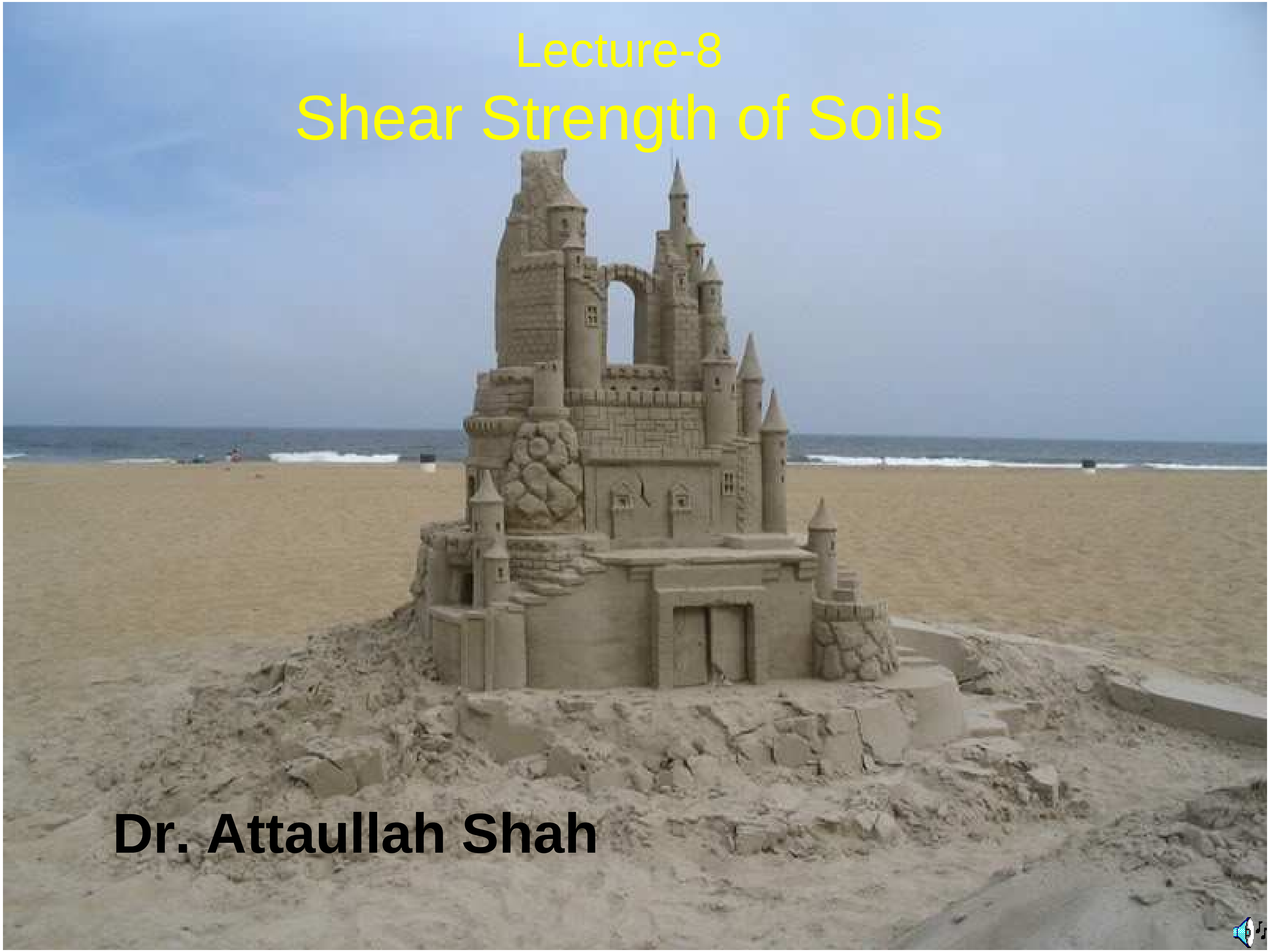
Lecture-8

Shear Strength of Soils



Dr. Attaullah Shah

Strength of different materials

Steel → Tensile strength

Concrete → Compressive strength

Soil → Shear strength → Presence of pore water → Complex behavior

What is Shear Strength?

- Shear strength in soils is the resistance to movement between particles due to physical bonds from:
  a. Particle interlocking
  b. Atoms sharing electrons at surface contact points
  c. Chemical bonds (cementation) such as crystallized calcium carbonate

Influencing Factors on Shear Strength

- The shearing strength, is affected by:
  - *soil composition*: mineralogy, grain size and grain size distribution, shape of particles, pore fluid type and content, ions on grain and in pore fluid.
  - *Initial state*: State can be describe by terms such as: loose, dense, over-consolidated, normally consolidated, stiff, soft, etc.
  - *Structure*: Refers to the arrangement of particles within the soil mass; the manner in which the particles are packed or distributed. Features such as layers, voids, pockets, cementation, etc, are part of the structure.

Shear Strength of Soil

- In reality, a complete shear strength formulation would account for all previously stated factors.

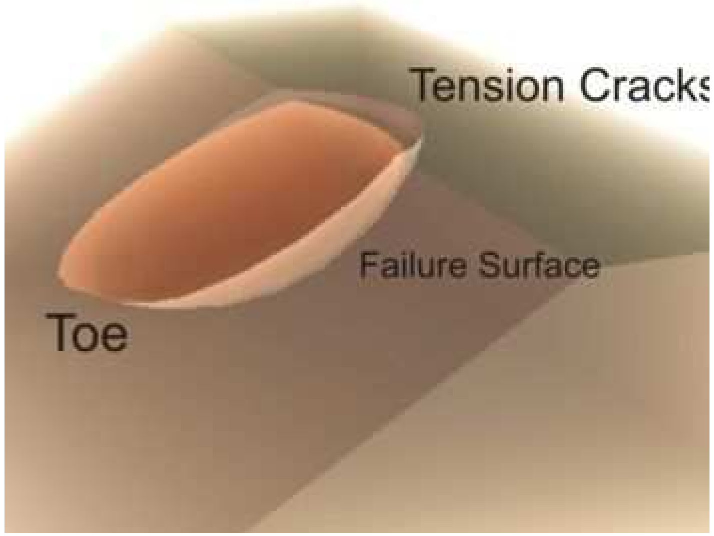
- Soil behavior is quite complex due to the possible variables stated.

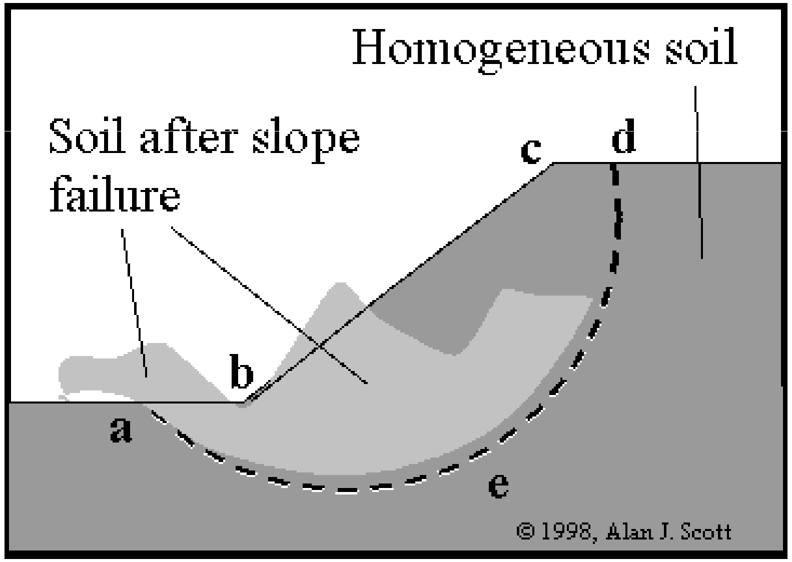
- Laboratory tests commonly used:
  - Direct Shear Test
  - Unconfined Compression Testing.

Soil Failure and shear strength.

- Soil failure usually occurs in the form of "shearing" along internal surface within the soil.
- Thus, structural strength is primarily a function of shear strength.
- Shear strength is a soils' ability to resist sliding along internal surfaces within the soil mass.

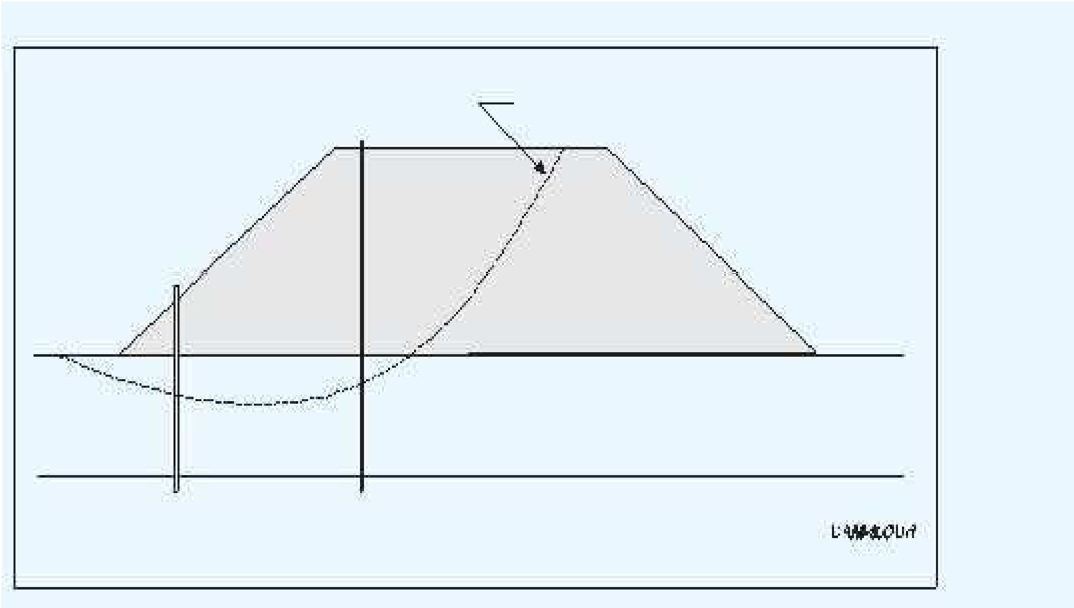
Slope Stability: Failure is an Example of Shearing Along Internal Surface



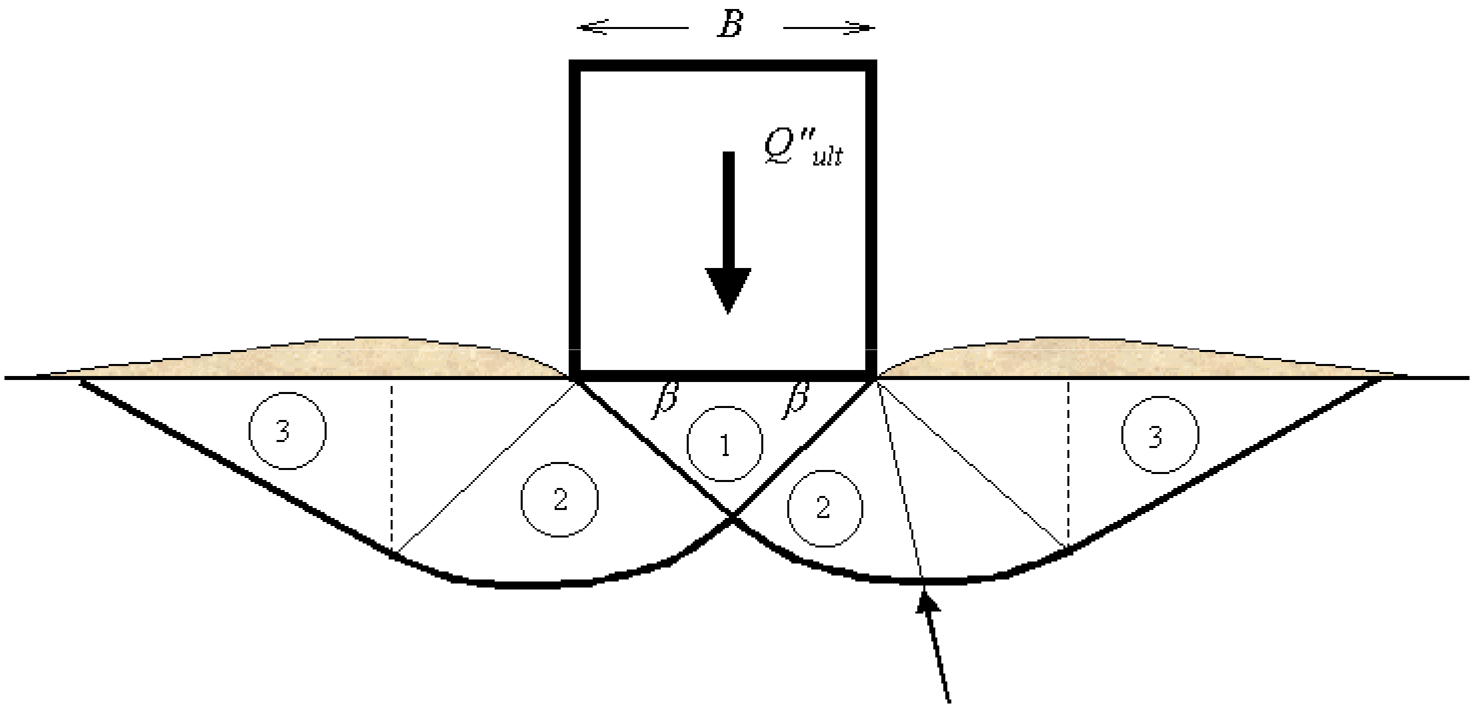


Mass Wasting: Shear Failure

Shear Failure: Earth Dam

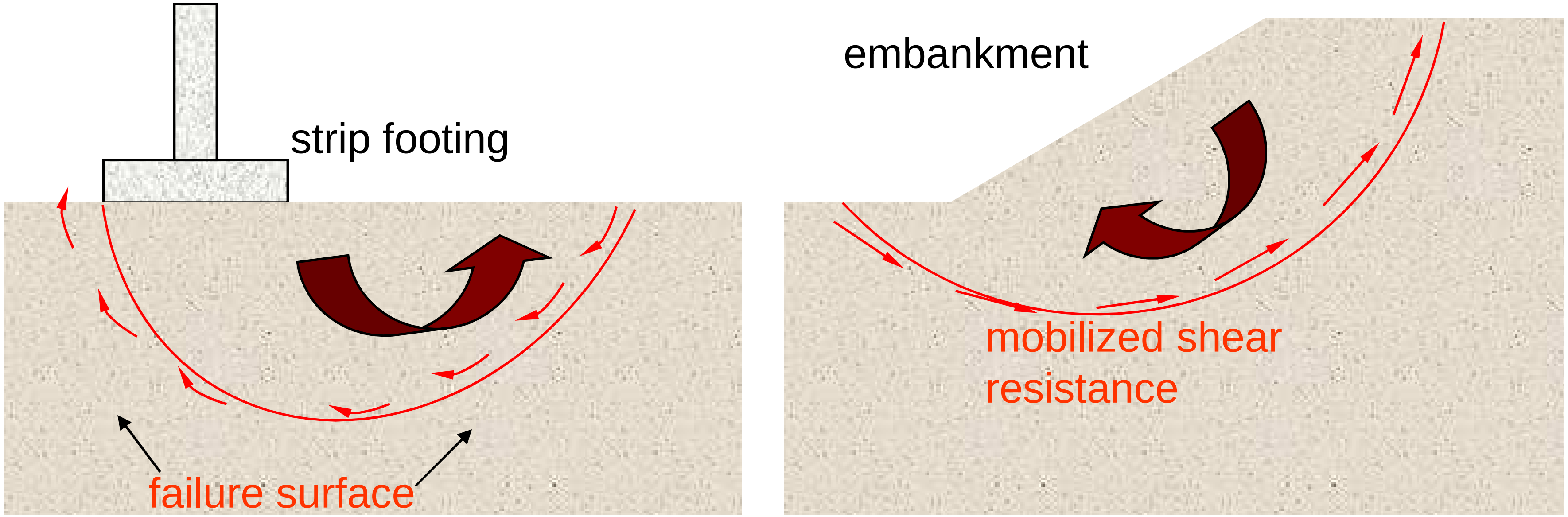


Shear Failure Under Foundation Load



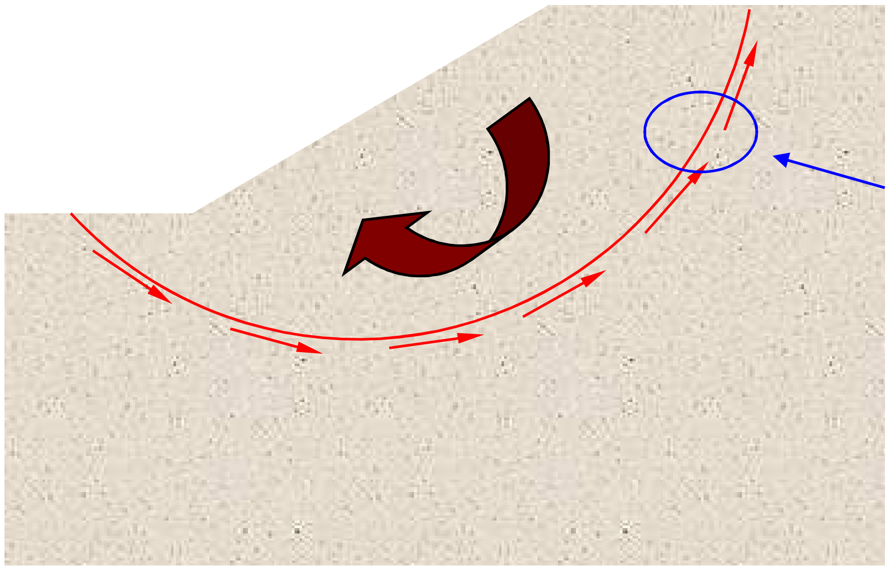
Shear failure

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



At failure, shear stress along the failure surface reaches the shear strength.

Shear failure

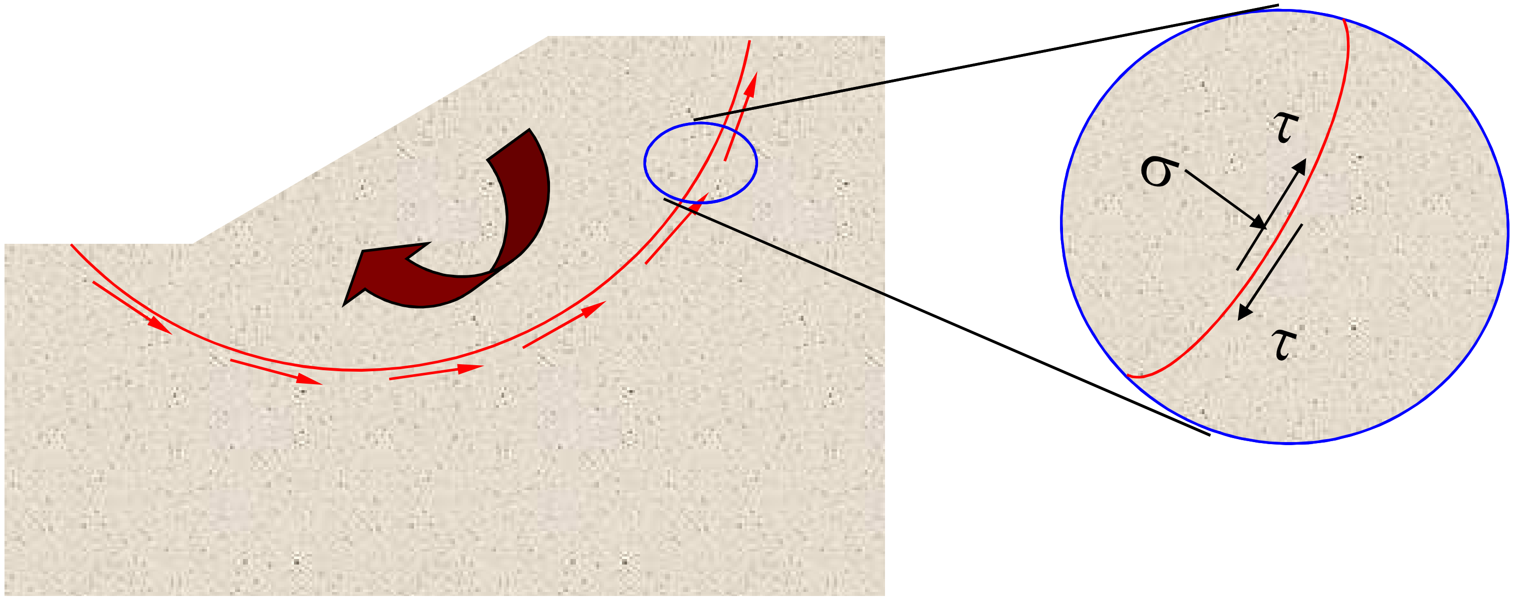


failure surface

The soil grains slide over each other along the failure surface.

No crushing of individual grains.

Shear failure mechanism



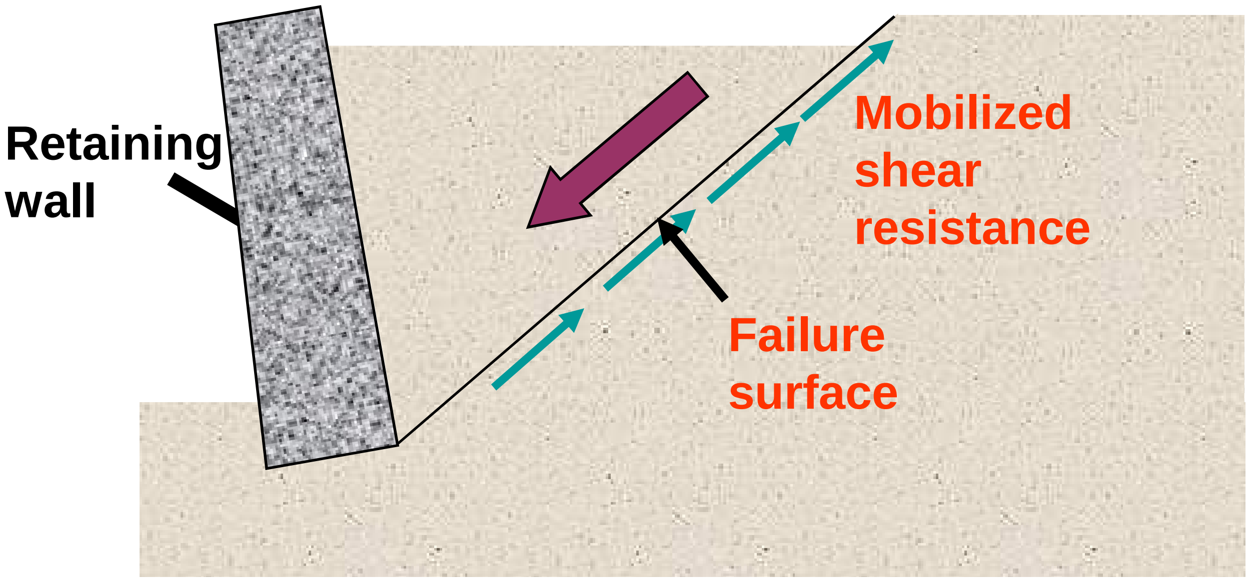
At failure, shear stress along the failure surface (τ) reaches the shear strength (τ_f).

Shear failure of soils

Soils generally fail in shear

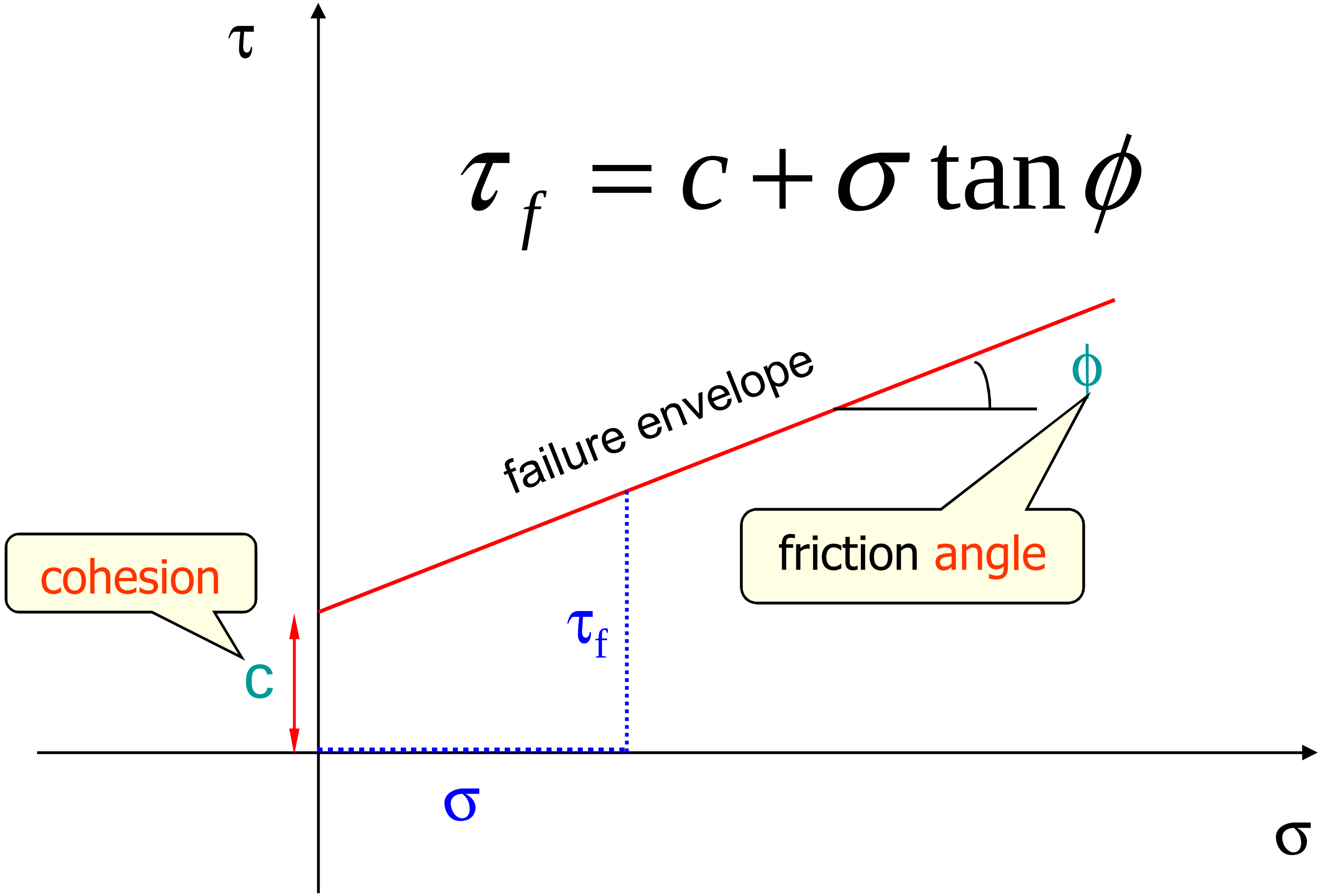
Shear failure of soils

Soils generally fail in shear



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

Mohr-Coulomb Failure Criterion

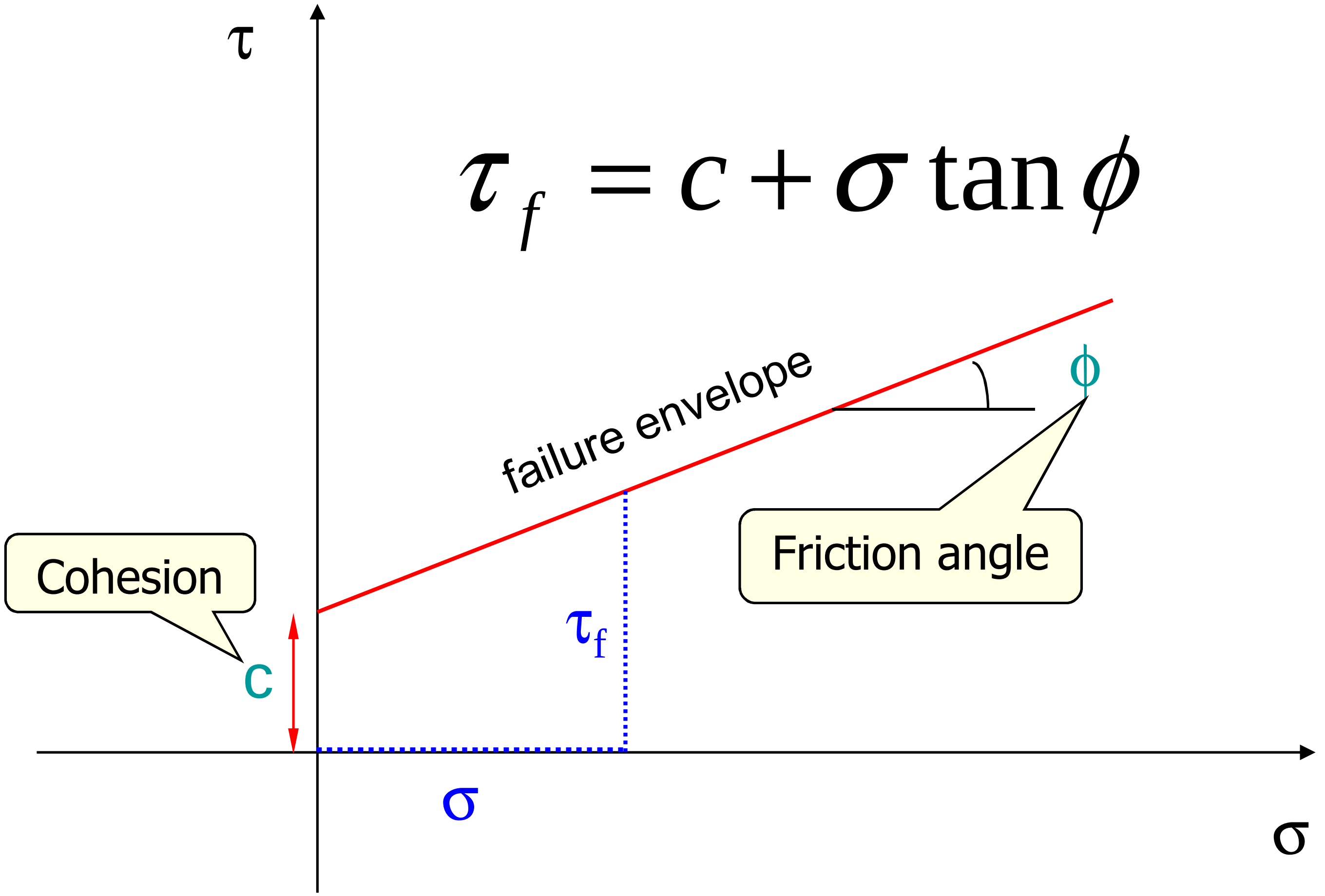


τ_f is the maximum shear stress the soil can take without failure, under normal stress of σ.

Mohr-Coulomb Failure Criterion

(in terms of total stresses)

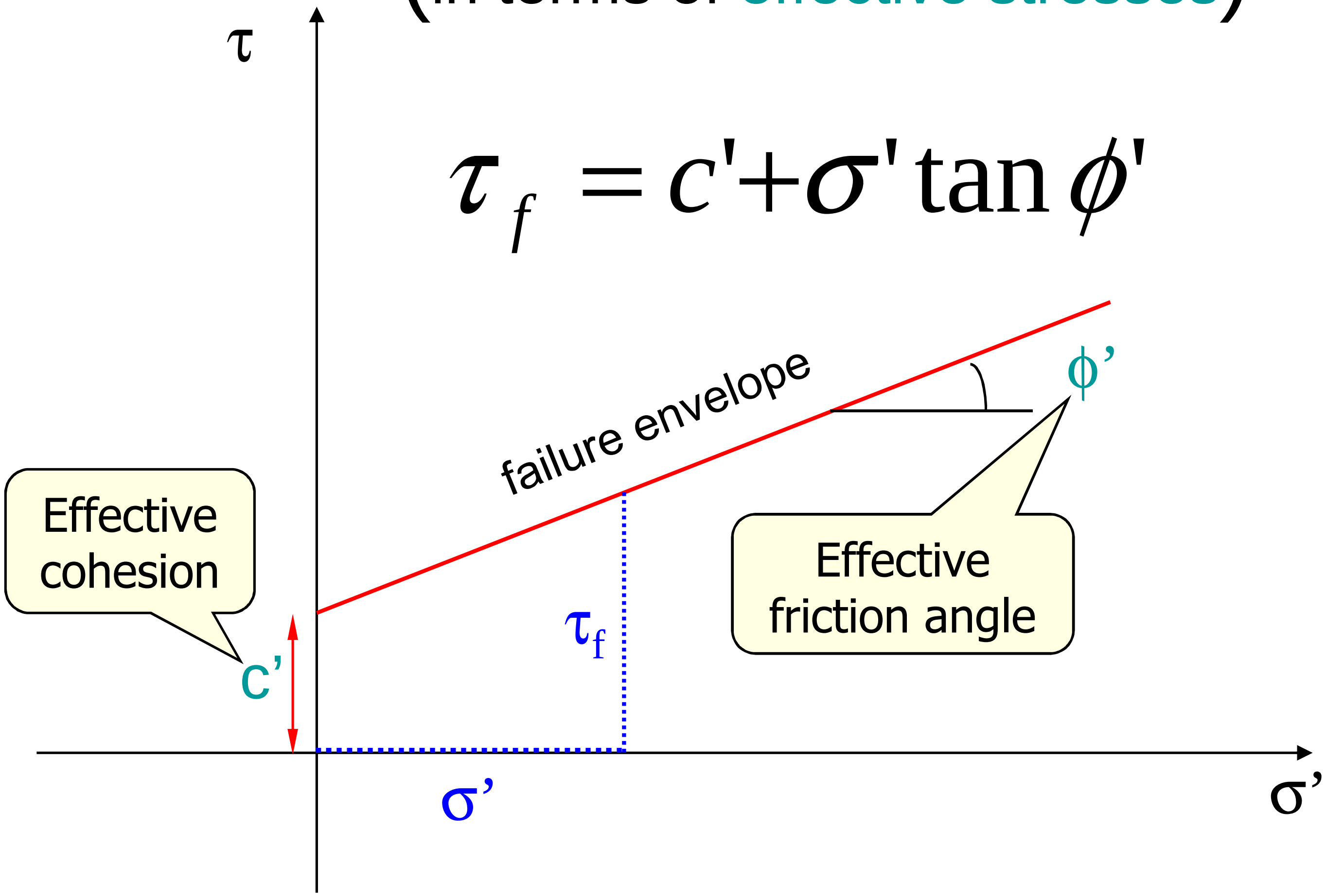
$$\tau_f = c + \sigma \tan \phi$$



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

Mohr-Coulomb Failure Criterion

(in terms of effective stresses)



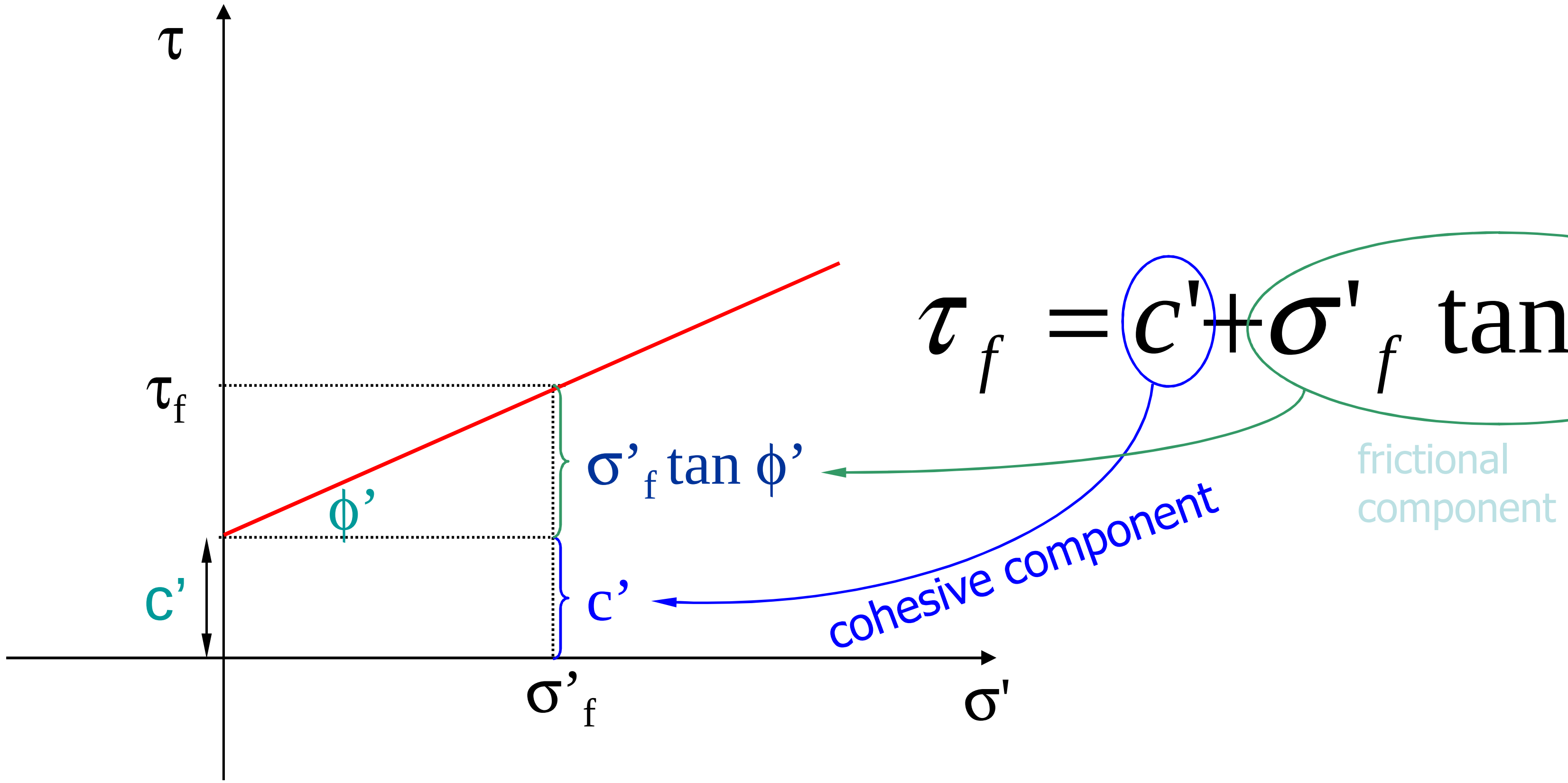
$$\sigma' = \sigma - u$$

u = pore water pressure

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

Mohr-Coulomb Failure Criterion

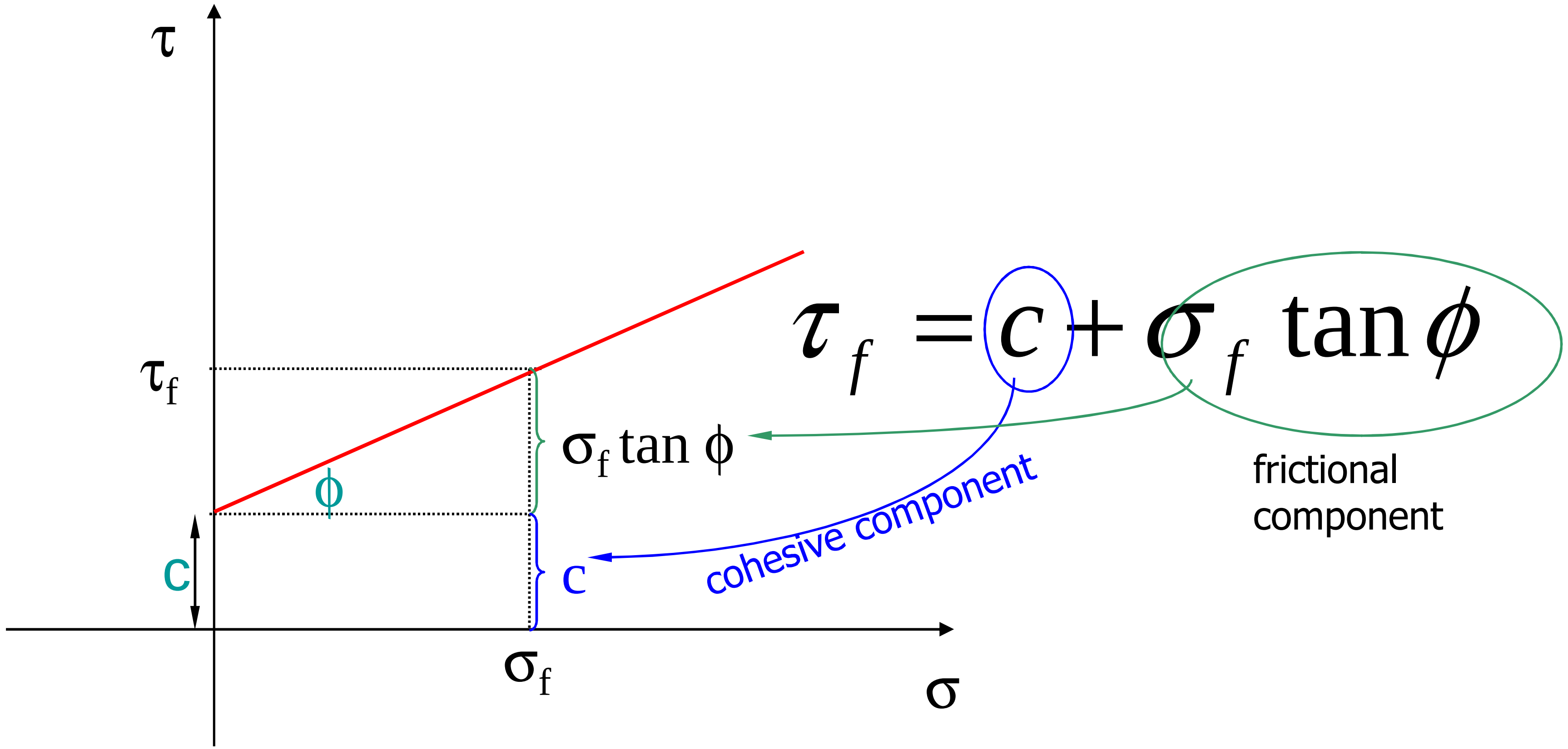
Shear strength consists of two components: cohesive and frictional.



$$\tau_f = c' + \sigma'_f \tan\phi'$$

Mohr-Coulomb Failure Criterion

Shear strength consists of two components: cohesive and frictional.

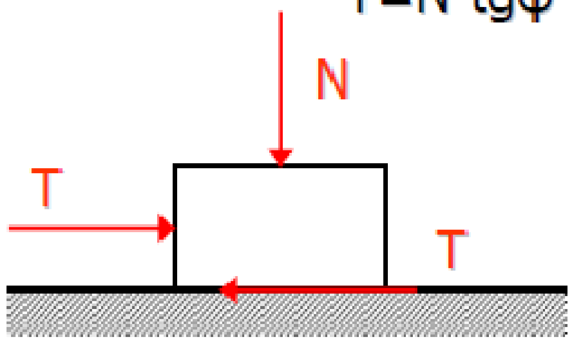


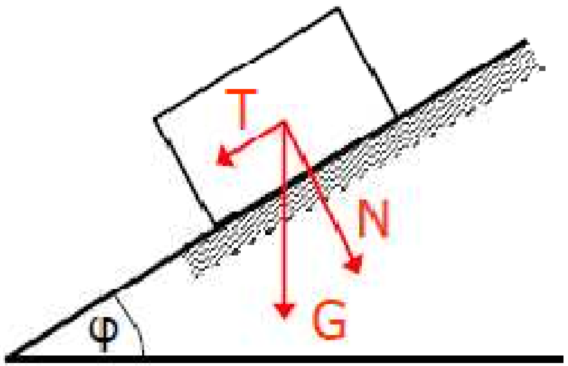
c and φ are measures of shear strength.

Higher the values, higher the shear strength.

Shear strength of soils

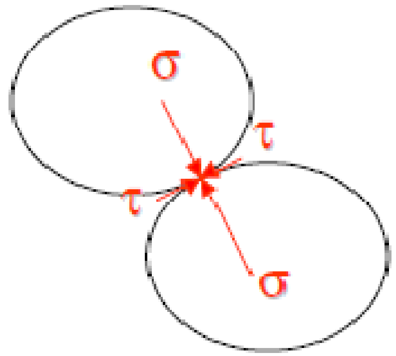
$T = N \cdot tg\varphi$





<u>Granular soils</u>

$\tau = \sigma \cdot \tan\varphi$

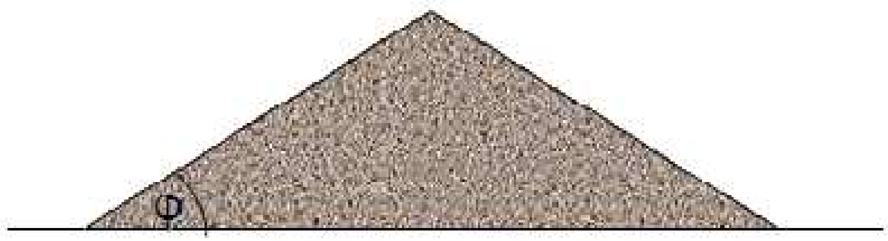


For soils this φ angle is called:

angle of internal friction or

friction angle

Angle of repose = φ



Shear strength of soils

Fine grained soils:

Their strength is, apart from from friction, due to internal forces holding the particles together

This propertiy is called cohesion, and soils possessing it are cohesive soils

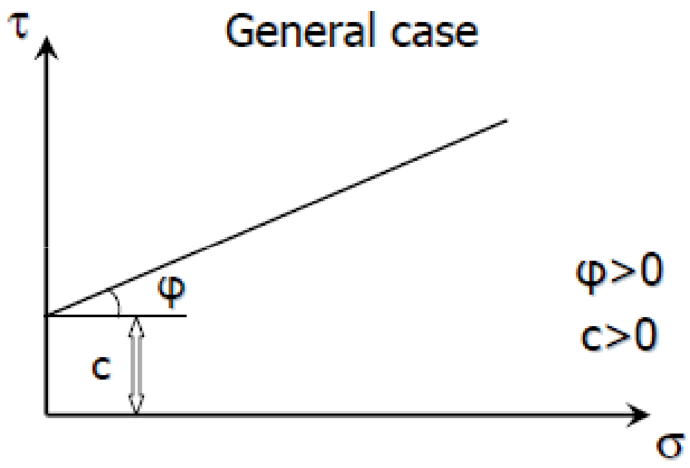
Coulomb's law extended to cohesive soils:

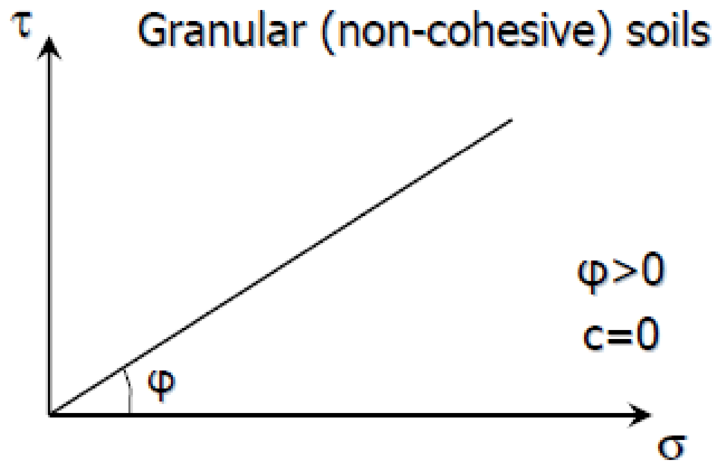
$$\tau = \sigma \cdot \tan\varphi + c$$

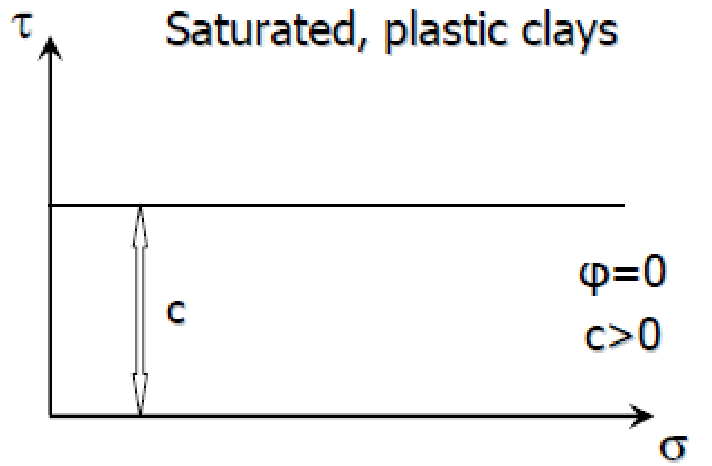
In case of saturated soils this can be expressed as:

$$\tau = (\sigma - u) \cdot \tan\varphi + c$$

Graphical represantation of Mohr Coulomb failure criteria







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

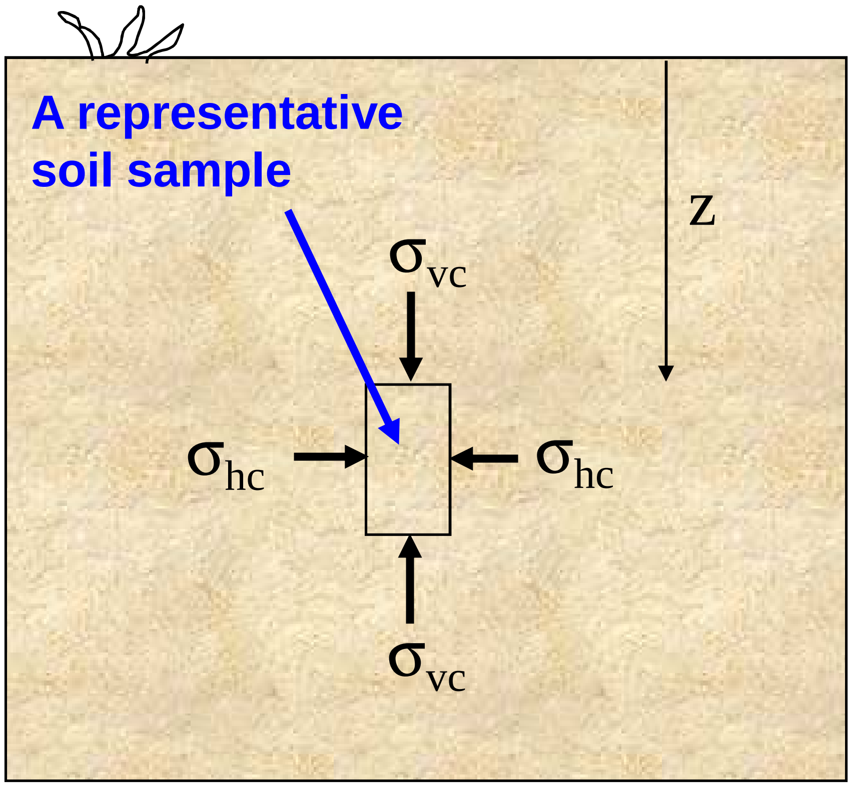
Other laboratory tests include, Direct simple shear test, torsional ring shear test, plane strain triaxial test, laboratory vane shear test, laboratory fall cone test

Field tests

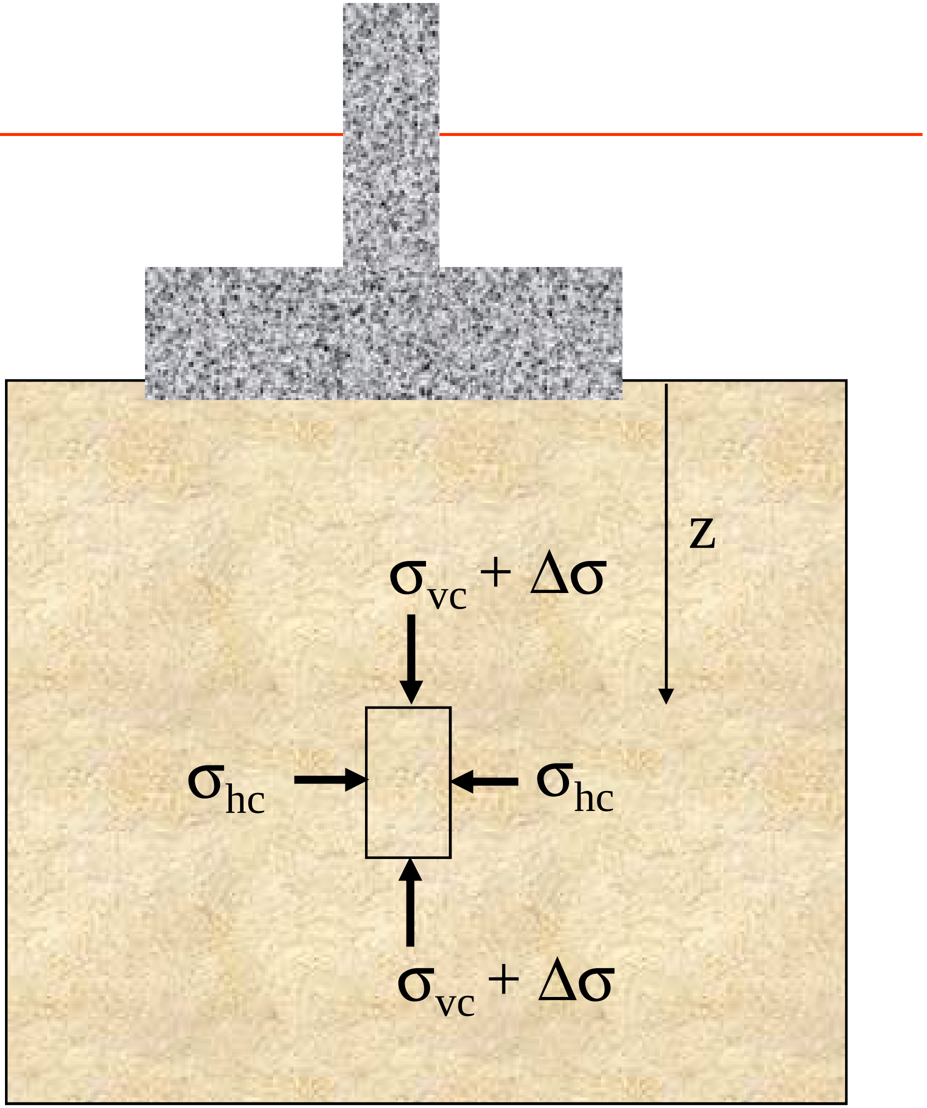
1. Vane shear test
2. Torvane
3. Pocket penetrometer
4. Fall cone
5. Pressuremeter
6. Static cone penetrometer
7. Standard penetration test

Laboratory tests

Field conditions



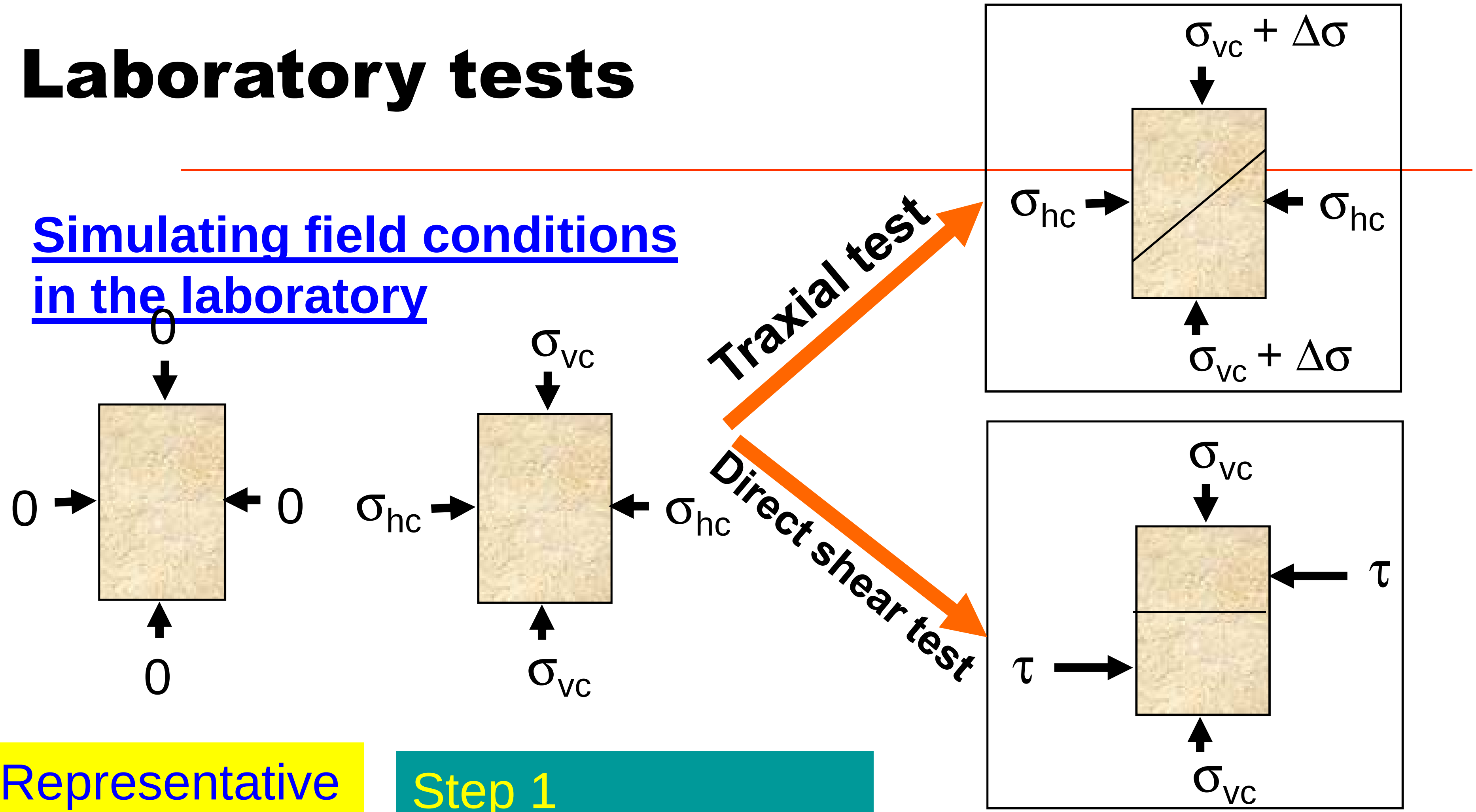
Before construction



After and during construction

Laboratory tests

Simulating field conditions in the laboratory



Representative soil sample taken from the site

Step 1

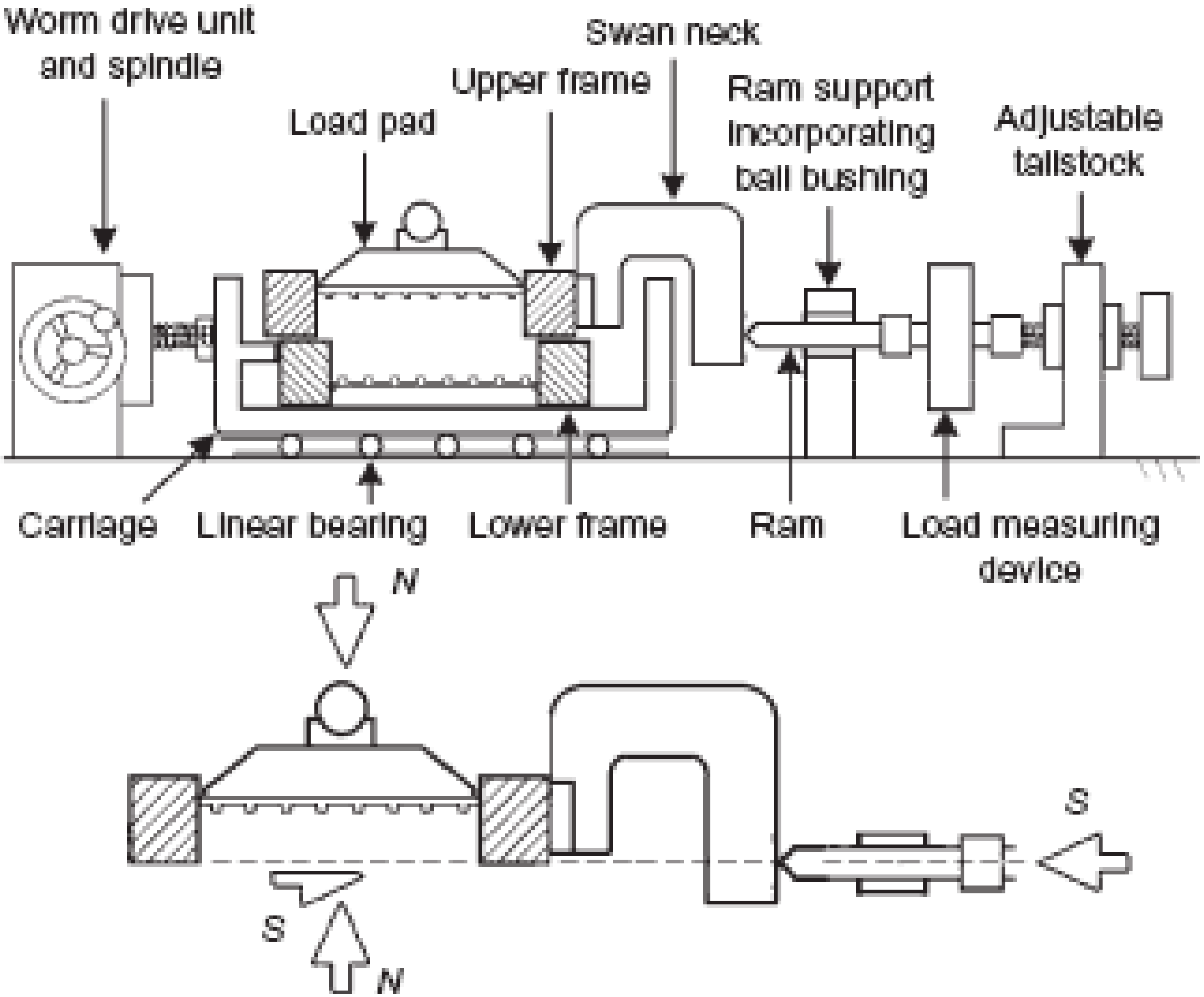
Set the specimen in the apparatus and apply the initial stress condition

Step 2

Apply the corresponding field stress conditions

Direct shear test

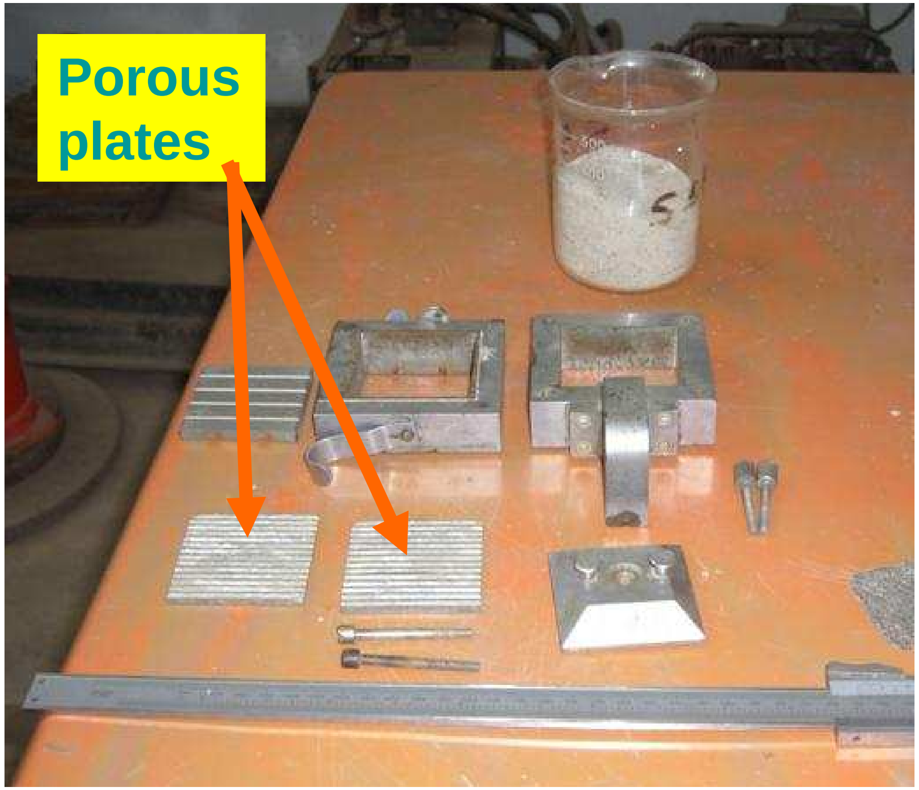
Schematic diagram of the direct shear apparatus



Direct shear test

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

Preparation of a sand specimen

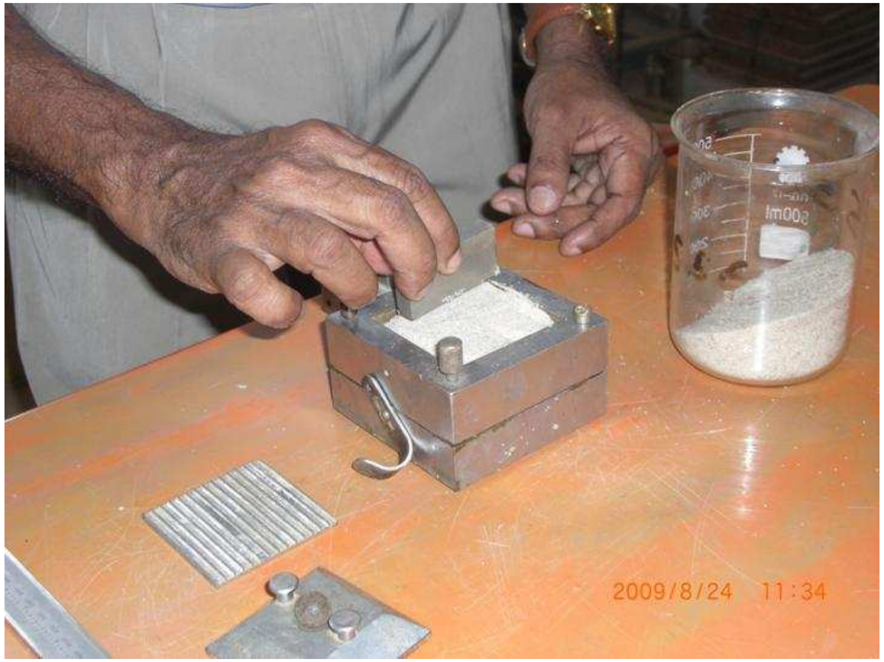


Components of the shear box

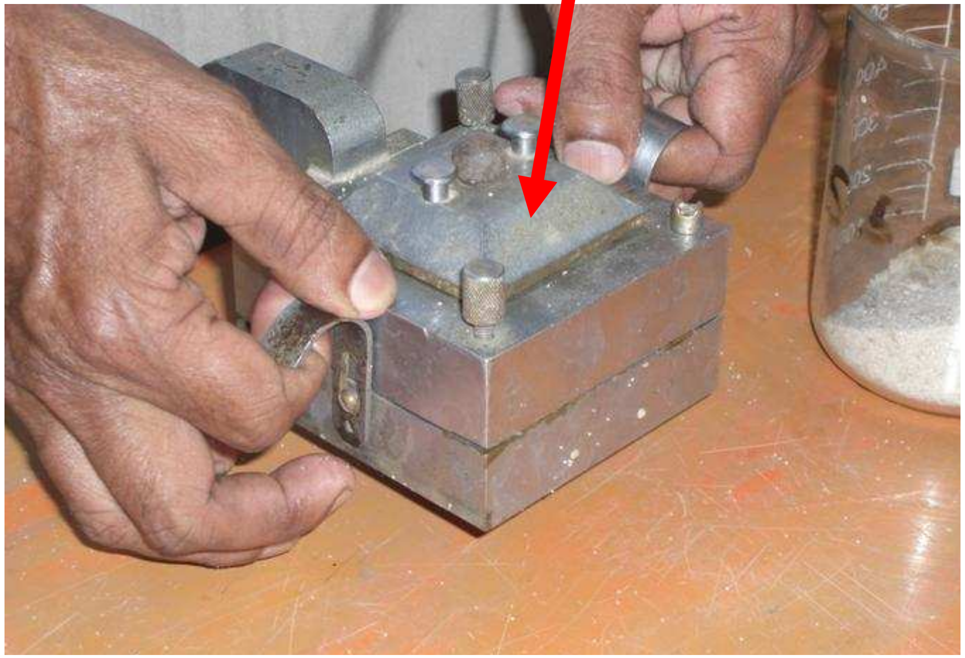
Preparation of a sand specimen

Direct shear test

Preparation of a sand specimen



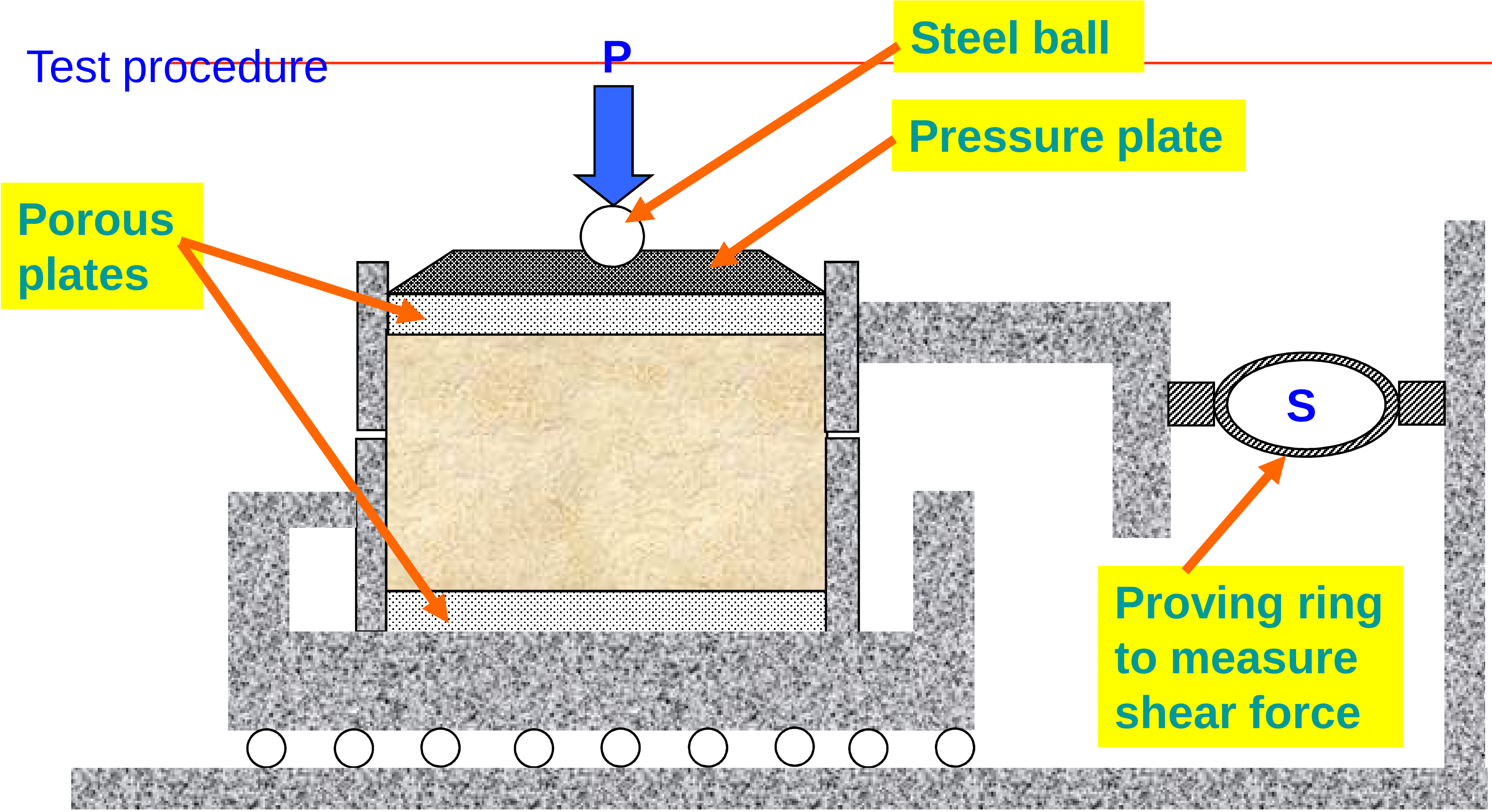
Leveling the top surface of specimen



Specimen preparation completed

Direct shear test

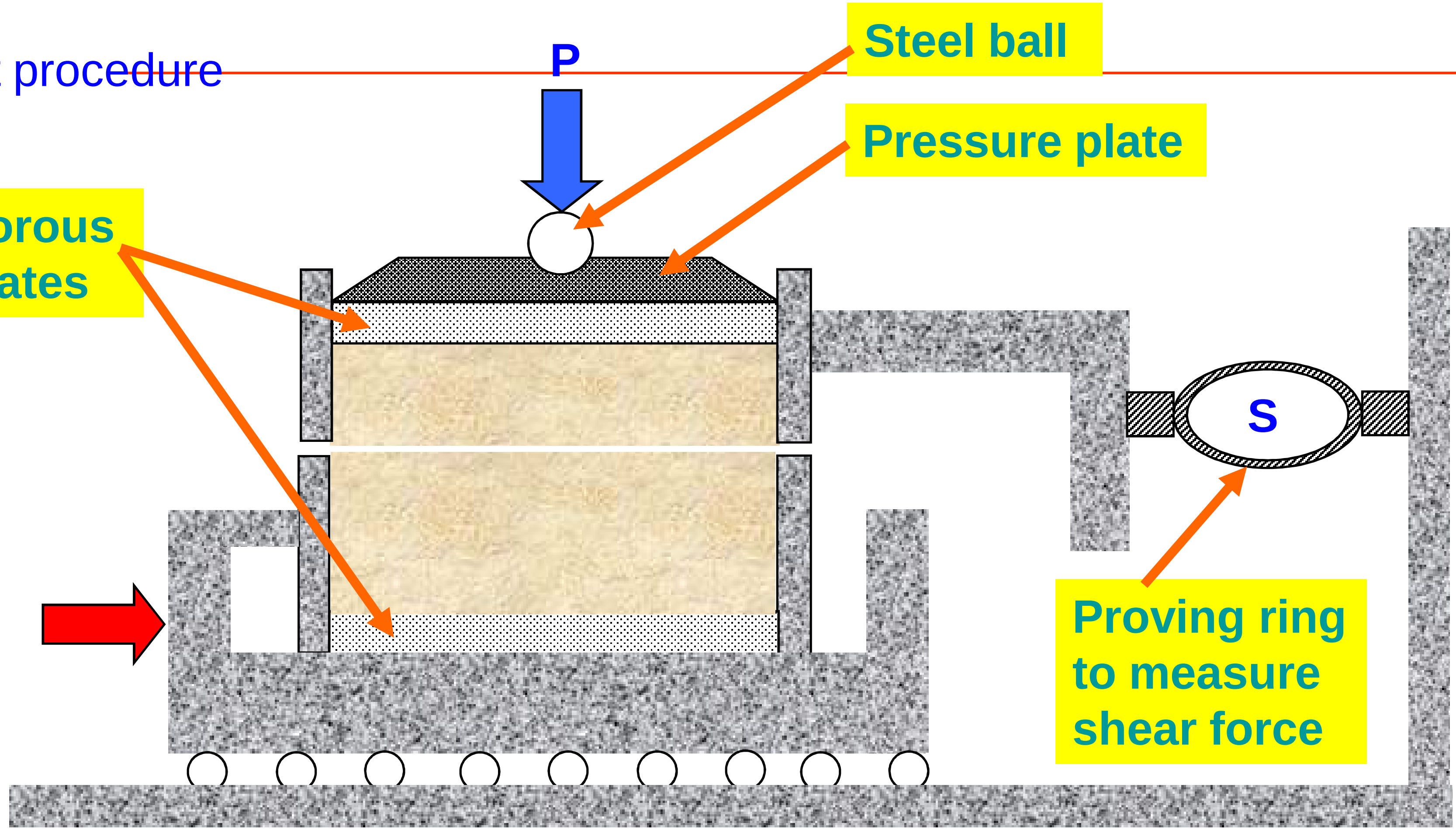
Test procedure



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

Direct shear test

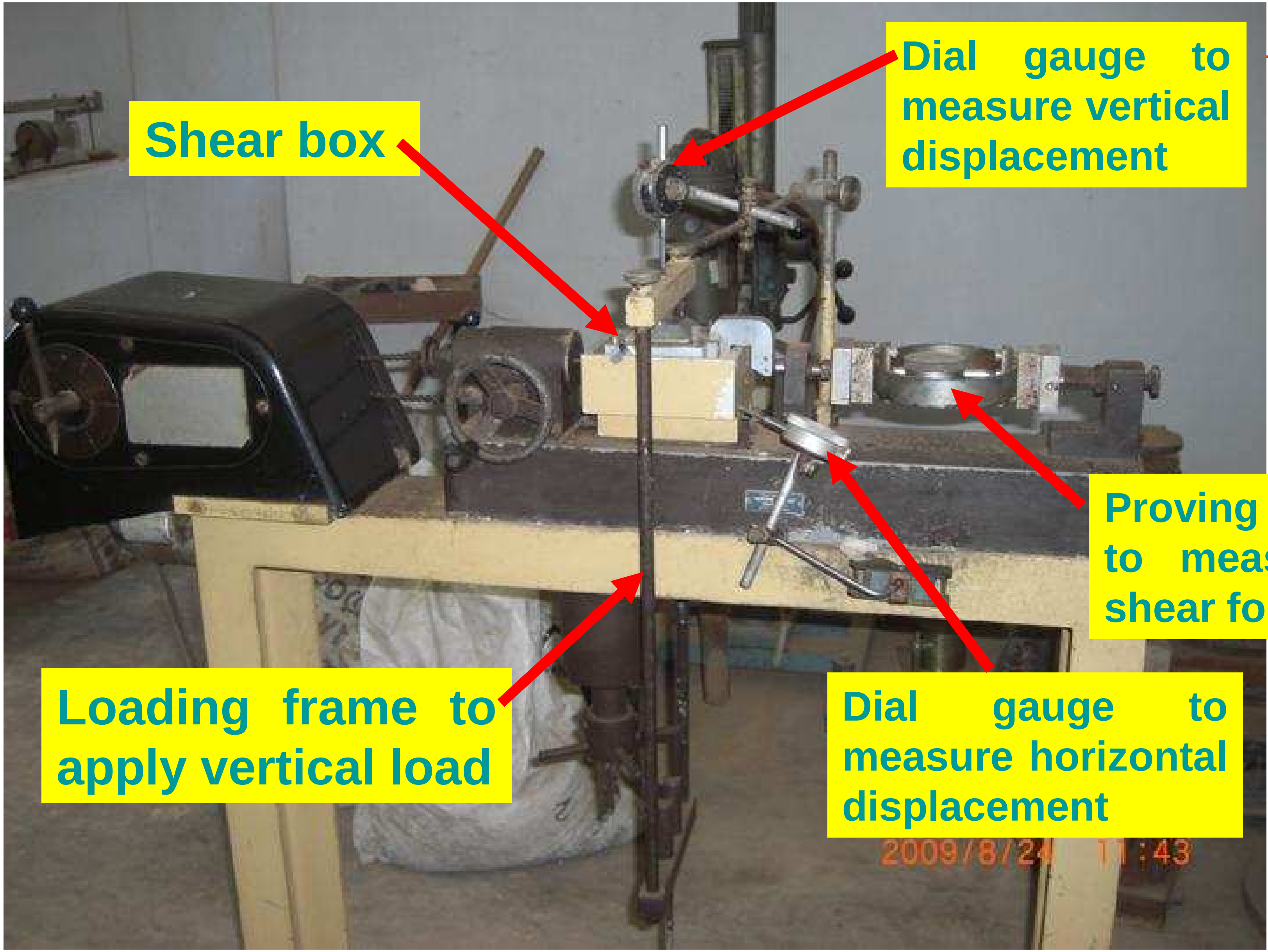
Test procedure



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

Direct shear test



Direct shear test

Analysis of test results

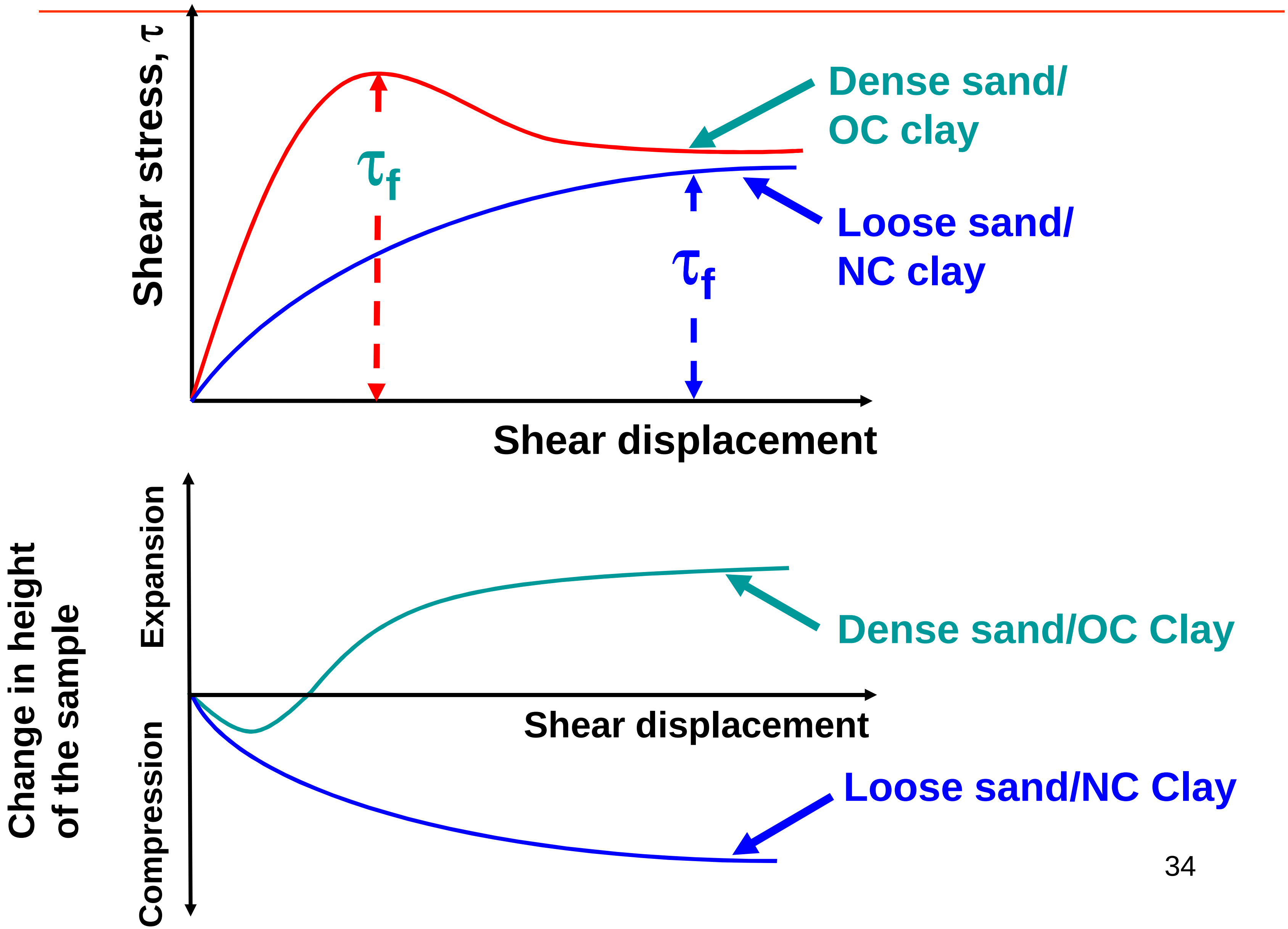
$$\sigma = \text{Normal stress} = \frac{\text{Normal force (P)}}{\text{Area of cross section of the sample}}$$

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

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

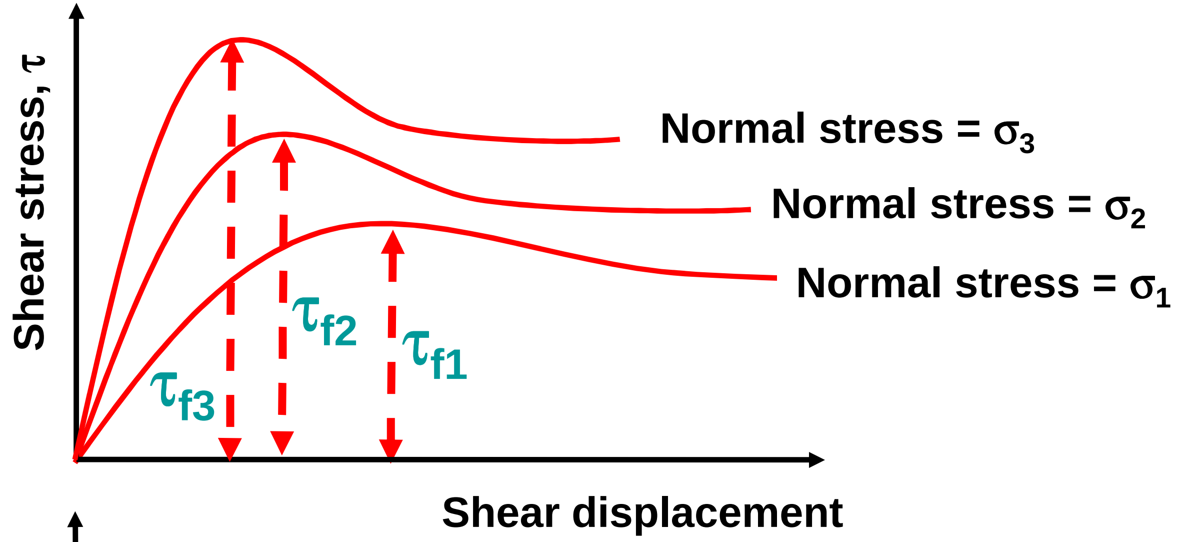
Direct shear tests on sands

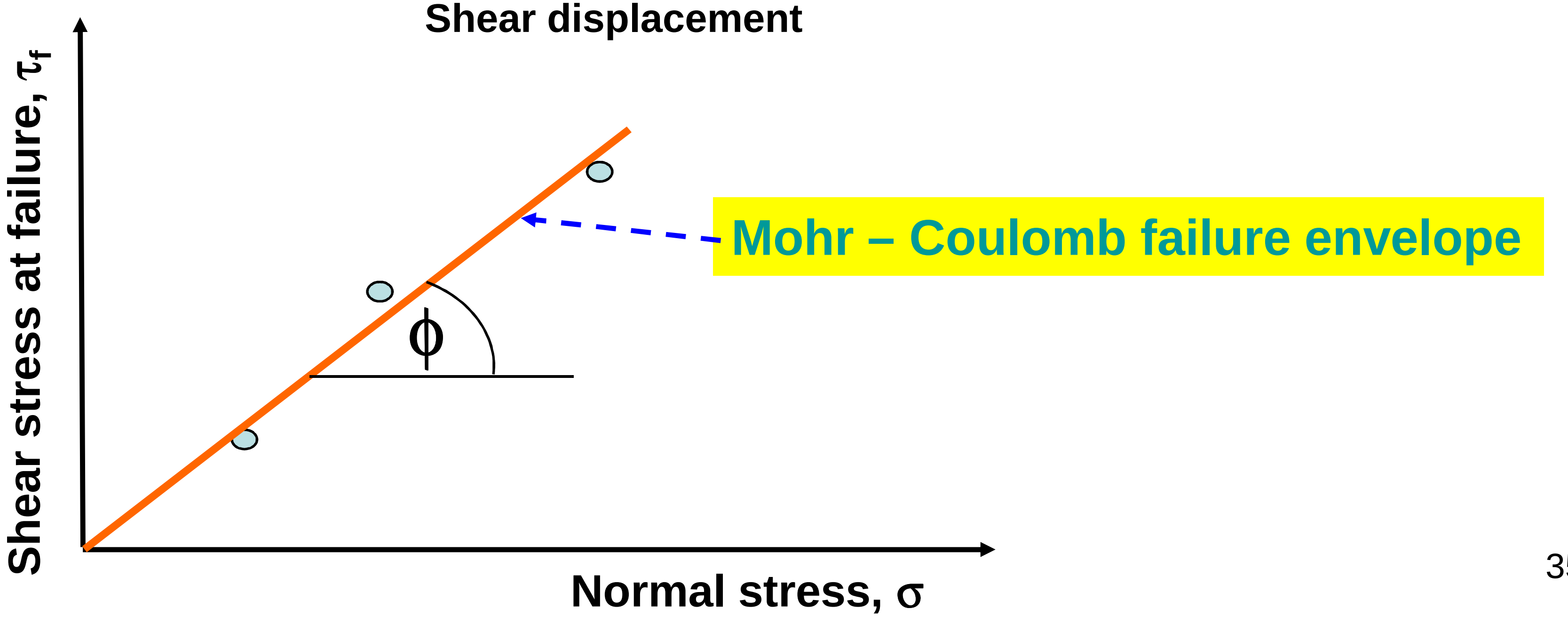
Stress-strain relationship



Direct shear tests on sands

How to determine strength parameters c and ϕ





Direct shear tests on sands

Some important facts on strength parameters c and ϕ of sand

Sand is cohesionless hence $c = 0$

Direct shear tests are drained and pore water pressures are dissipated, hence $u = 0$

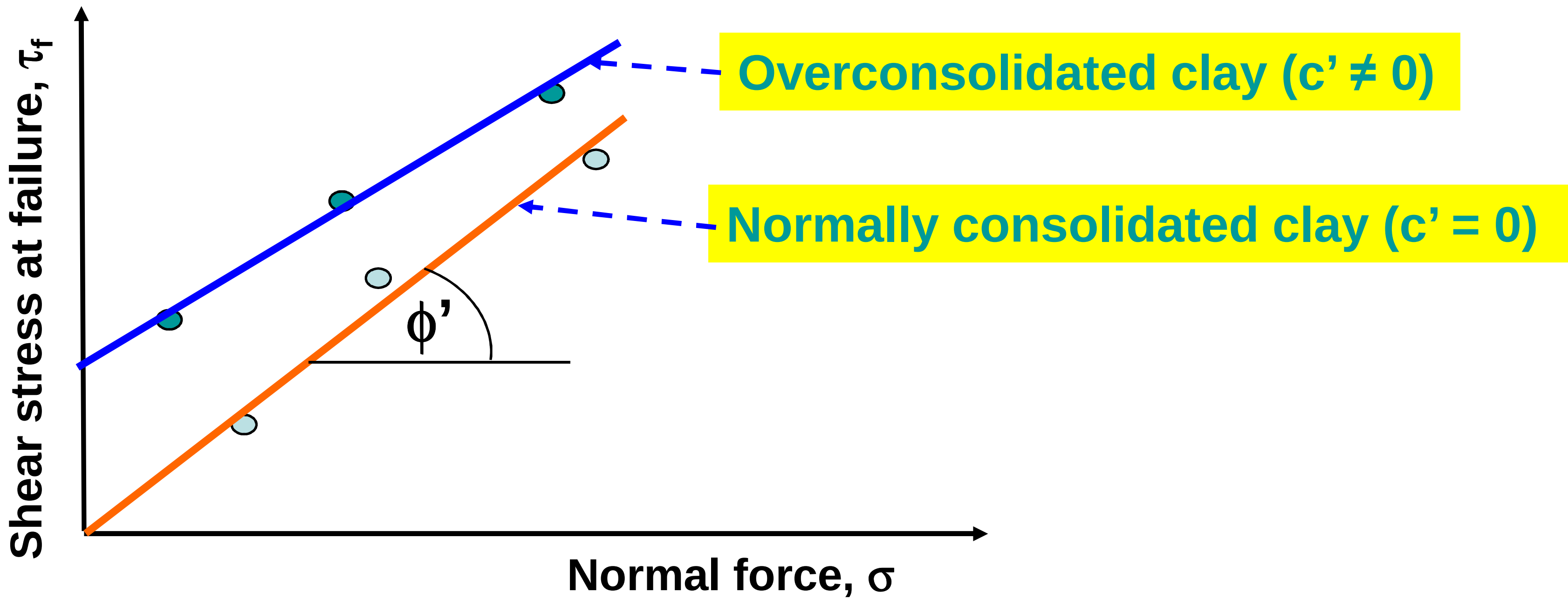
Therefore,

$\phi' = \phi$ and $c' = c = 0$

Direct shear tests on clays

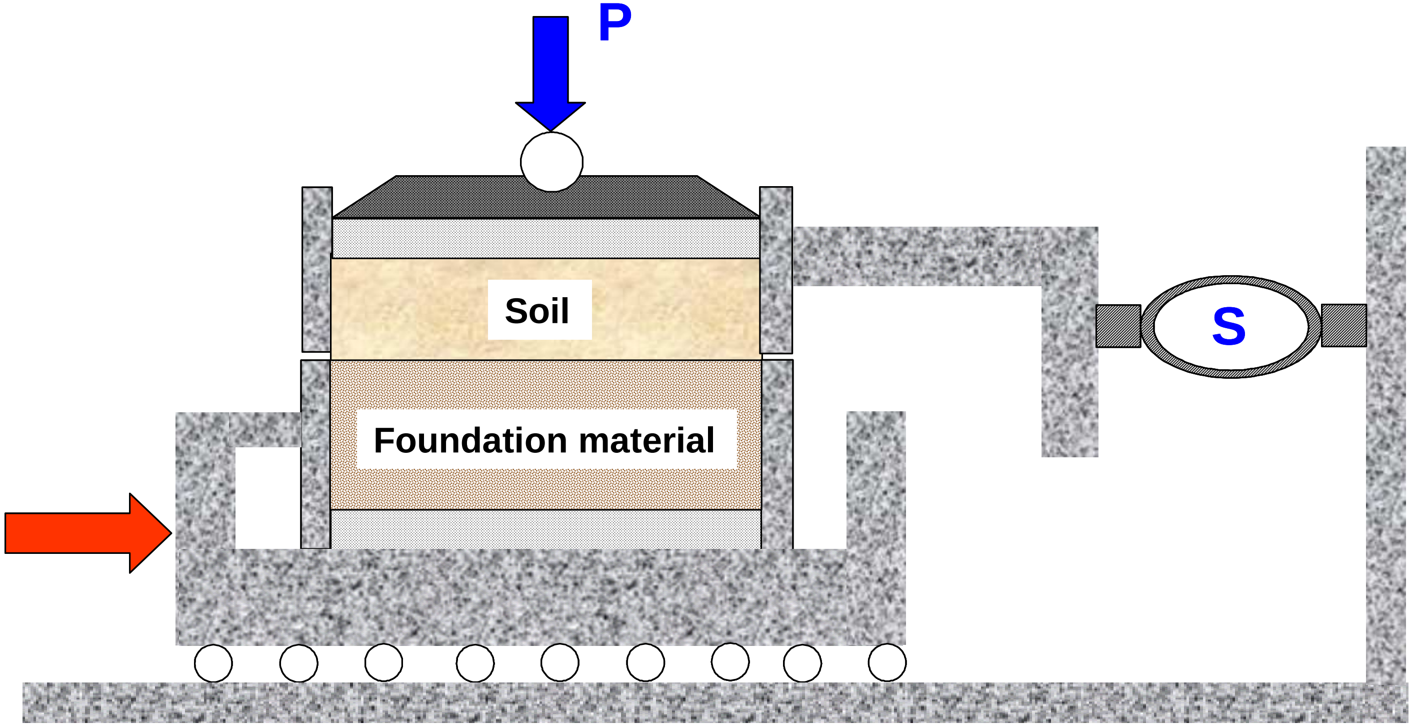
In case of clay, horizontal displacement should be applied at a very slow rate to allow dissipation of pore water pressure (therefore, one test would take several days to finish)

Failure envelopes for clay from drained direct shear tests



Interface tests on direct shear apparatus

In many foundation design problems and retaining wall problems, it is required to determine the angle of internal friction between soil and the structural material (concrete, steel or wood)



$$\tau_f = c_a + \sigma' \tan \delta$$

Where,

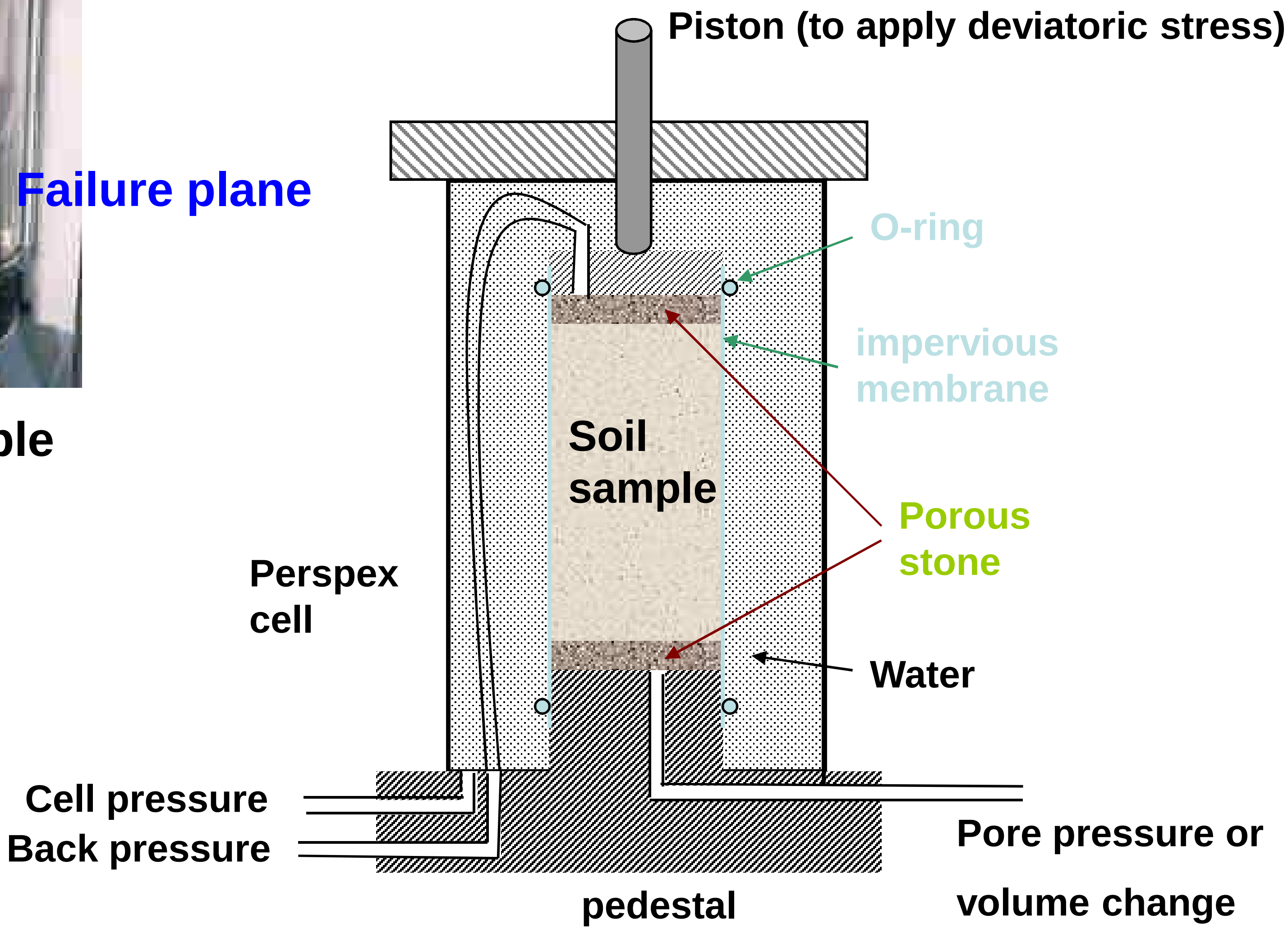
c_a = adhesion,

δ = angle of internal friction

Triaxial Shear Test

Failure plane

Soil sample at failure



Triaxial Shear Test

Specimen preparation (undisturbed sample)

Sampling tubes

Sample extruder

Triaxial Shear Test

Specimen preparation (undisturbed sample)

Edges of the sample are carefully trimmed

Setting up the sample in the triaxial cell

Triaxial Shear Test

Specimen preparation (undisturbed sample)

Sample is covered with a rubber membrane and sealed

Cell is completely filled with water

Triaxial Shear Test

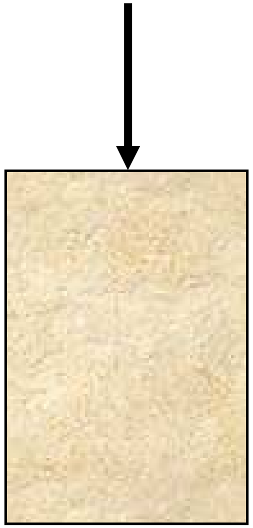
Specimen preparation (undisturbed sample)

Proving ring to measure the deviator load

Dial gauge to measure vertical displacement

Unconfined Compression Test (UC Test)

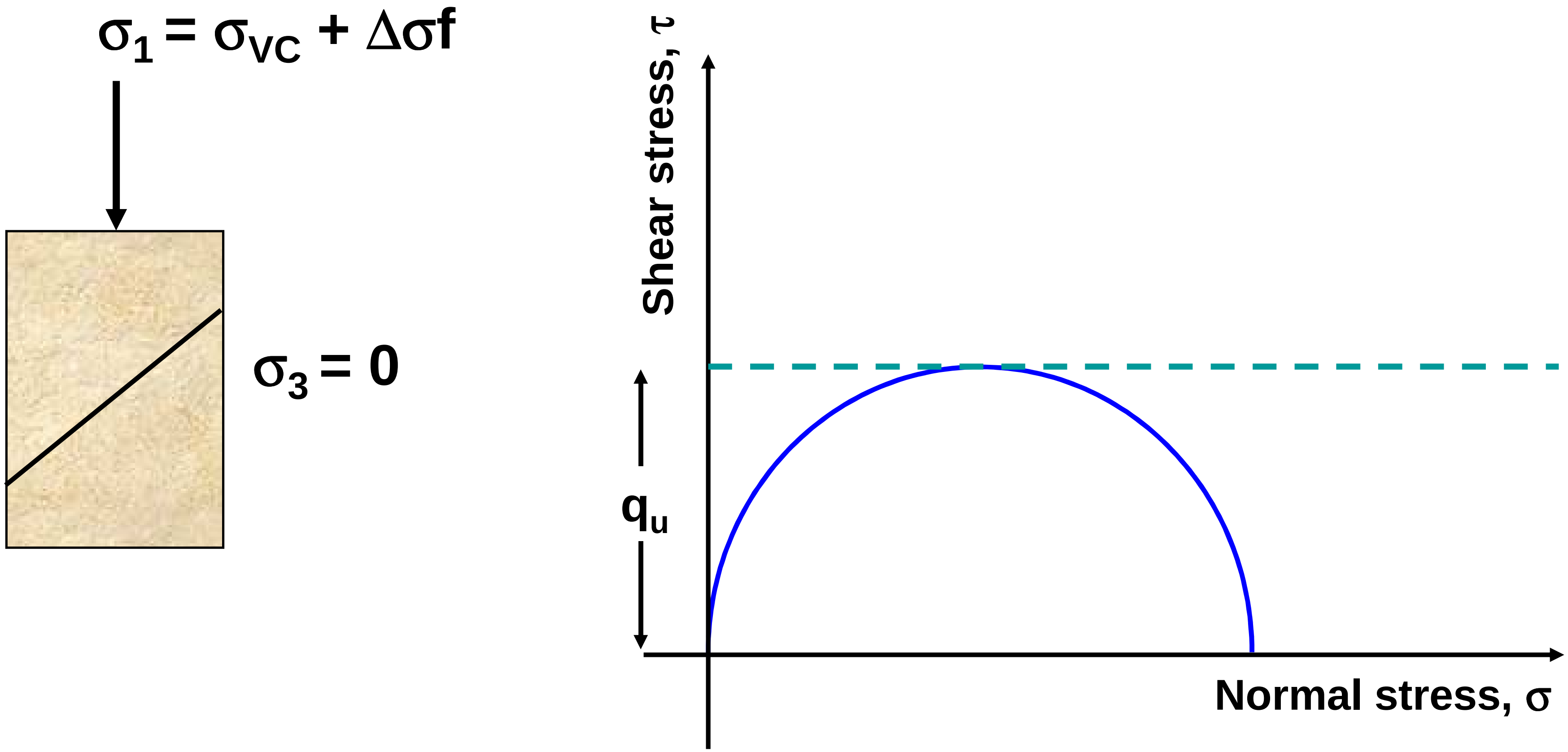
$$\sigma_1 = \sigma_{VC} + \Delta\sigma$$



$$\sigma_3 = 0$$

Confining pressure is zero in the UC test

Unconfined Compression Test (UC Test)



$$\tau_f = \sigma_1/2 = q_u/2 = c_u$$

THE END

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