Stress, Strain, Deformation Characteristics

Pressure - force per unit area applied to solid by a load.

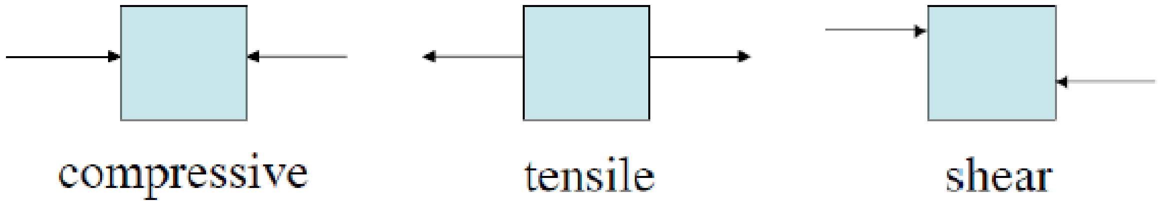
Stress - pressure transmitted from the external face to an internal location, also force per unit area.

Types of stresses:

Compressive - stresses of equal magnitude that act toward a point from opposite directions.

Tensile - stresses of equal magnitude that act away from a point.

Shear - stresses that are offset from one another and act in opposite directions.



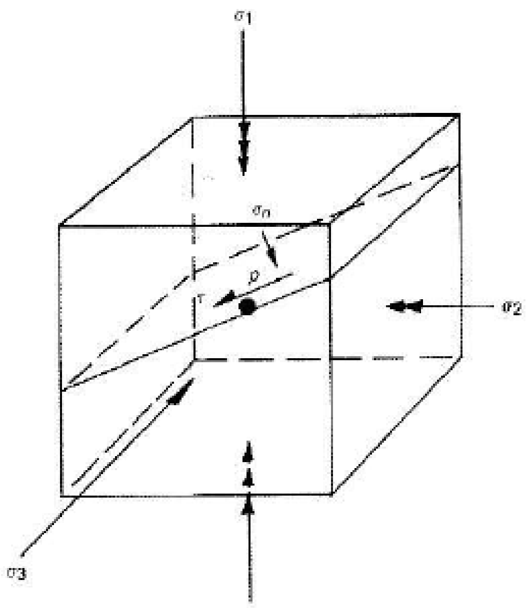
Maximum, intermediate and minimum stress:

At any point within an object…

Stresses can be resolved into three principle stresses that are mutually perpendicular (**σ_1, σ_2, σ_3**)

On any plane within an object…

There is a **normal** stress (**σ_n**) perpendicular to the plane and **shear** stress (**τ**) acting parallel to the plane.



Vertical stress σ_v acting on a horizontal plane at shallow depth **h** can be calculated as:

$\sigma_v = \gamma h + P_a$

γ = unit weight of rock

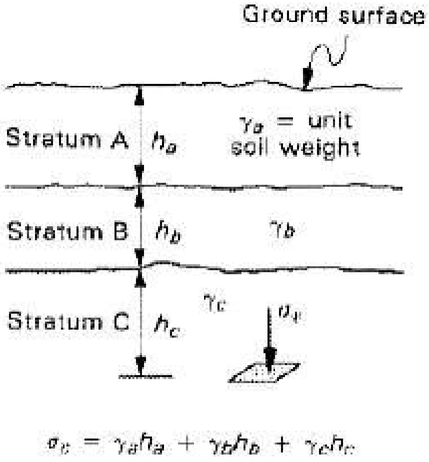
h = depth to point below surface

P_a = atmospheric pressure (usually neglected)

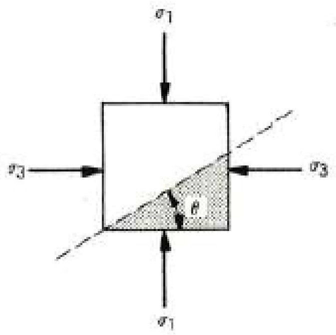
This equation assumes a consistent body of rock above point.

If multiple layers of different rock types…

$\sigma_v = \gamma_a h_a + \gamma_b h_b + \gamma_c h_c \ldots$

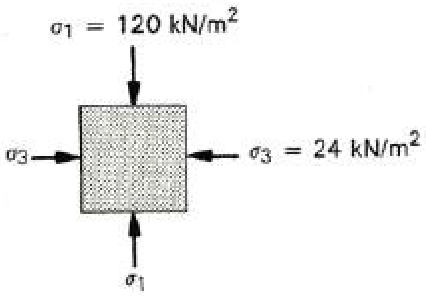


Previous equation can be applied if we wish to determine the stress on the major (horizontal) principle plane. What if we want to know the stress on an inclined plane?

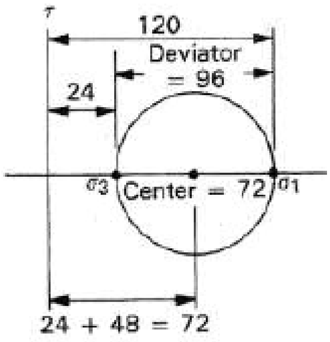


Position of a randon plane oriented at angle θ measured counter-clockwise from the major principal plane.

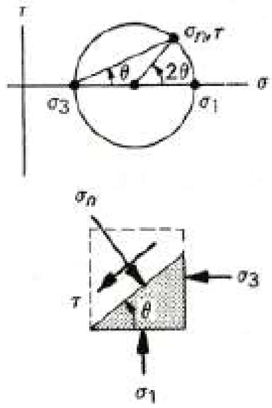
Mohr Circle: Graphical representation of shear and normal stresses on inclined planes



Stresses acting on an incremental element surrounding a point in the subsurface.

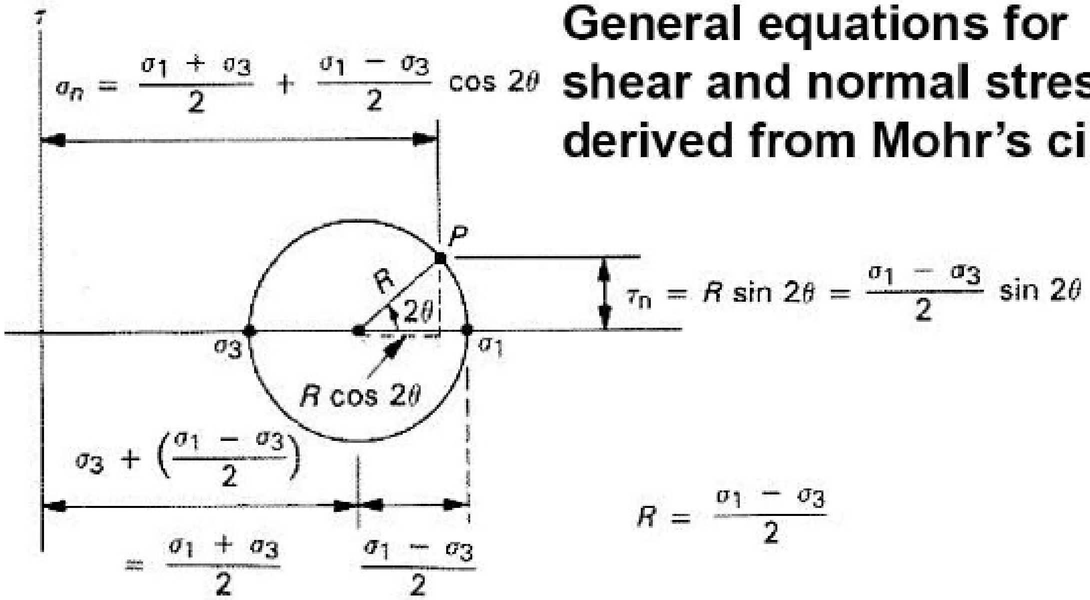


Deviator stress is the difference between σ1 and σ3.



Relationship of planes on the incremental element to points on Mohr's circle.

General equations for shear and normal stress derived from Mohr's circle



Deformation - Response to Stress:

Application of stress causes a body of rock to yield or deform. The amount of deformation is called **strain**. The type and amount of strain that a particular material experiences depends on:

- Type of stresses applied
- Depth and temperature

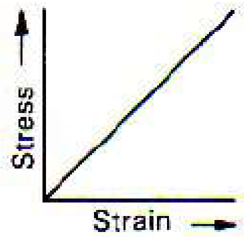
Ideal Materials:

Elastic (e.g. spring):

- Linear regression on a plot of stress vs strain
- Slope of regression line is ***modulus of elasticity***

  $E = \sigma/\varepsilon$; σ = applied stress; ε = strain
- Strain is change in length vs original length

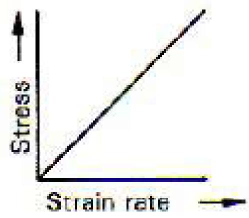
  $\varepsilon = \Delta L / L$
- Strain in elastic systems is recoverable



Elastic

Viscous (fluids):

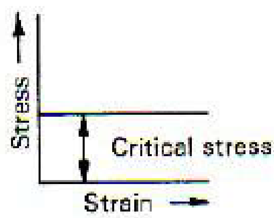
- Linear regression in a plot of stress vs strain rate
- Viscosity is slope of regression line in a stress strain rate plot



Viscous

Plastic:

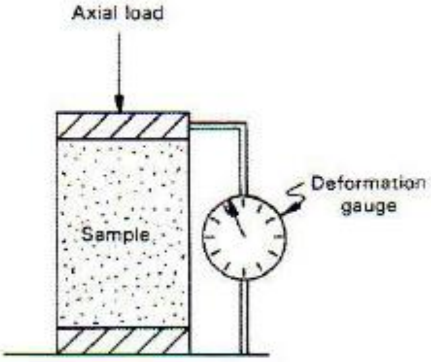
- No strain until some critical stress value has been reached; then continuous deformation

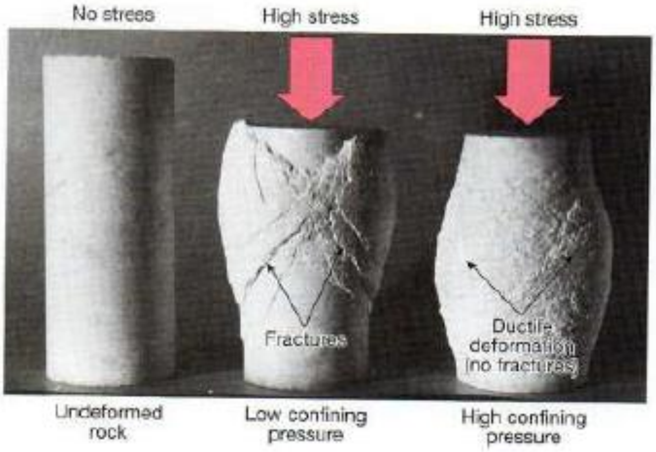


Plastic

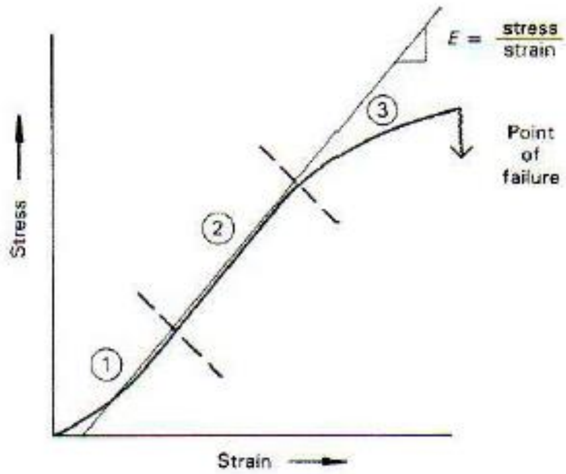
Rock behavior is more complex than ideal materials.

Common method of testing rock behavior is the ***unconfined compression test***.





Generalized stress-strain curve for rocks:



Stress/strain relationships are generally **not linear**

Usually show 3 distinct segments:

Region 1: closing of void spaces

Region 2: approximately elastic behavior

Region 3: approximately plastic behavior

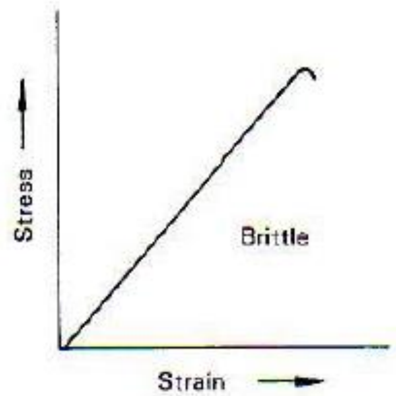
Failure: rock breaks and loses all shear strength

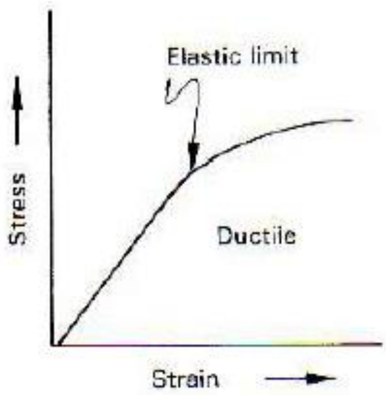
Different types of rocks vary considerably in their stress-strain behavior.

Two types of 'responses'

Brittle - respond in a mostly elastic fashion until failure.

Ductile - respond elastically until the "Elastic Limit", then in plastic fashion until failure.





Compressive Strength:

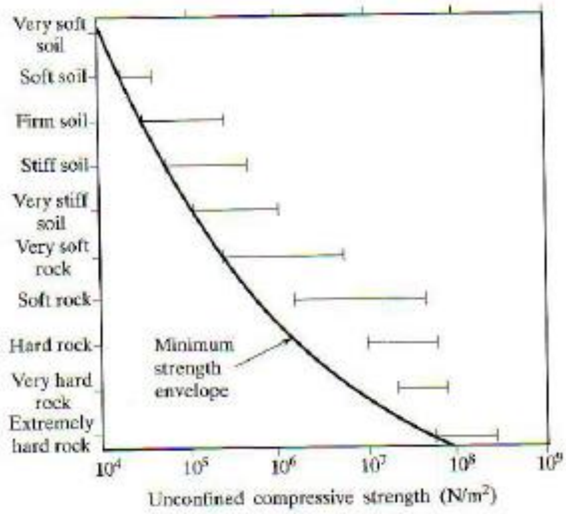
Failure of a brittle rock - point when the rock loses all resistance to stress and crumbles.

In plastic material, specific point of failure difficult to identify - because deformation continues indefinitely at a constant level of stress.

Strength (in plastic materials) – is defined as the level of stress at failure.

On a plane within a rock body…

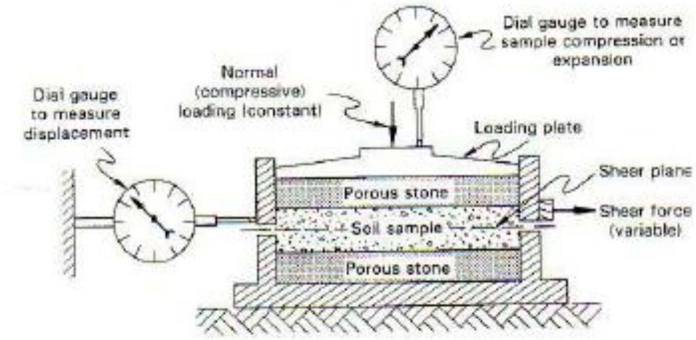
- Normal stresses tend to resist failure
- Shear stresses tend to cause failure
- If shear stress exceeds the **shear strength** – failure occurs.



Relationship between shear and normal stresses during a strength test (and at failure) is critical to understanding deformation behavior of the material.

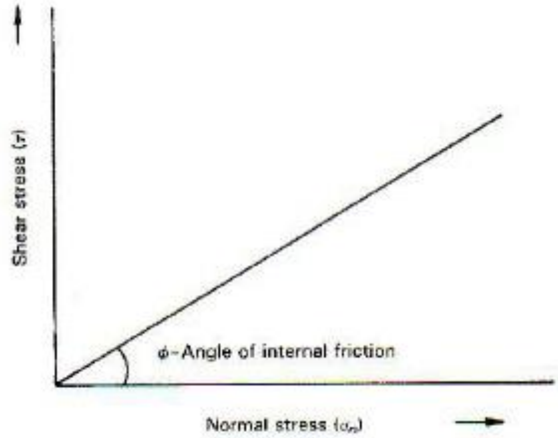
Way to test shear strength - **Direct shear test**

Variable shear and normal stresses can be applied.



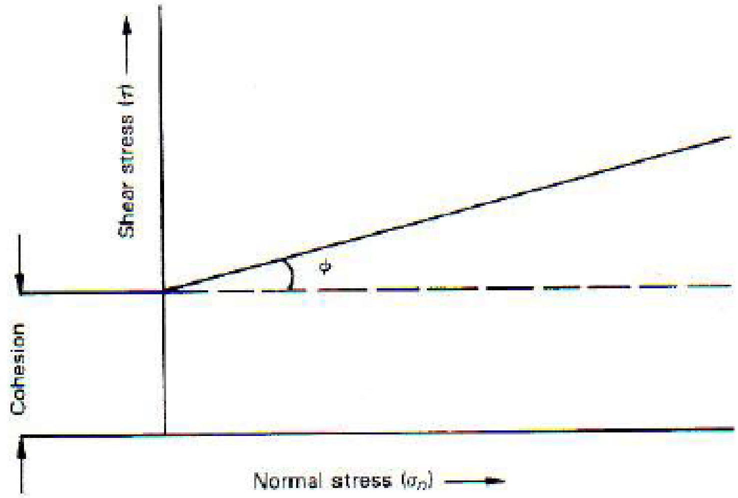
For **unconsolidated materials** (e.g. **dry sand**) the relationship between **normal** stress (σ_n) and **shear strength** (S) is linear, passes through the origin:

$$S = \sigma_n \tan \varphi$$



For **consolidated materials or cohesive soils**, relationship also linear, but there is inherent shear strength due to interparticle bonding (cohesion - C):

$\mathbf{S = C + \sigma_n \tan \varphi}$ φ = Angle of internal friction



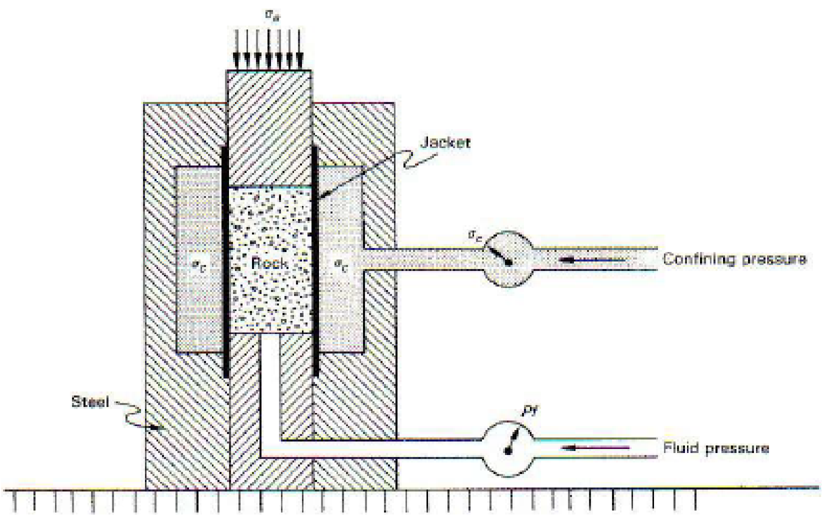
Confining Pressure:

Weight of overlying rock applies pressure in all directions to given body of rock - confining pressure

- Not always equal in all directions.
- Underground mine, tunnel construction.

Triaxial test:

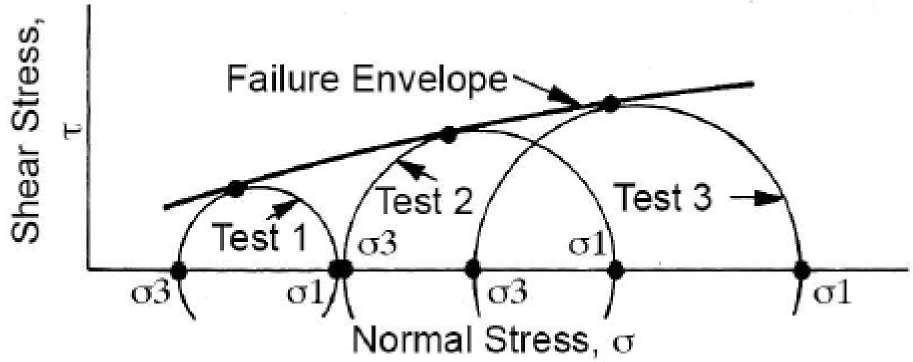
Confining pressure can be applied to better mimic depth conditions.



▲ FIGURE 7.21
Schematic diagram of triaxial test cell.

Confining Pressure (cont'd)

Varying principle stresses (both axial and confining) allows for creation of multiple Mohr's Circles and **Definition** of the **failure envelope**.

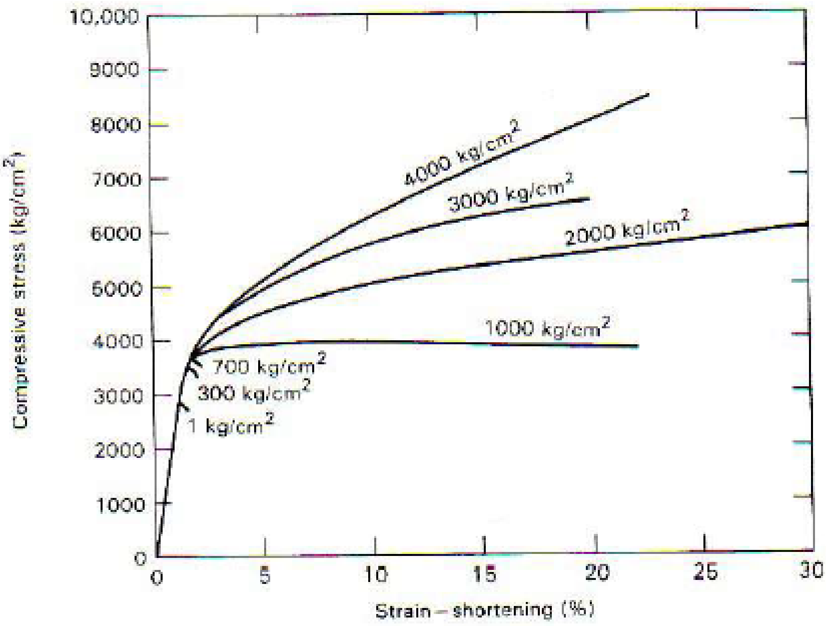


Effect of increasing confining pressure:

• Rocks change from brittle to ductile behavior.

Ductile response dominant beyond 700 kg/cm^2.

• **Strength of rock increases** with increasing confining pressure.



Effect of increasing temperature:

• **Strength decreases** with increasing temperature.

• Ductile response occurs at lower pressures (stress) under higher temperatures.

Effect of time:

• Stress applied in geologic systems occurs over millions of years.

• **Rock strength decreases** with decreasing strain rate (apply same amount of strain over a very long period of time).

Tensile Strength:

Tensile strength = resistance to failure under tensile stress.

Typically, much lower than compressive strength

10% of compressive strength typical

Horizontal rock beams can be dangerous because of the weak tensile strength – rock unit must be homogeneous and composed of resistant minerals.

Arches overcome this by transferring tensile stress to compressive stresses around the arch.