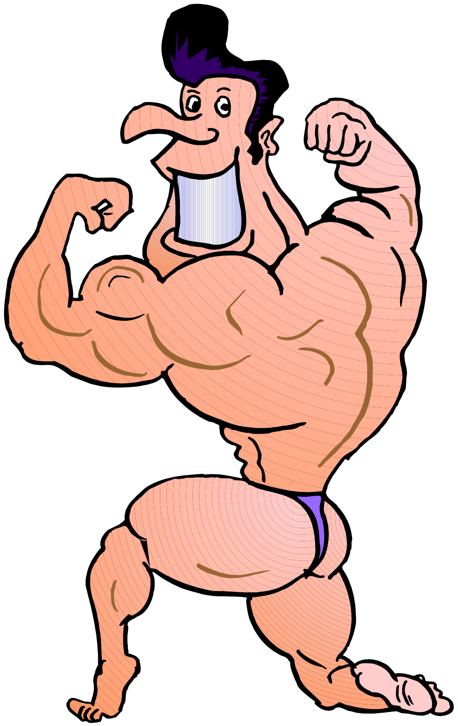
# SOIL SHEAR STRENGTH



**Prepared by:**

**Dr. Hetty**

**Muhammad Azril**

**Fauziah Kassim**

**Norafida**

# What is shear strength

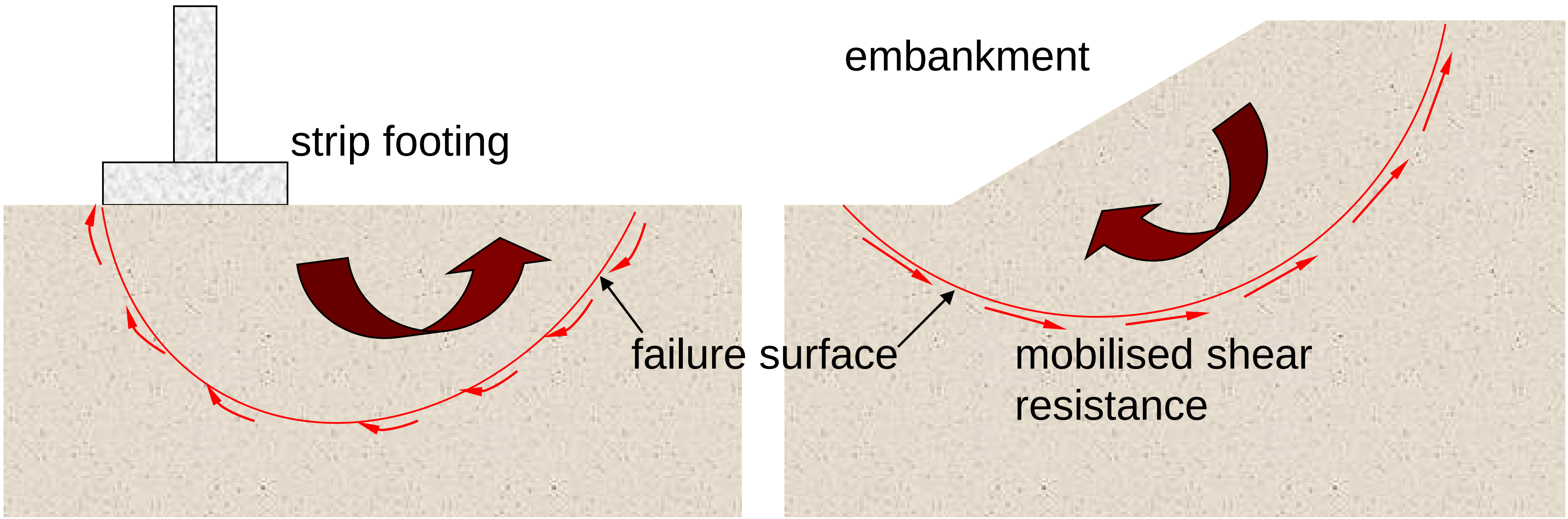
**Shear strength of a soil is the maximum internal resistance to applied shearing forces**

## Why it is important

**The safety if any geotechnical structure dependent on the strength of the soil. If the soil fails, a structure founded on it can collapse, endangering lives and causing economic damage**

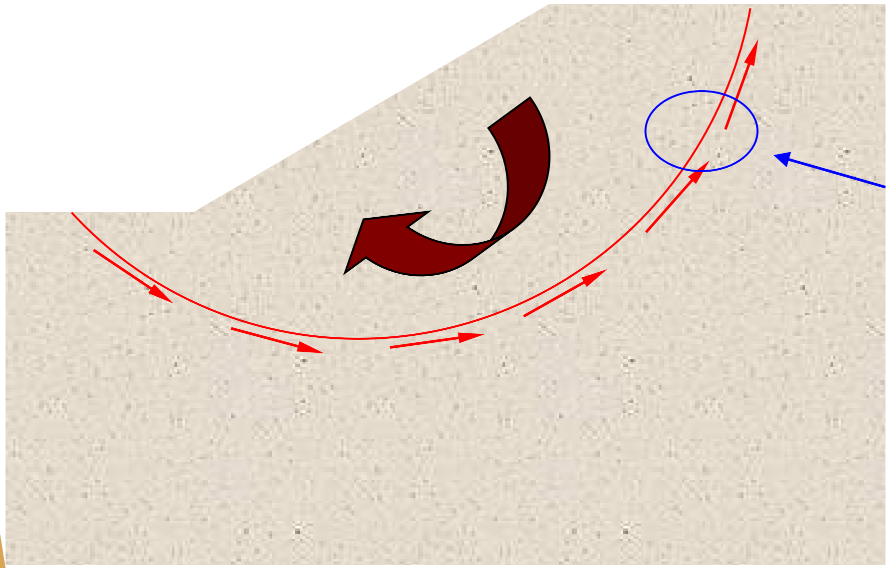
# Shear failure

Soils generally fail in shear




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

# Shear failure

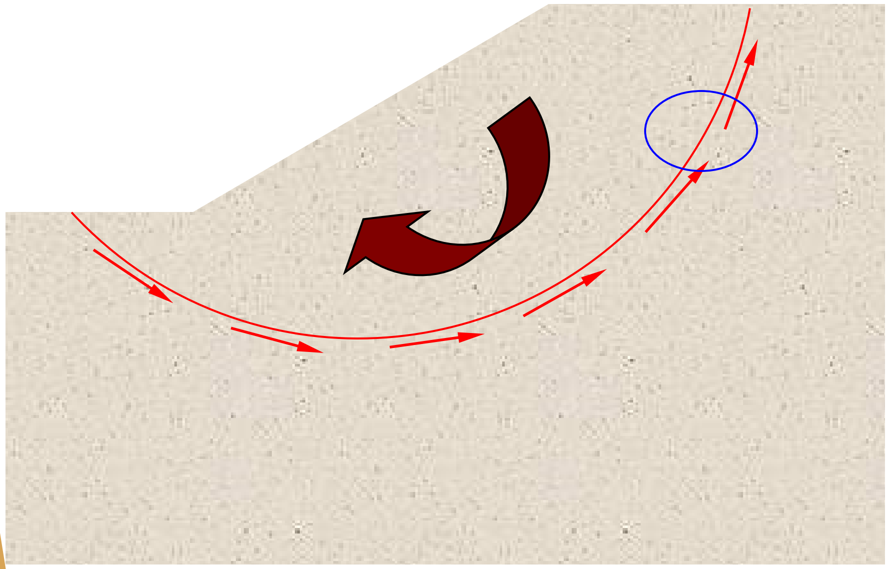


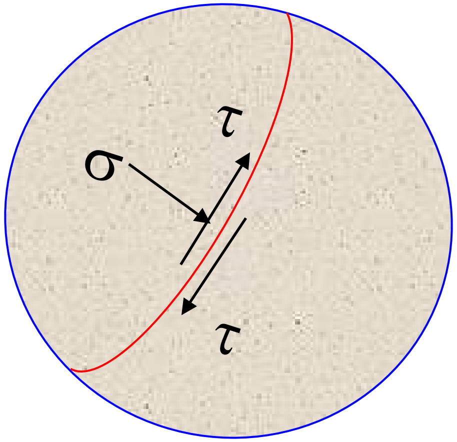
failure surface

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

No crushing of individual grains.

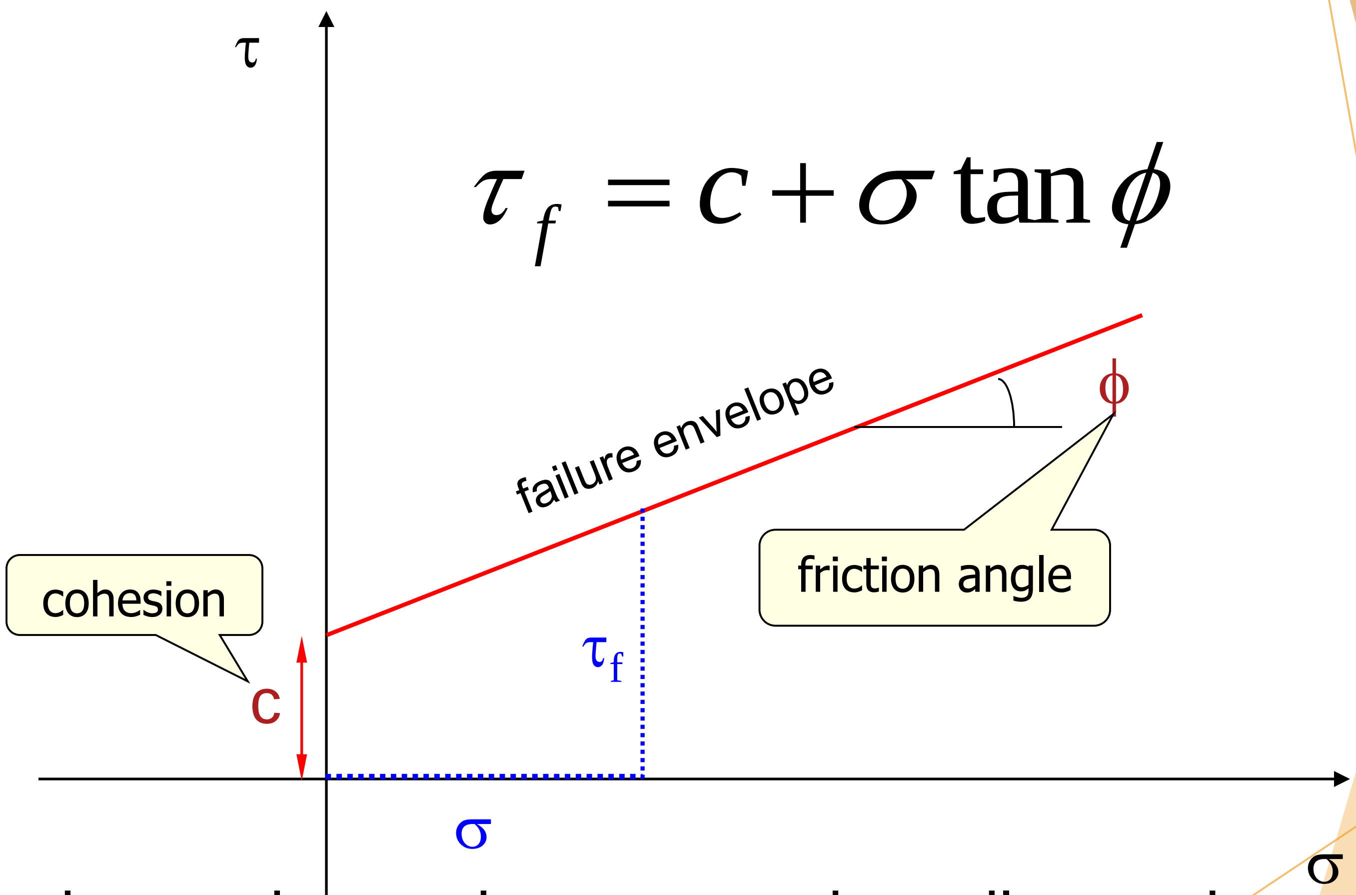
# Shear failure






At failure, shear stress along the failure surface ($\tau$) reaches the shear strength ($\tau_f$).

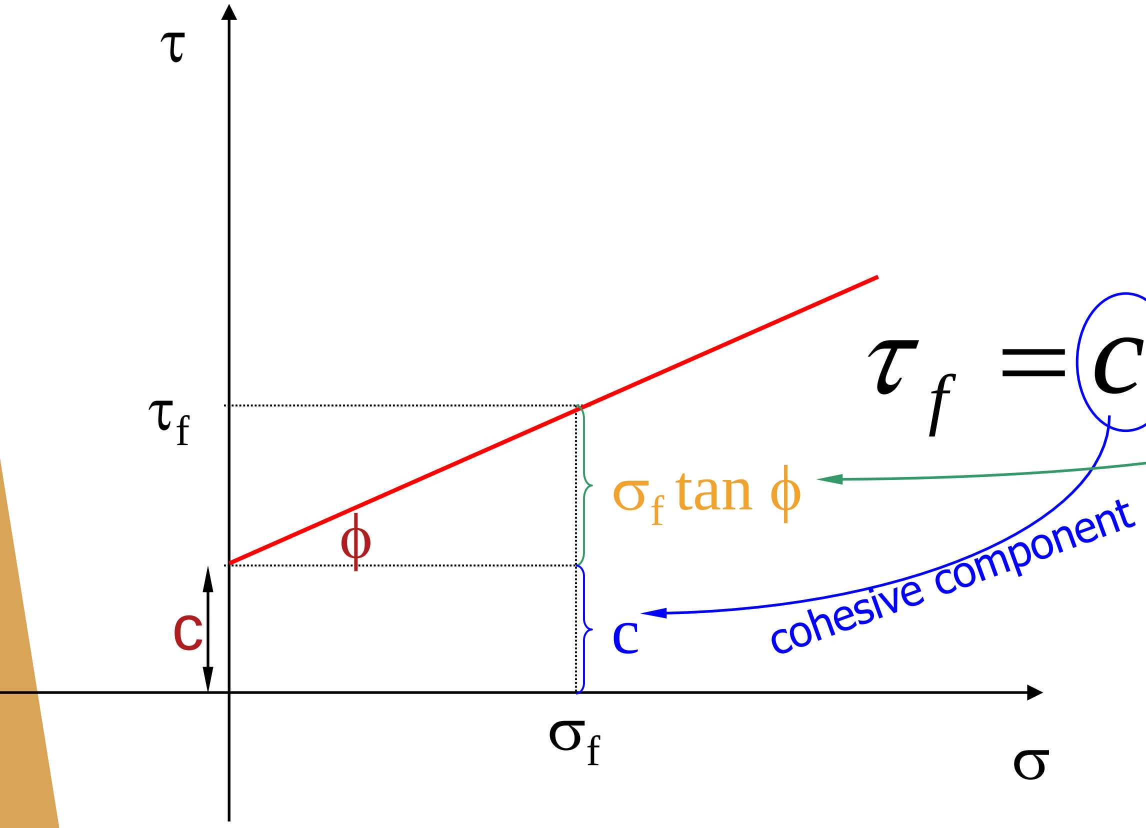
# Mohr-Coulomb Failure Criterion




$\tau_f$ is the maximum shear stress the soil can take without failure, under normal stress of $\sigma$.

# Mohr-Coulomb Failure Criterion

Shear strength consists of two components: cohesive and frictional.




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

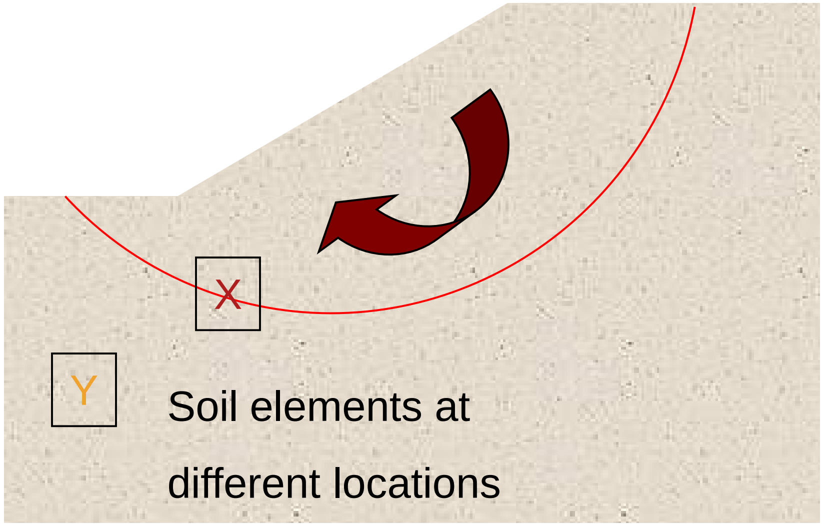

c and $\phi$ are measures of shear strength.

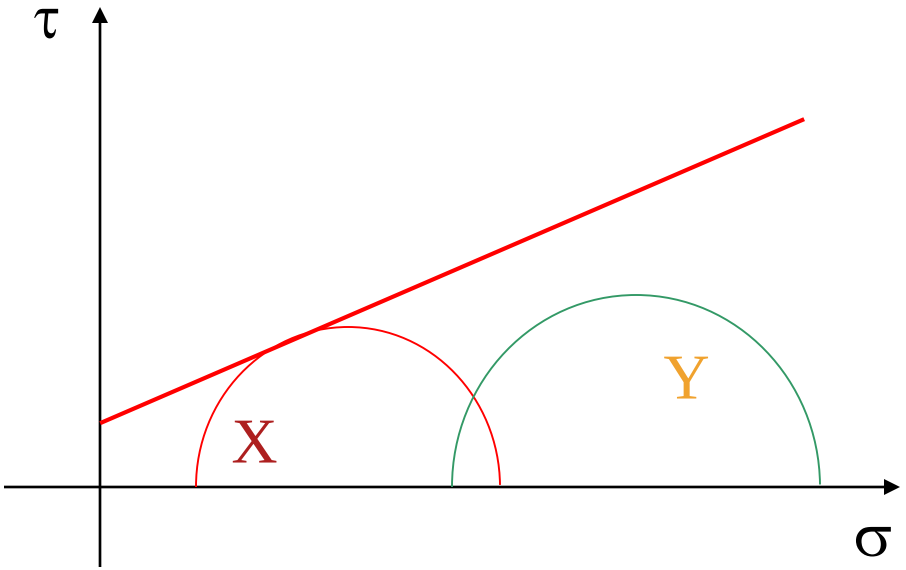
Higher the values, higher the shear strength.

# Factors controlling shear strength of soils

- **Soil composition (basic soil material)**: mineralogy, grain size and grain size distribution, shape of particles, pore fluid type and content, ions on grain and in pore fluid.
- **State (initial)**: Define by the initial void ratio, effective normal stress and shear stress (stress history). State can be describe by terms such as: loose, dense, overconsolidated, normally consolidated, stiff, soft, contractive, dilative, etc.
- **Structure:** Refers to the arrangement of particles within the soil mass; the manner the particles are packed or distributed. Features such as layers, joints, fissures, slickensides, voids, pockets, cementation, etc, are part of the structure. Structure of soils is described by terms such as: undisturbed, disturbed, remolded, compacted, cemented; flocculent, honey-combed, single-grained; flocculated, deflocculated; stratified, layered, laminated; isotropic and anisotropic.
- **Loading conditions:** Effective , i.e., drained, and undrained; and type of loading, i.e., magnitude, rate (static, dynamic), and time history (monotonic, cyclic)).

# Mohr Circles & Failure Envelope



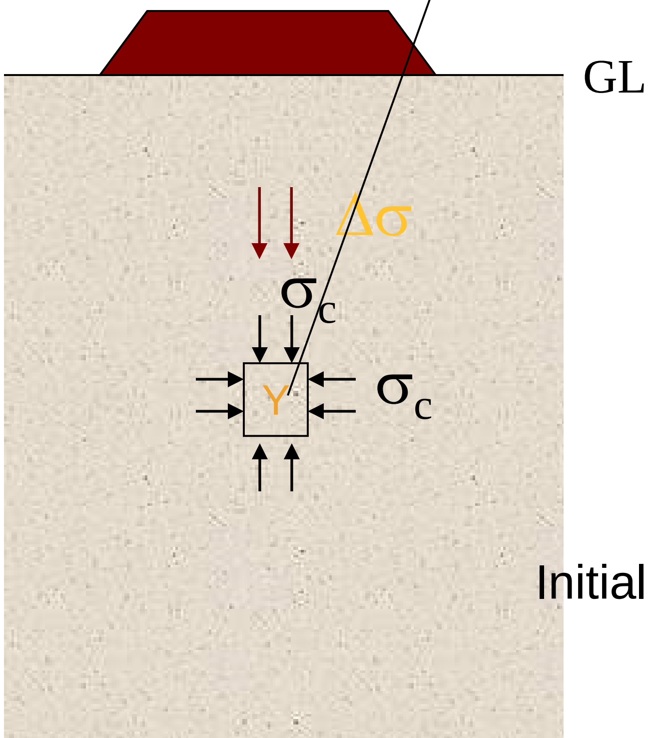



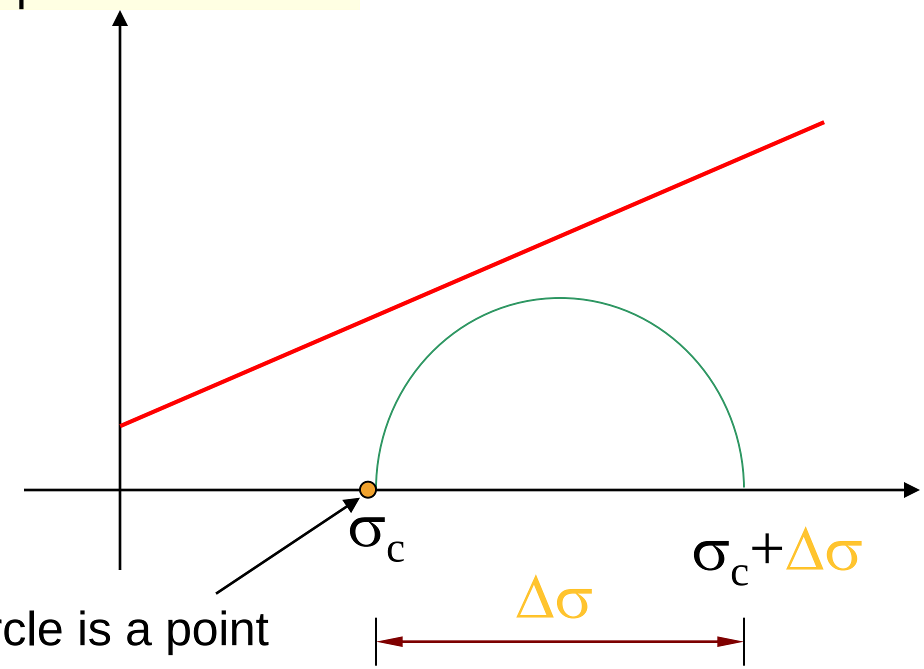

X ~ failure

Y ~ stable

# Mohr Circles & Failure Envelope

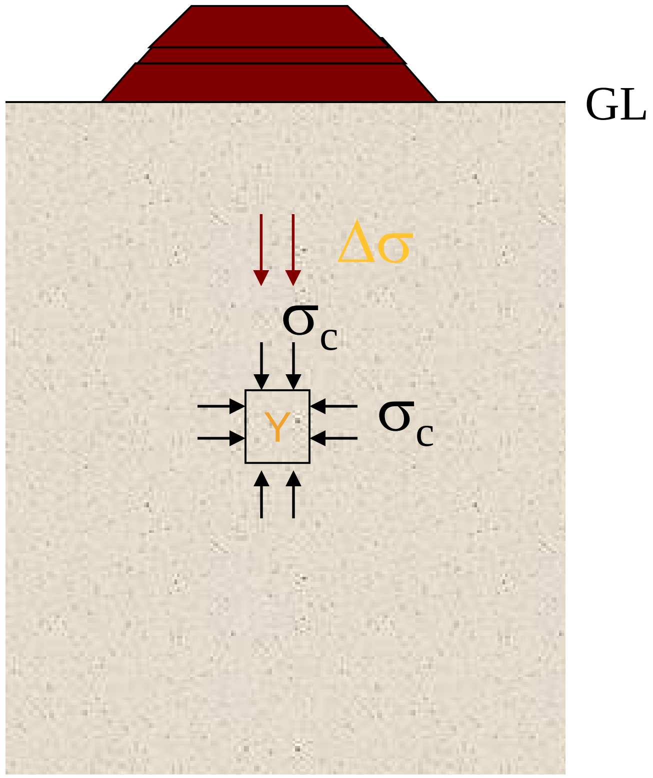
The soil element does not fail if the Mohr circle is contained within the envelope



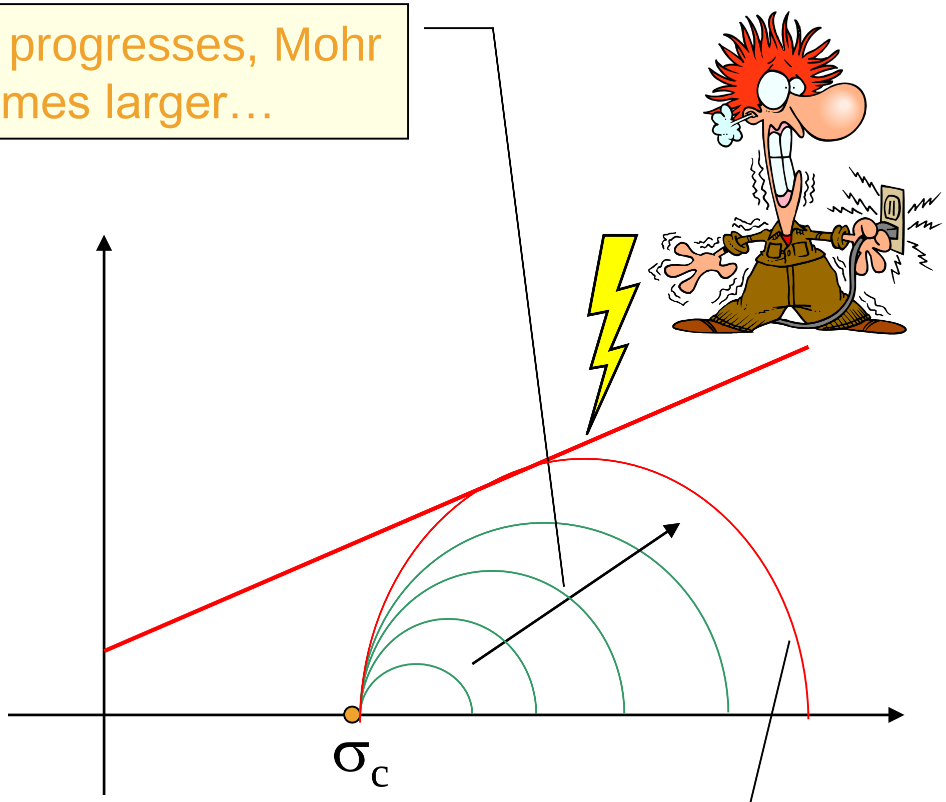




Initially, Mohr circle is a point

# Mohr Circles & Failure Envelope

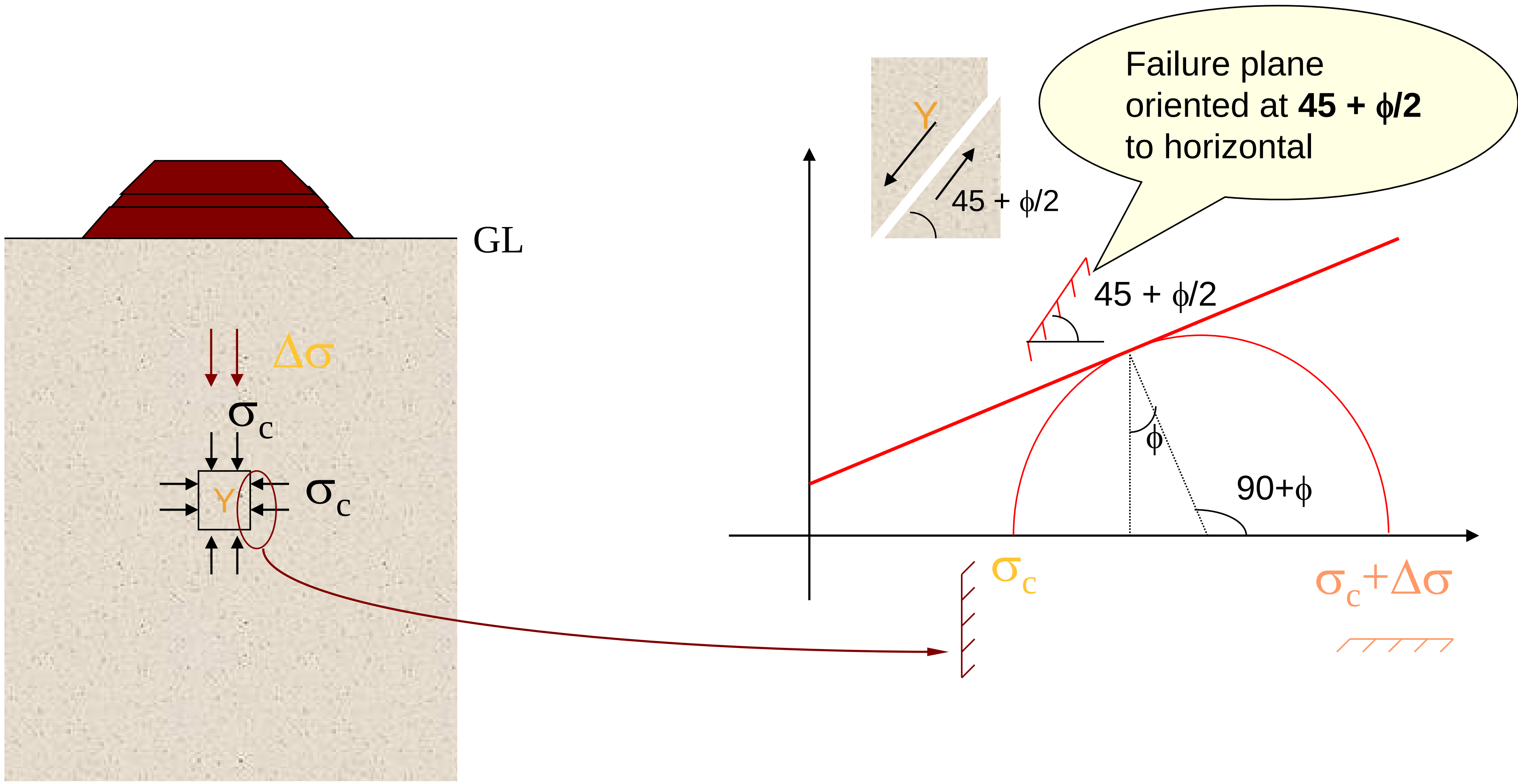



As loading progresses, Mohr circle becomes larger…

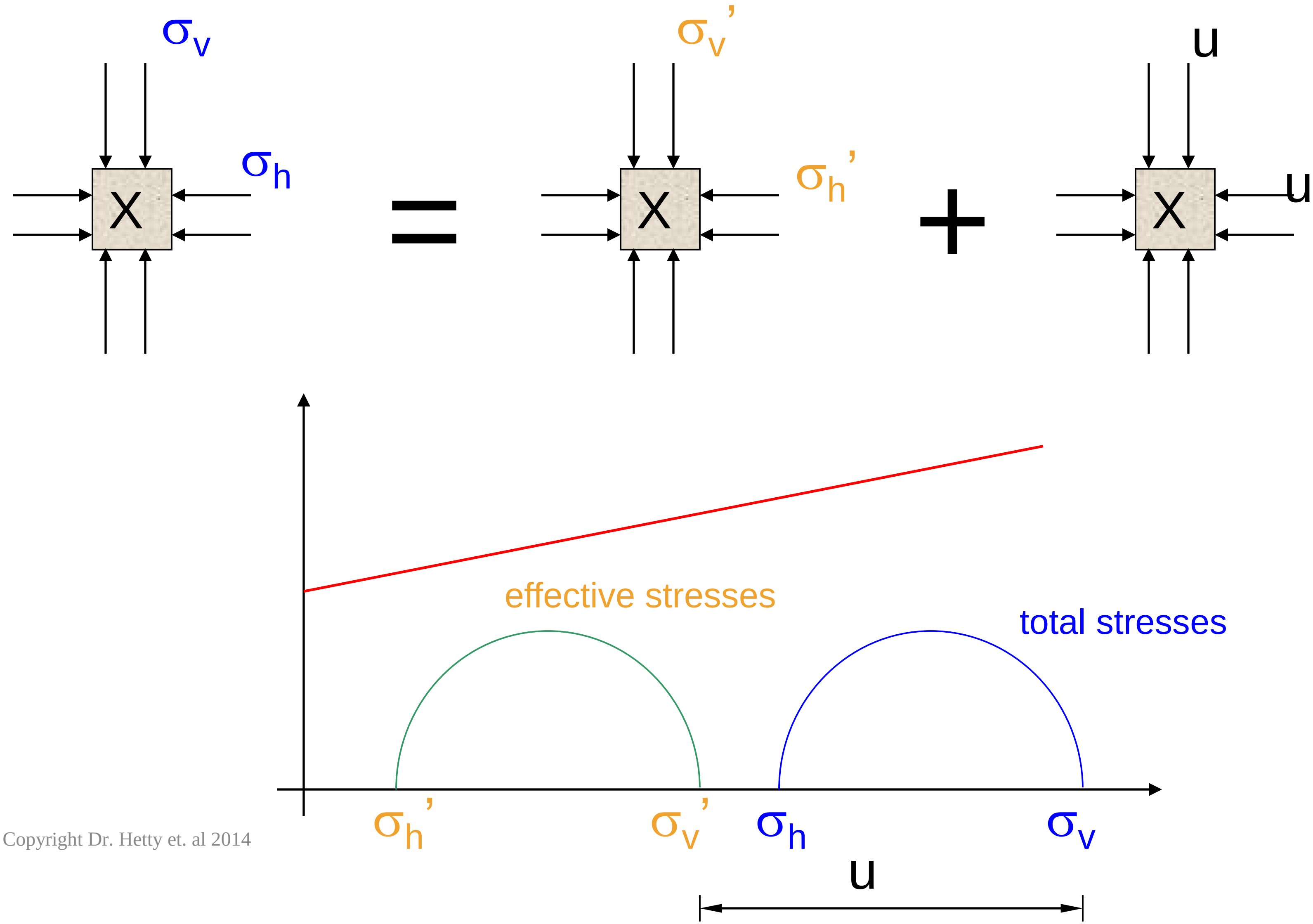



.. and finally failure occurs when Mohr circle touches the envelope

# Orientation of Failure Plane

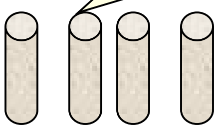


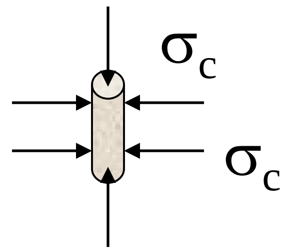
# Mohr circles in terms of σ & σ'



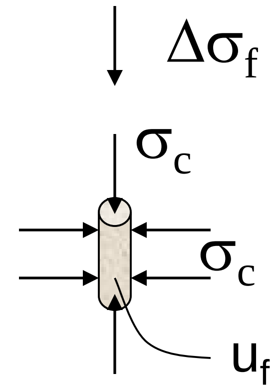
# Envelopes in terms of σ & σ'

Identical specimens initially subjected to different isotropic stresses ($\sigma_c$) and then loaded axially to failure






Initially…

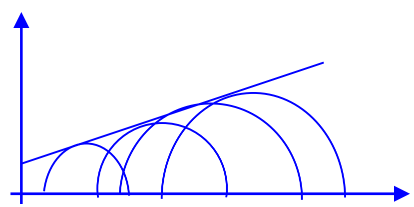



Failure

At failure,

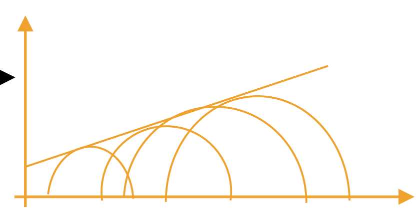
$\sigma_3 = \sigma_c$;  $\sigma_1 = \sigma_c + \Delta\sigma_f$

$\sigma_3' = \sigma_3 - u_f$ ;  $\sigma_1' = \sigma_1 - u_f$



c, ϕ

in terms of **σ**

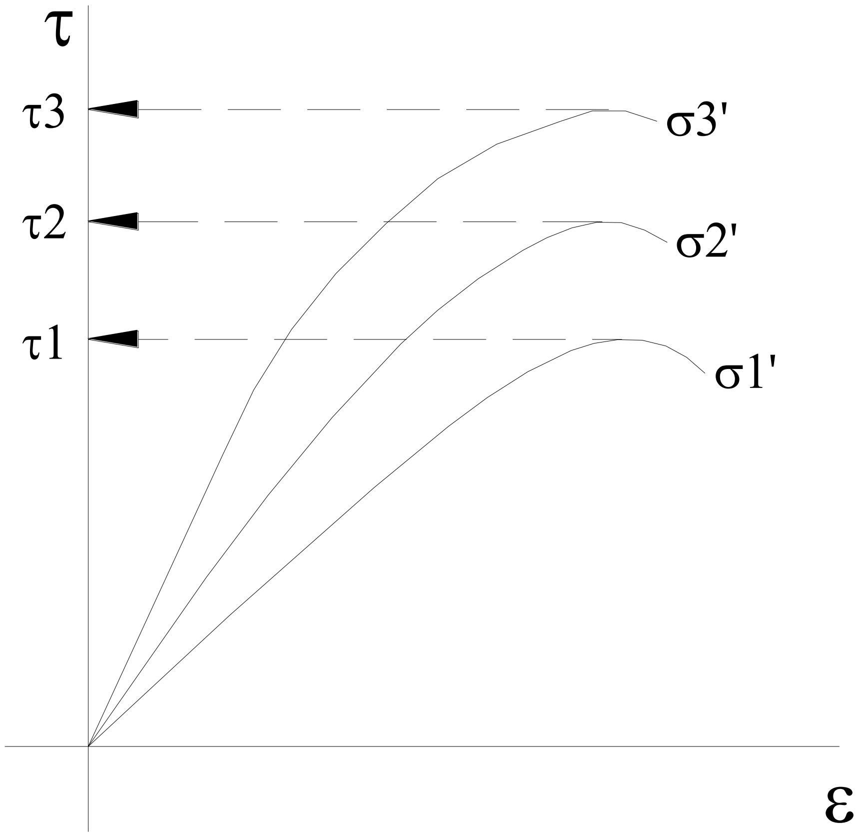


c', ϕ'

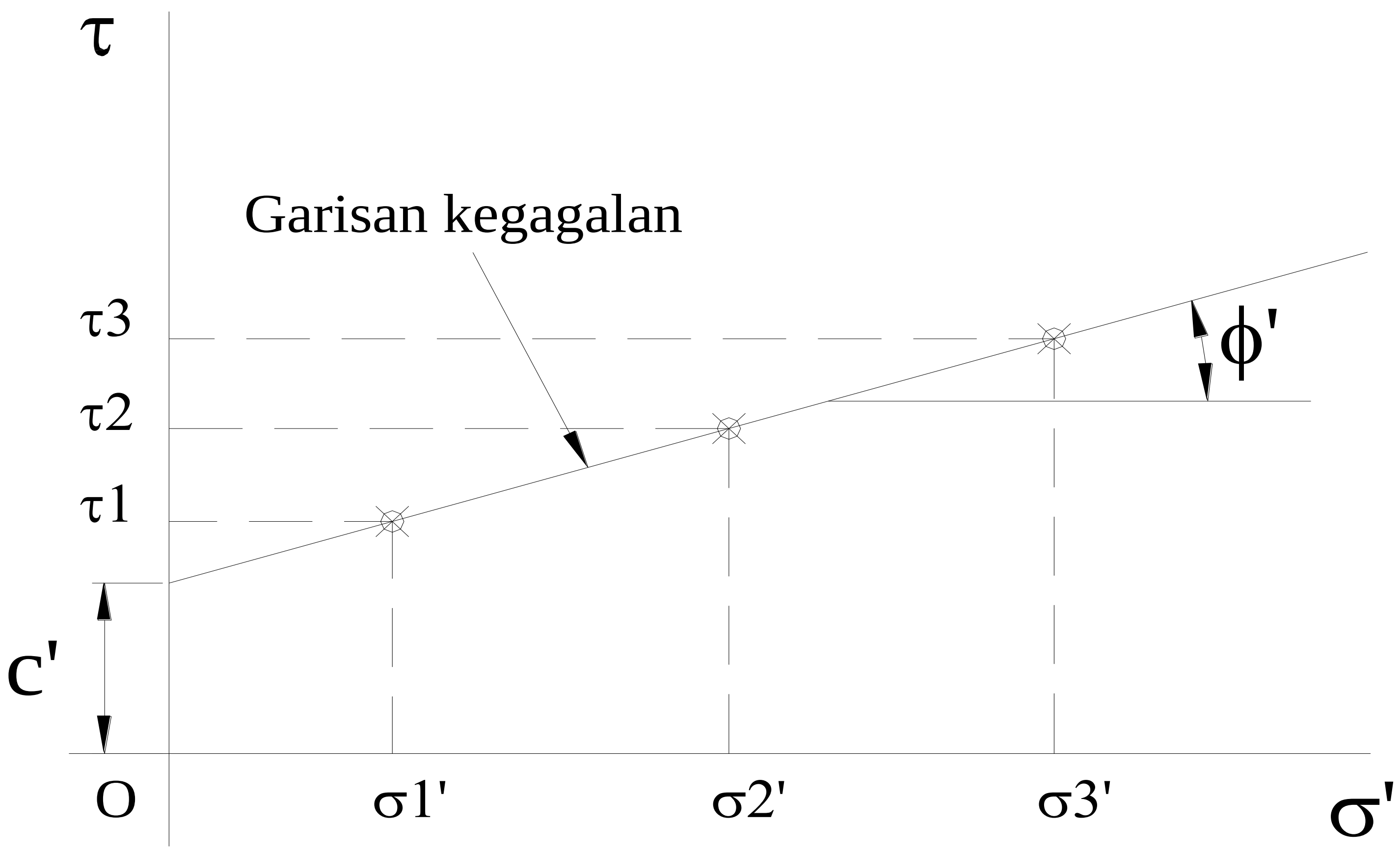
in terms of **σ'**

# Direct Shear

# Shear stress vs strain



# Shear stress vs normal stress

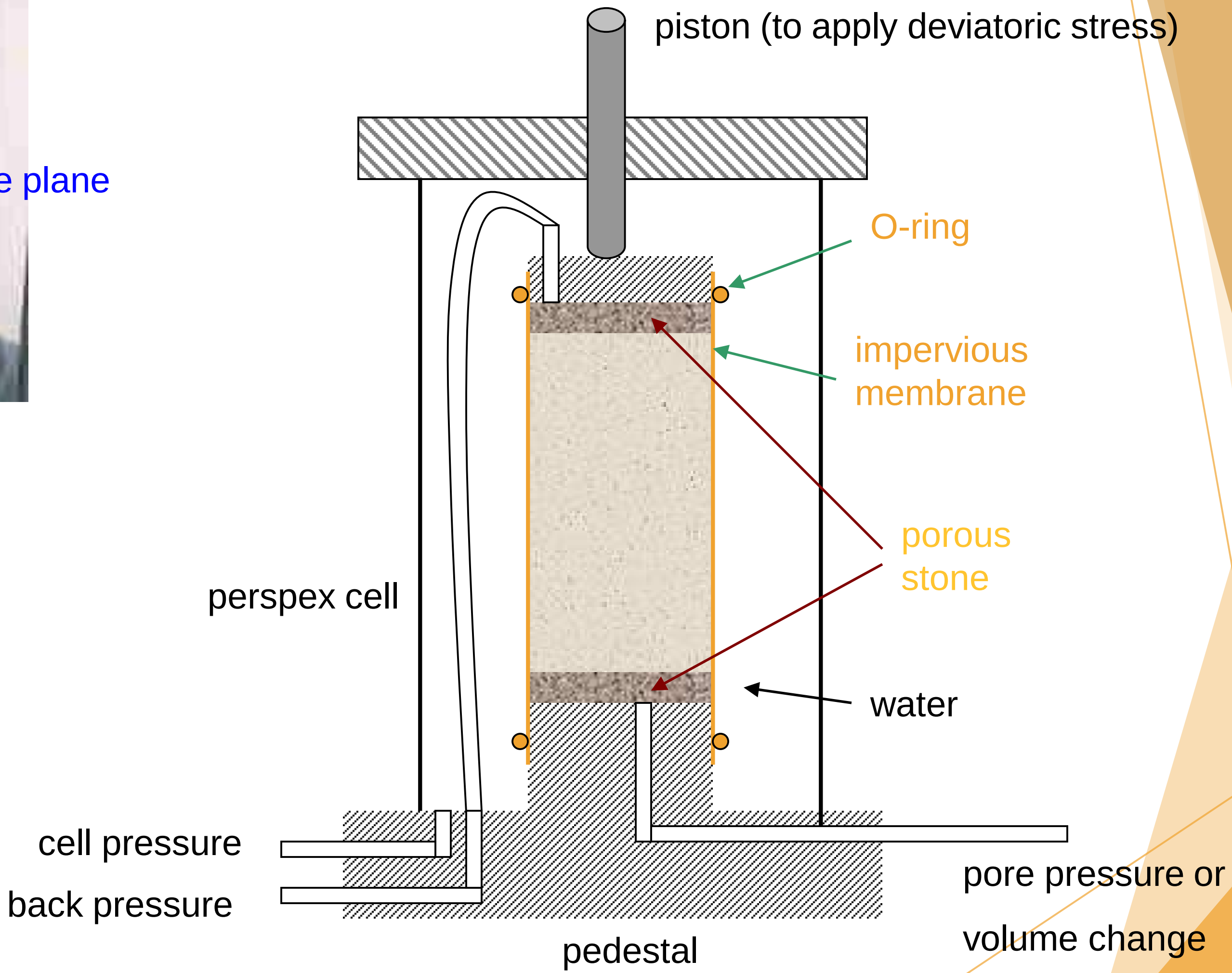


# Direct Shear - Question

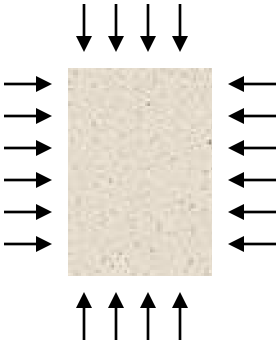
| No | Normal Stress ($kN/m^2$) | Shear stress at failure ($kN/m^2$) |
|---|---|---|
| *1* | *100* | *98* |
| *2* | *200* | *139* |
| *3* | *300* | *180* |

# Triaxial Test Apparatus

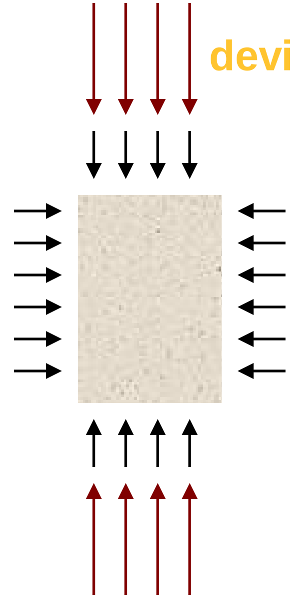

soil sample at failure



# Types of Triaxial Tests



**Under all-around cell pressure $\sigma_c$**



deviatoric stress ($\Delta\sigma$)

**Shearing (loading)**

**Is the drainage valve open?**

yes → **Consolidated** sample

no → **Unconsolidated** sample

**Is the drainage valve open?**

yes → **Drained** loading

no → **Undrained** loading

# Types of Triaxial Tests

Depending on whether drainage is allowed or not during

- initial isotropic cell pressure application, and
- shearing,

there are three special types of triaxial tests that have practical significances. They are:

**Consolidated Drained (CD) test**
**Consolidated Undrained (CU) test**
**Unconsolidated Undrained (UU) test**

For unconsolidated undrained test, in terms of total stresses, $\phi_u = 0$

Granular soils have no cohesion.
$c = 0$ & $c' = 0$

For normally consolidated clays, $c' = 0$ & $c = 0$.

# CD, CU and UU Triaxial Tests

## Consolidated Drained (CD) Test

- no excess pore pressure throughout the test
- very slow shearing to avoid build-up of pore pressure

Can be days!
$\therefore$ not desirable

- gives c′ and $\phi'$

Use c′ and $\phi'$ for analysing fully drained situations (e.g., long term stability, very slow loading)

# CD, CU and UU Triaxial Tests

## Consolidated Undrained (CU) Test

- pore pressure develops during shear

  Measure → σ′

- gives c′ and ϕ′

- faster than CD (∴ preferred way to find c′ and ϕ′)

# CD, CU and UU Triaxial Tests

## Unconsolidated Undrained (UU) Test

- pore pressure develops during shear

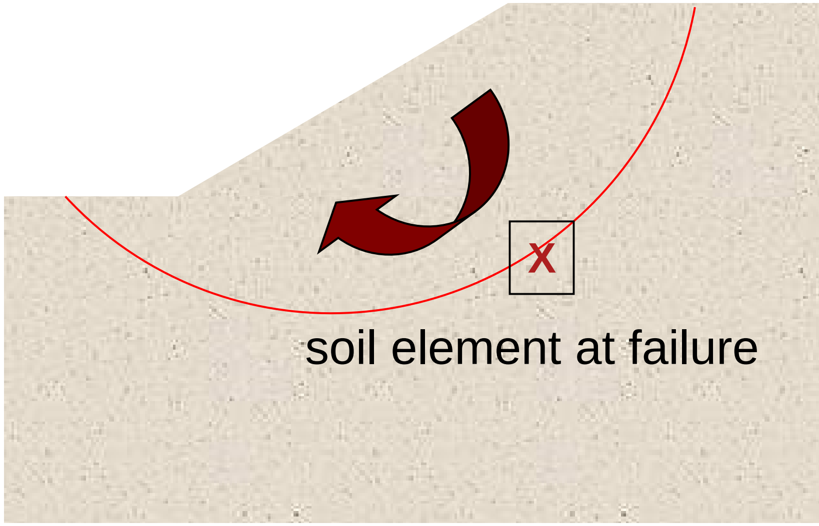
Not measured
$\therefore \sigma'$ unknown

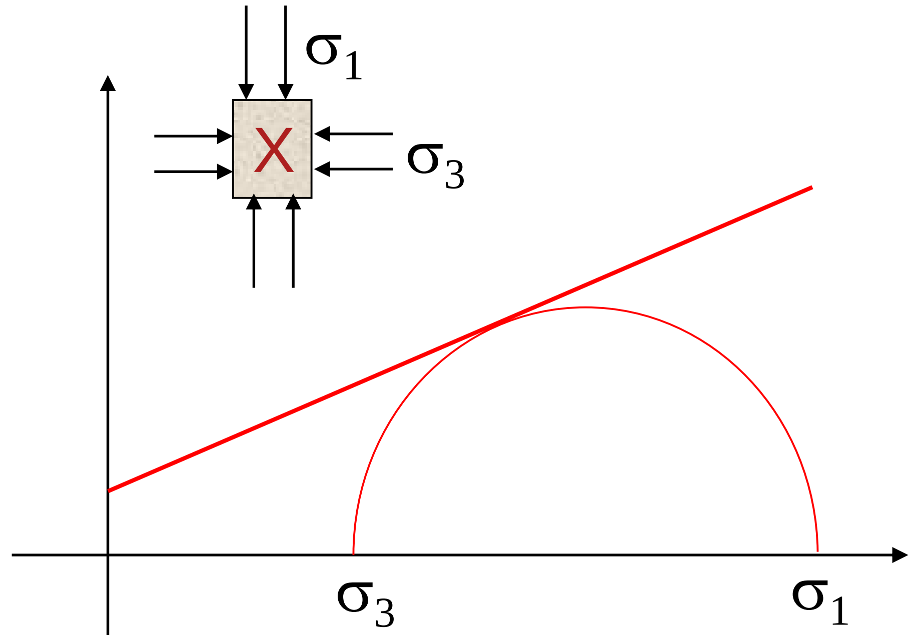
= **0**; i.e., failure envelope is horizontal

- analyse in terms of $\sigma$ ➔ gives $c_u$ and $\phi_u$
- very quick test

Use $c_u$ and $\phi_u$ for analysing undrained situations (e.g., short term stability, quick loading)

# $\sigma_1$- $\sigma_3$ Relation at Failure

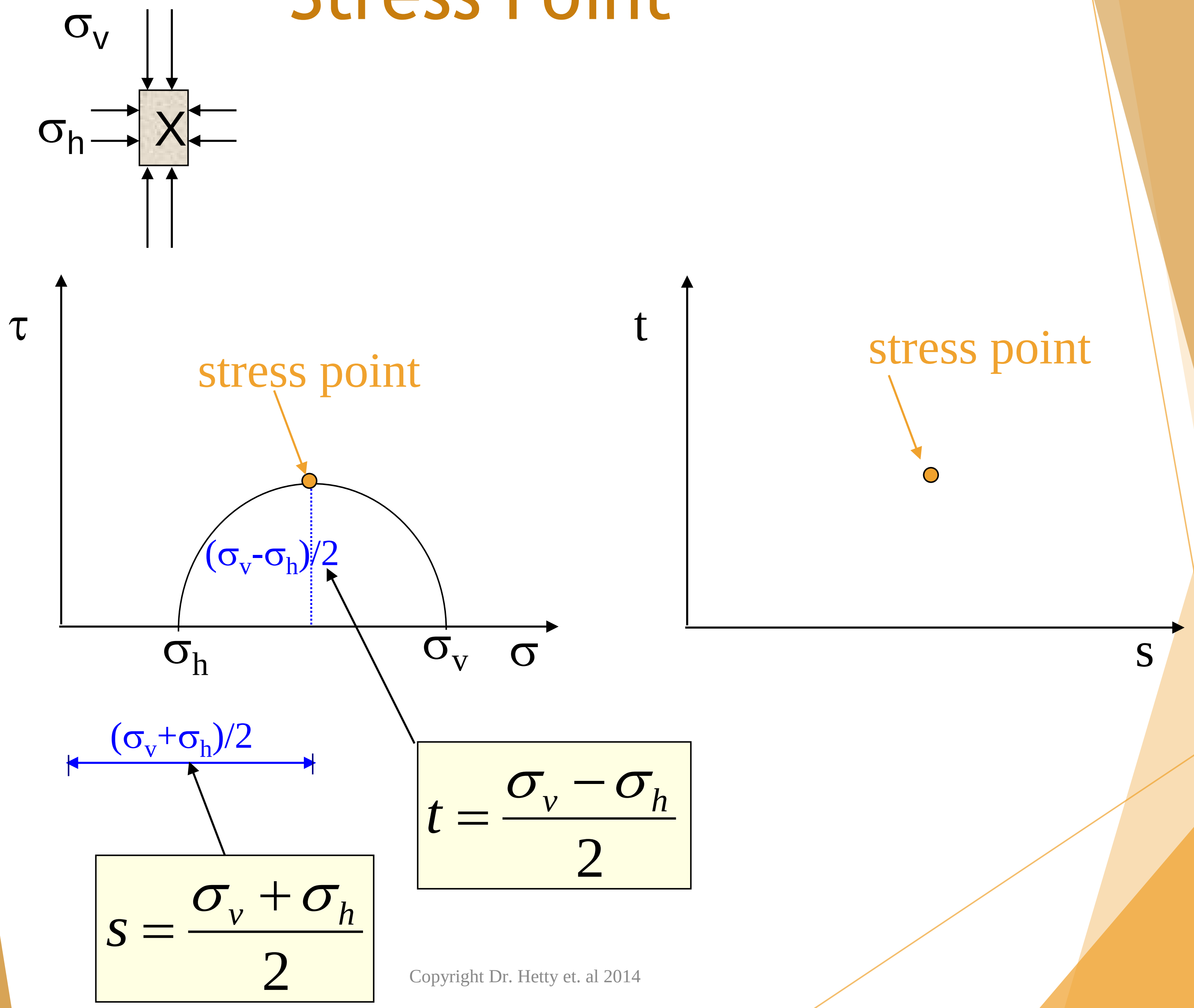



$$\sigma_1 = \sigma_3 \tan^2(45 + \phi/2) + 2c\tan(45 + \phi/2)$$

$$\sigma_3 = \sigma_1 \tan^2(45 - \phi/2) - 2c\tan(45 - \phi/2)$$

# Stress Point

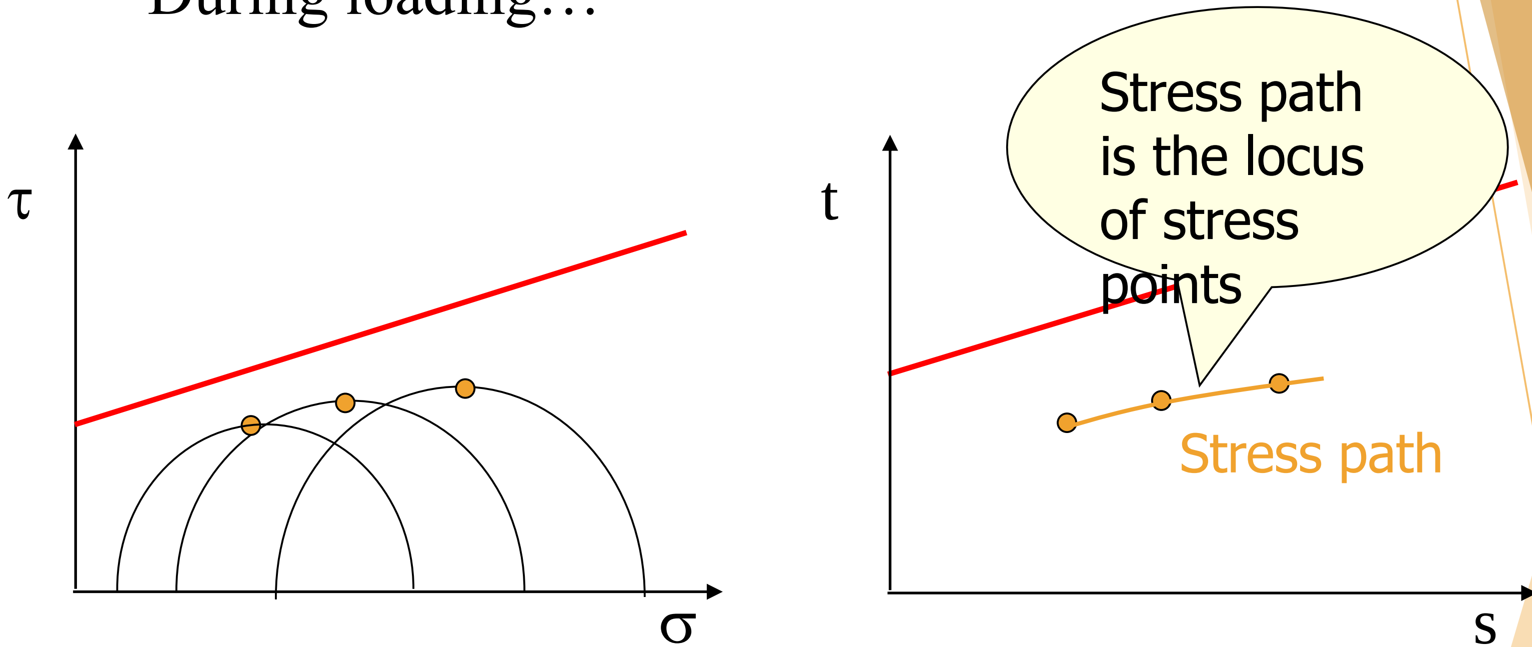



$$t = \frac{\sigma_v - \sigma_h}{2}$$

$$s = \frac{\sigma_v + \sigma_h}{2}$$

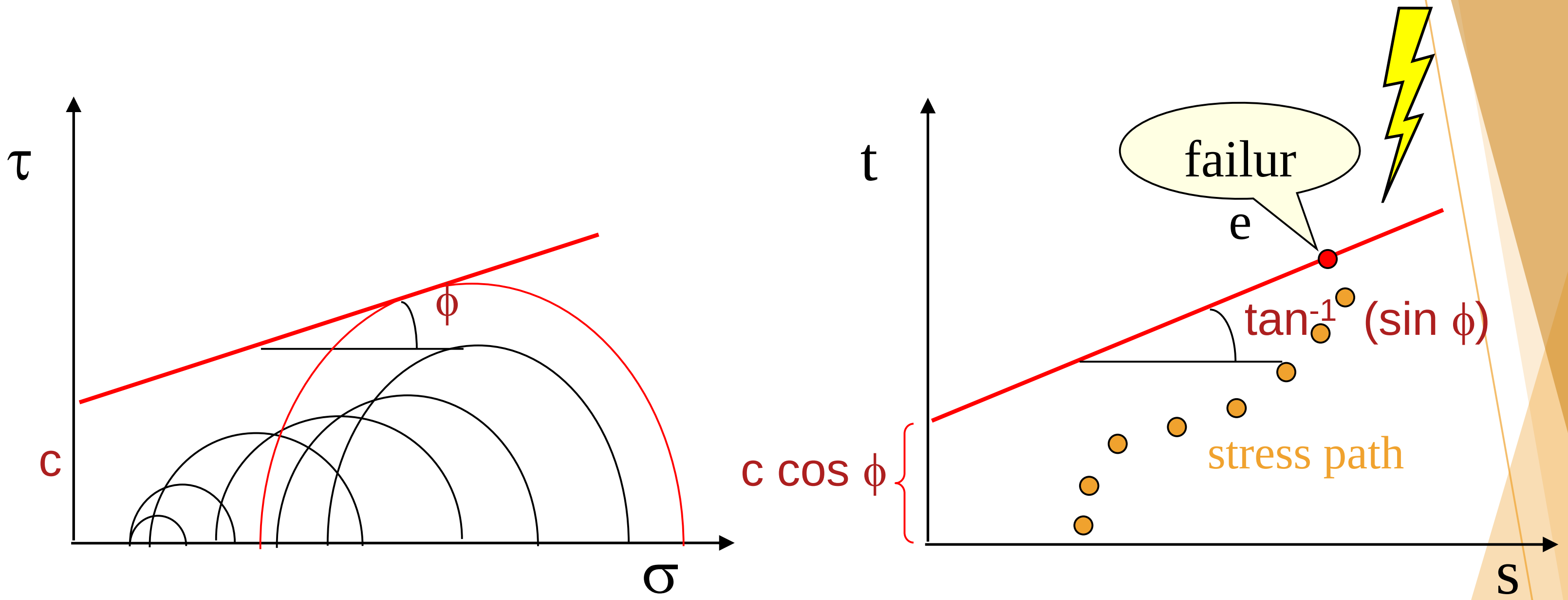
# Stress Path

During loading…



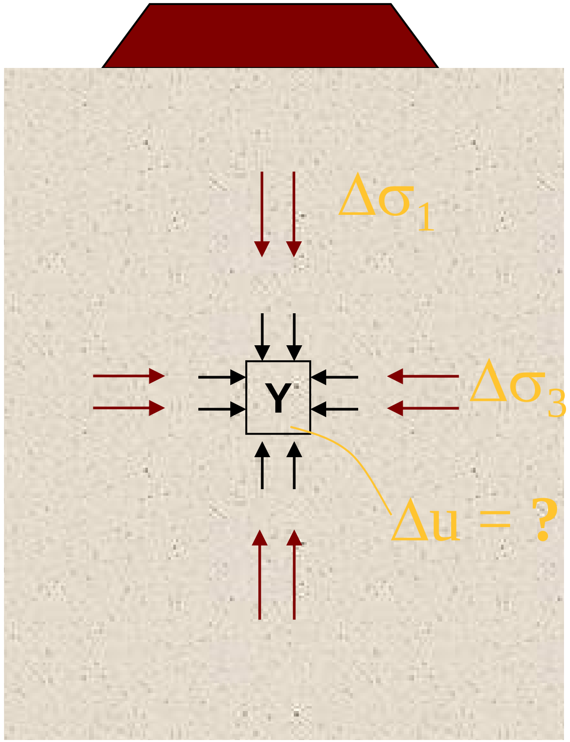

Stress path is a convenient way to keep track of the progress in loading with respect to failure envelope.

# Failure Envelopes




During loading (shearing)….

# Pore Pressure Parameters




A simple way to estimate the pore pressure change in undrained loading, in terms of total stress changes ~ after Skempton (1954)

$$\Delta u = B\left[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)\right]$$

Skempton's pore pressure parameters A and B

# Pore Pressure Parameters

**B-parameter**

$B = f$ (saturation,..)

For saturated soils, $B \approx 1$.

**A-parameter at failure ($A_f$)**

$A_f = f(OCR)$

For normally consolidated clays $A_f \approx 1$.

For heavily overconsolidated clays $A_f$ is negative.