EPFL

Rock mass characterization: In situ testing and stress characterization.

Rock mass characterization

Laboratoire de Mécanique des Roches – LEMR

Prof. M. VIOLAY

Adapting the project to the geological conditions

- Before a construction or excavation it is important to pay attention to the **in-situ stresses orientation.**

- Avoid **major geological features** like faults, mylonites and cataclasites, too fissured rocks, weathered rocks, high overburden and stress, low strengthened rocks, swelling ground, non cohesive soils…

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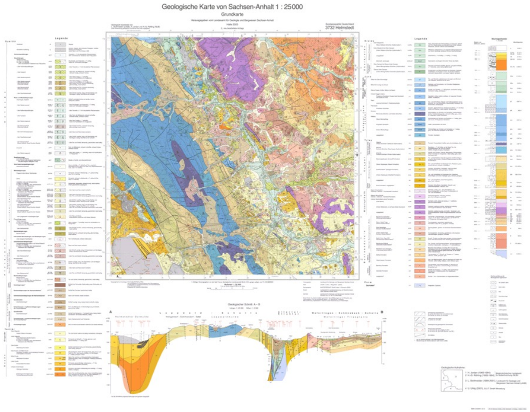
Literature Review and Photographic Studies

1. Maps, air photographs, imagery and satellite data relating to the site
2. Additional information from various institutions (e.g., other projects)
3. Site visit



Identify where more detailed information is needed

Geological Investigations

- Aim:

  Identify geological and hydrogeological conditions to be encountered and potential problems during construction or excavation phase (e.g. water inflow, faults, gas..) + knowledge of the **deformation and strength properties** of rock

  → Confirm the basic geology of the region and the site through simple tests performed in situ

Two types of exploration:

1. ***Direct* exploration → probe hole *drilling***
2. *Indirect* exploration → *geophysics (done in the last 9 lectures)*

Field Reconnaissance and Recognition

1. Geophysical survey
2. Drilling *and testing boreholes*

   + Laboratory testing (next lab sessions)

- need for ground improvements, type of excavation and appropriate methods need for relocation of the structure
- *if necessary, alignment improvement*

Field investigations (Geophysics)

Method	Measured property	Geological information
Seismic refraction	Velocities of induced seismic wave travelling in soil and bedrocks	Beds depth and continuity
Seismic reflection	Average velocity of seismic wave travelling between the surface and a reflecting surface	Depths to lithological changes and discontinuities (Primarily sedimentary rocks)
Electrical resistivity	Relative electrical resistivity of rocks	Aquifers, gravel deposits, and bedrock profiles
Electromagnetic	Amplitude and phase angle of electromagnetic field	Aquifers
Magnetometry	Total magnetic field intensities	Faults and metallic intrusions
Gravimetry	Total density of rocks	Change of rock type, cavities, faults, domes, intrusions
Radar probing profiling	Electromagnetic wave	Metallic pipes, bedrock, boulders

Survey technique	Area of application					
	Geological structures/ barriers	Hydraulically active structures	Landfills/ Waste dumps	Contamination plumes	Landslides/ Ground sinking	Pre-excavation archaeology
Gravity	+	○	○	–	○	○
Magnetic[a]	+	–	+	–	–	+
Self-potential	○	+	○	○	+	–
Resistivity +IP[b]	+	+	+	+	+	+
Electromagnetic[a]	○	+	+	+	–	○
Ground radar	○	○	+	○	○	+
Radioactivity[a]	○	○	○	○	○	–
Seismic refraction	+	○	○	–	○	○
Seismic reflection	+	○	–	–	–	–
Geothermy[a]	○	+	○	–	○	–

Notes:

\+ applicable; ○ limited applicability; – not applicable.

[a]Technique applicable to both ground and airborne surveying.

[b]Induced polarization.

Technique	Area of application					
	Depth to and constitution of bedrock	Rippability/ Rock strength	Fracture/Flow seepage detection	Location of cavities/voids	Permafrost/Thaw zones delineation	Pipes/Metal detection
Gravity	+	−	−	+	−	−
Magnetic	+	−	−	+	−	+
Self-potential	−	−	+	−	−	○
Resistivity +IP[a]	+	−	+	+	+	○
Electromagnetic	○	−	+	○	+	+
Ground radar	+	○	+	+	+	○
Radioactivity	−	−	○	−	−	−
Seismic refraction	+	+	○	○	+	−
Seismic reflection	+	+	○	○	○	−

Notes:
+applicable; ○ limited applicability; −not applicable.
[a] Induced polarization.

Rock mass structure

intact rock blocks of various sizes ➔ lab testing!

- **Rock mass = Rock materials + Rock discontinuities + stress state**

fractures, joints, faults➔ geophysics, lab testing

- Most rocks are cut by discontinuities which typically have little to no tensile strength. The engineering performance (strength, compressibility, permeability and durability) of any mass of rock containing such fractures will be significantly influenced by their presence. The description of these fractures is clearly an important aspect of rock description in general.

- Understanding stress fields is crucial in geotechnical engineering as it directly influences the stability and behavior of soil and rock structures.

In-situ testing

Test during which the geomaterial is mechanically stressed in its environment, with the minimum possible disturbance of the area.

Strengths:

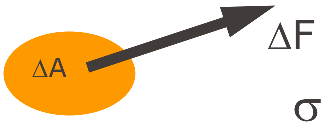
- Measures the response of the in-place massif (without extracting samples ~ point measurement).
- Measures the response of the massif over a large area
- Measures the response of massifs from which it is impossible to extract samples (poor quality massif).
- Measures the state of stress in place.

Weaknesses:

- -Difficult to determine the 3D stress state = interpretation of the test is difficult.
- Possibility of modification of in-situ stresses before starting the measurement..

Stress, Strain and Deformation (I hope these are reminders, 10 key points)

1. Stress is a property at a point. It is a tensor.



$$\sigma = \lim_{\Delta A \to 0} (\Delta F/\Delta A)$$

2. There are normal and shear stresses.

Normal stress σ

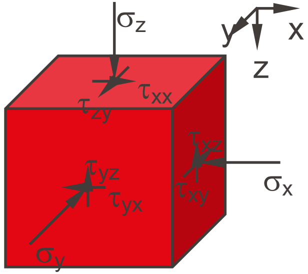
$$\sigma = \lim_{\Delta A \to 0} (\Delta N/\Delta A)$$

Shear stress τ

$$\tau = \lim_{\Delta A \to 0} (\Delta S/\Delta A)$$

Stress, Strain and Deformation

3. There are nine stress components on a small cube.



Three normal stresses σ_{xx} σ_{yy} σ_{zz}

Six shear stresses τ_{xy} τ_{yx} τ_{xz} τ_{zx} τ_{yz} τ_{zy}

4. These stress components can be listed out in matrix form.

$$\begin{vmatrix} \sigma_{xx} & \tau_{yx} & \tau_{zx} \\ \tau_{xy} & \sigma_{yy} & \tau_{zy} \\ \tau_{xz} & \tau_{yz} & \sigma_{zz} \end{vmatrix}$$

Stress, Strain and Deformation

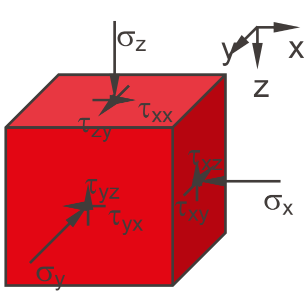
5. Corresponding shear stresses are equal and stress tensor is symmetrical.

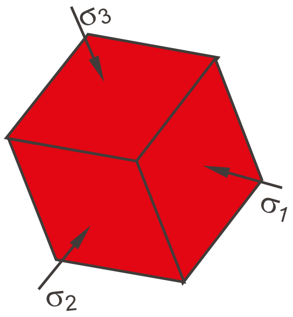
$$\tau_{xy} = \tau_{yx},\ \tau_{xz} = \tau_{zx},\ \tau_{yz} = \tau_{zy}$$

$$\begin{vmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{xy} & \sigma_{yy} & \tau_{yz} \\ \tau_{xz} & \tau_{yz} & \sigma_{zz} \end{vmatrix}$$

Stress, Strain and Deformation

6. There is an inclination of the axes at which all shear stresses disappear (stress transformation). The remaining stresses are principal stresses.





$$\begin{vmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{vmatrix}$$

σ_1 = Maximum (major) principal stress.

σ_2 = Intermediate principal stress.

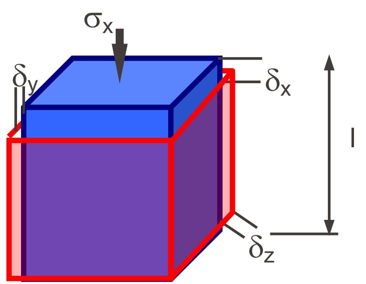
σ_3 = Minimum (minor) principal stress.

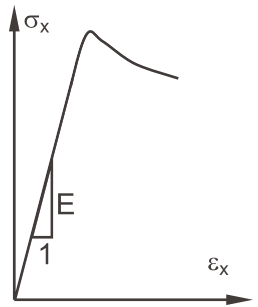
Stress, Strain and Deformation

7. Strain is deformation per length caused by stress. In the elastic region, it is related to the Young's Modulus.

$$\varepsilon = \delta_x / l$$

$$E = d\sigma_x / d\varepsilon_x$$

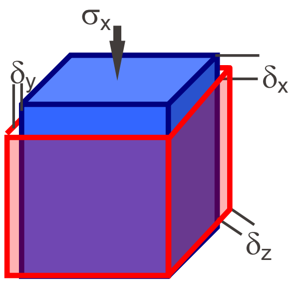




Stress, Strain and Deformation

8. Strain in one direction always causes strain in other directions. The ratio of strains is the Poisson's ratio.

$\nu = -\varepsilon_y / \varepsilon_x, \qquad \nu = -\varepsilon_z / \varepsilon_x$



Stress, Strain and Deformation

9. Stresses and strains are related by constitutive laws.

$$\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{zz}\\ \gamma_{xy}\\ \gamma_{yz}\\ \gamma_{zx}\end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} & S_{15} & S_{16}\\ S_{21} & S_{22} & S_{23} & S_{24} & S_{25} & S_{26}\\ S_{31} & S_{32} & S_{33} & S_{34} & S_{35} & S_{36}\\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} & S_{46}\\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} & S_{56}\\ S_{61} & S_{62} & S_{63} & S_{64} & S_{65} & S_{66}\end{bmatrix} \begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{zz}\\ \tau_{xy}\\ \tau_{yz}\\ \tau_{zx}\end{bmatrix}$$

$$[\varepsilon] = [S]\,[\sigma]$$

$$\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{zz}\\ \gamma_{xy}\\ \gamma_{yz}\\ \gamma_{zx}\end{bmatrix} = 1/E \begin{bmatrix} 1 & -\nu & -\nu & 0 & 0 & 0\\ -\nu & 1 & -\nu & 0 & 0 & 0\\ -\nu & -\nu & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 2(1+\nu) & 0 & 0\\ 0 & 0 & 0 & 0 & 2(1+\nu) & 0\\ 0 & 0 & 0 & 0 & 0 & 2(1+\nu)\end{bmatrix} \begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{zz}\\ \tau_{xy}\\ \tau_{yz}\\ \tau_{zx}\end{bmatrix}$$

$\varepsilon_{xx} = [\sigma_{xx} - \nu\,(\sigma_{yy} + \sigma_{zz})] / E$

$\gamma_{xy} = \tau_{xy} / G$ where $G = E / [2\,(1+\nu)]$

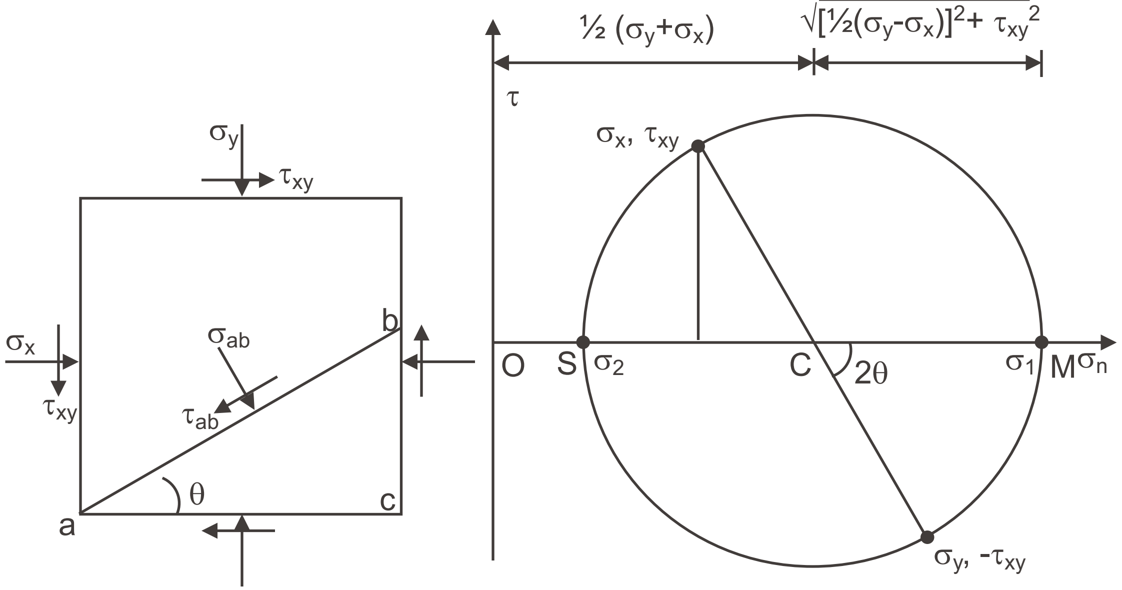
E = Young's modulus

ν = Poisson's ratio

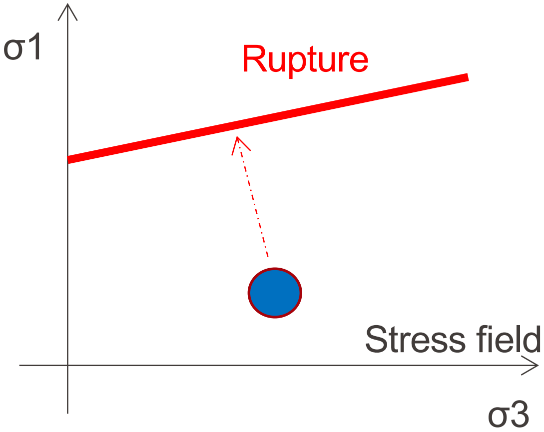
G = shear modulus

Stress, Strain and Deformation

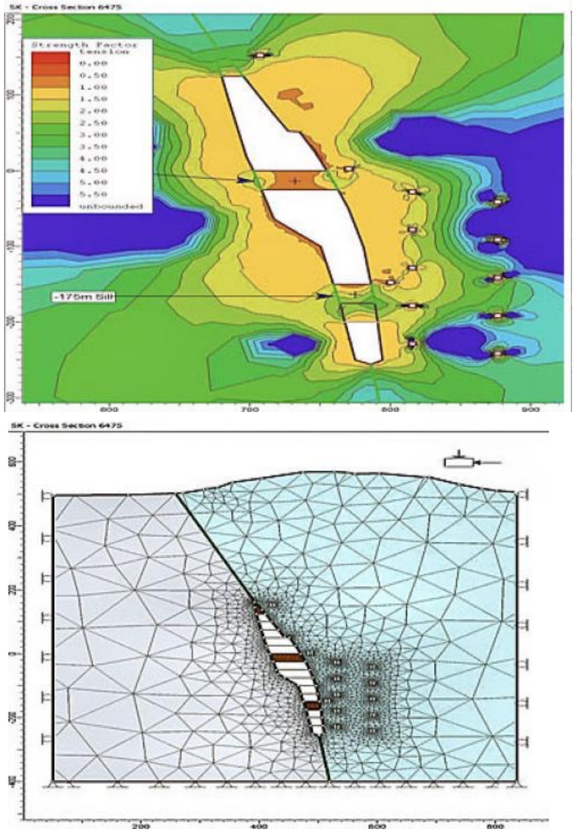
10. Plane stresses and strains can be represented by Mohr circles.



Why determine in-situ stresses?

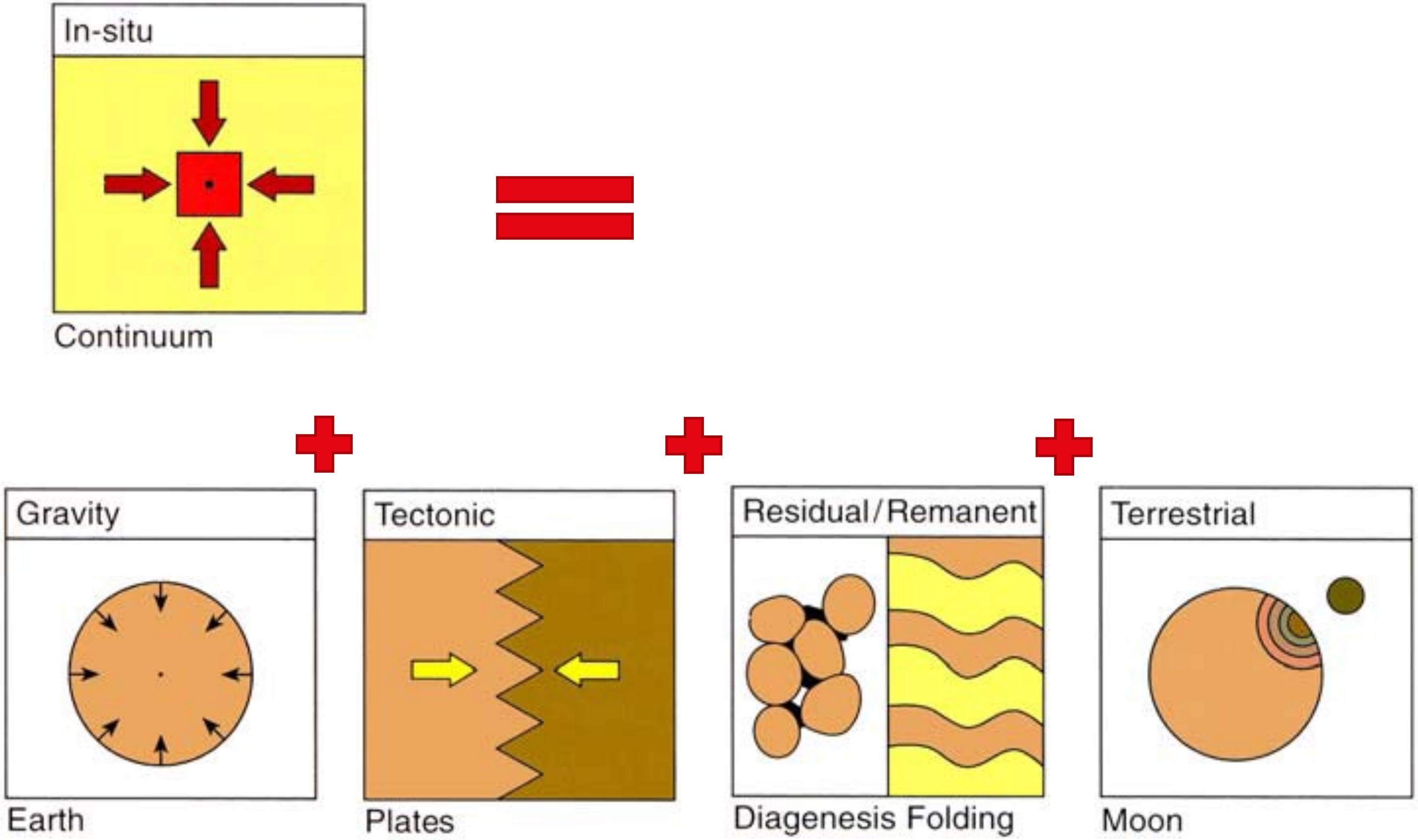


How far is the rock mass from rupture?



http://www.srk.co.uk/en/our-services/geotechnical-engineering/uk-underground-mine-geotechnics

Stress fields in rocks



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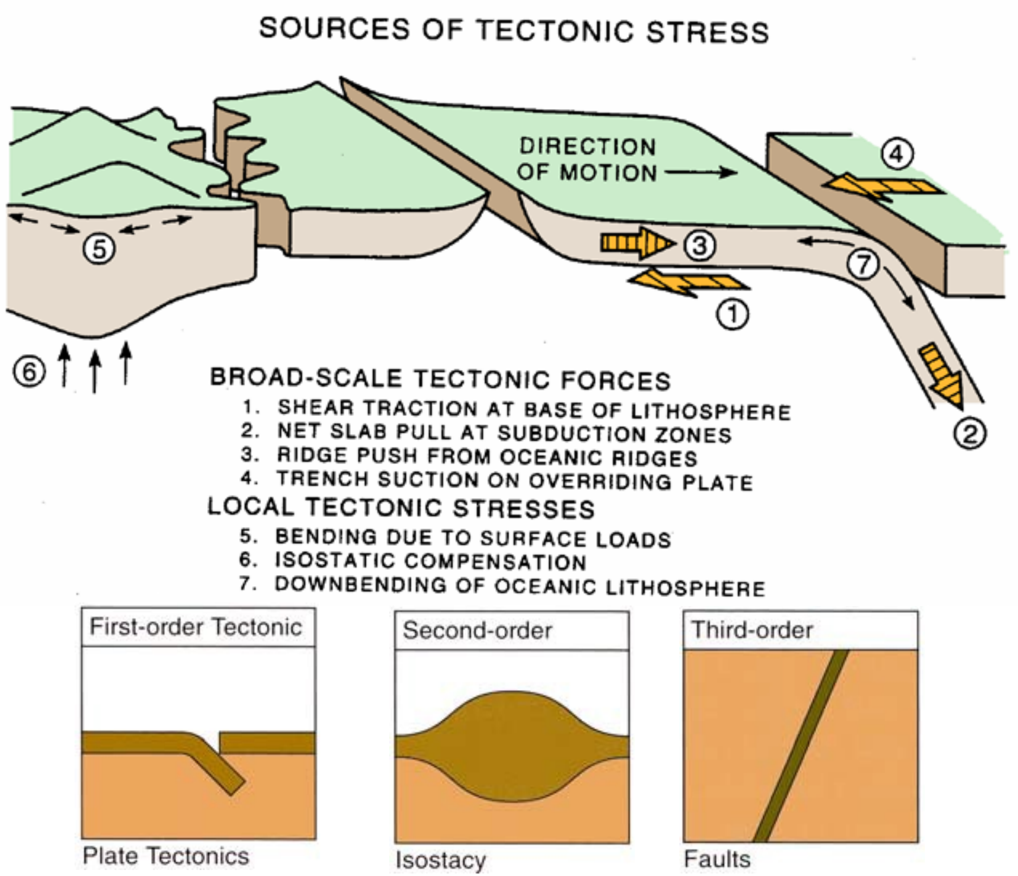
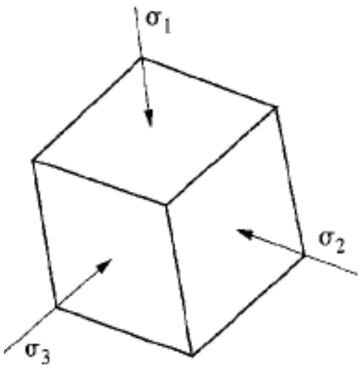
Stress fields in rocks



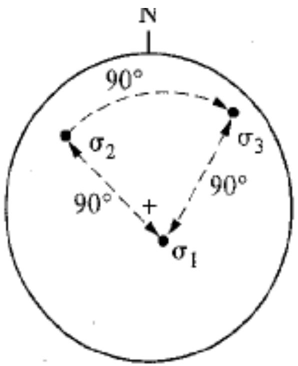
Zoback et al. (1989)

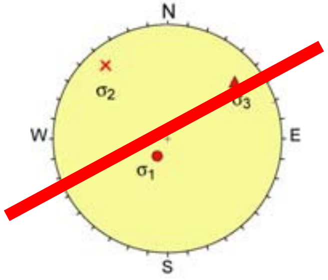
Stress field

The stress field on a point in the rock mass is typically represented by the magnitude and orientation of the principal stresses.



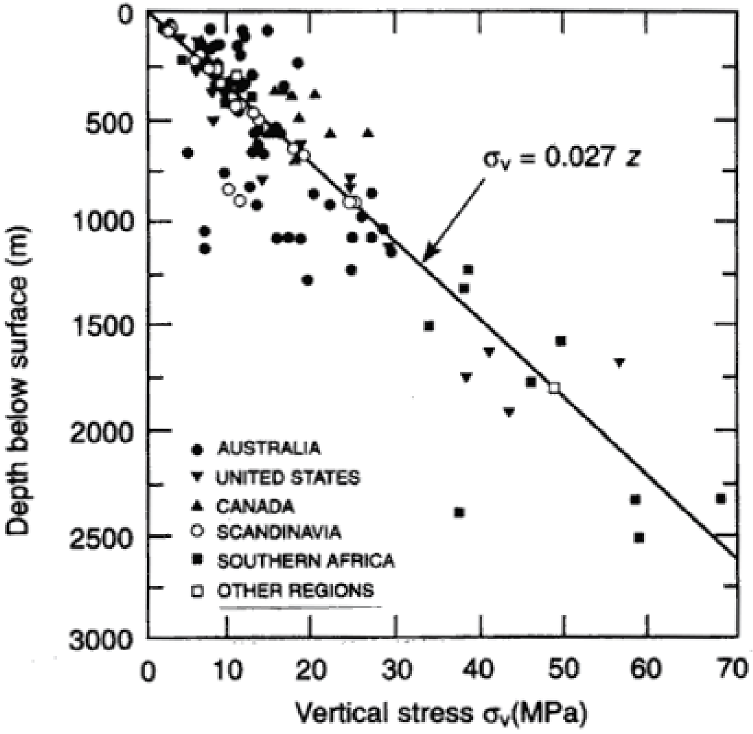
$$\begin{bmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{bmatrix}$$





Need to know the in-situ stresses in the direction of tunnel excavation for potential deformation analysis

Vertical stress



Hoek & Brown (1980)

$\sigma v = \gamma z$

$\gamma = specific\ weight\ (N/m^3)$

$Z\ depth\ (m)$

Horizontal stress

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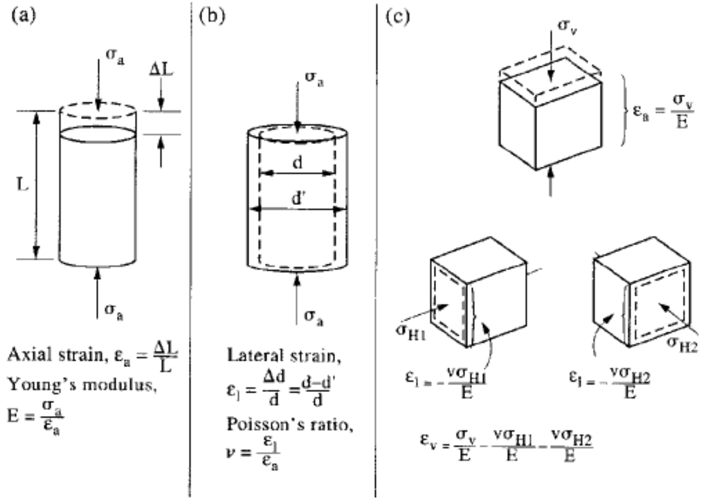
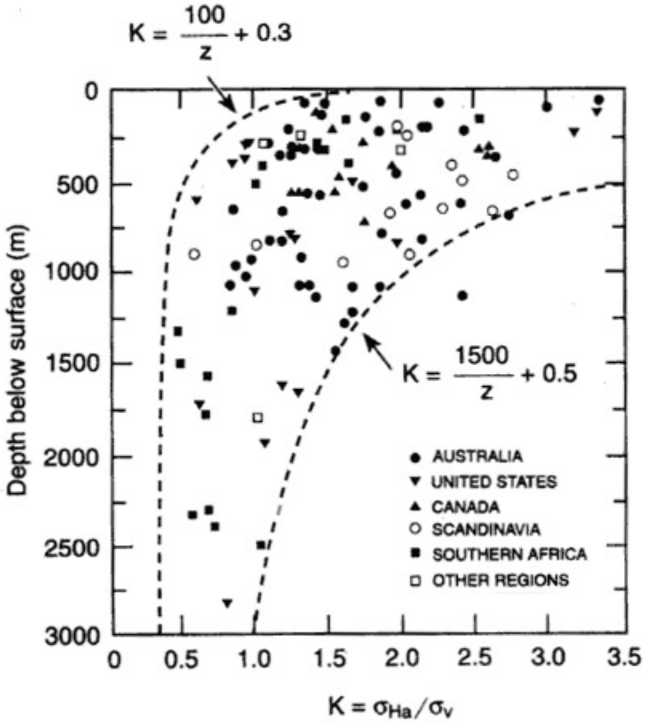


Hoek & Brown (1980)



In-situ testing program

It depends on:

- Geology and hydrogeology
- Type of structure
- Geotechnical parameters required
- Calculation method

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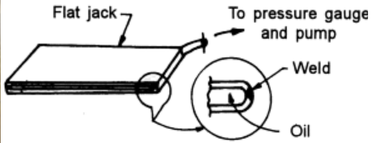
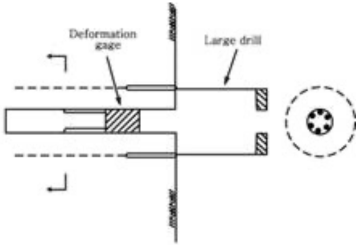
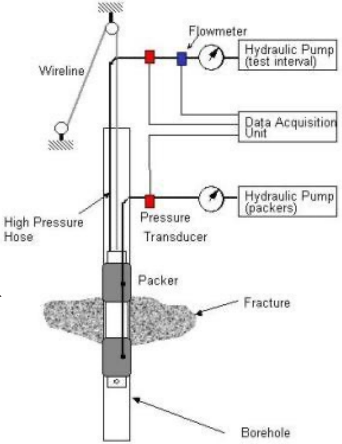
Field investigations (Downhole & In Situ Testing)

In situ stresses

Flat-jack	Stress compensation principle: inserting a flat jack in a cut slot in rock and jack the rock to its original position before cutting
Overcoring	A small borehole is instrumented, and overcored: deformation due to stress release is measured during overcoring. Stresses can be estimated (deformation + elastic properties of the rock).
Hydraulic fracturing	Borehole is sealed and pressurised. In situ stress field is modified from fluid pressure to open a fracture and to keep the fracture open and propagating.

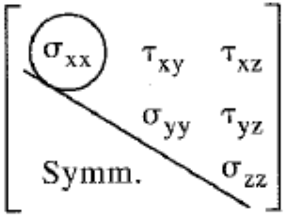






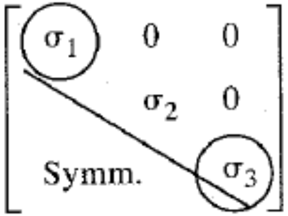
3 methods recommended by the ISRM for determining stress fields

1. **Flatjack**



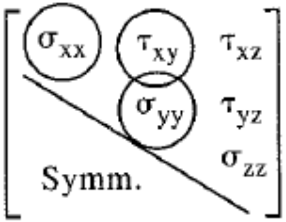
One normal stress component determined, say parallel to x-axis.

2. **Hydraulic fracturing**



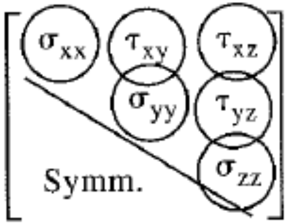
Principal stresses assumed parallel to axes i.e. plane of the fracture, two determined, say σ_1 and σ_3, one estimated, say σ_2.

3. **USBM overcoring torpedo**



Three components in 2-D determined from three measurements of borehole diameter change.

4. **CSIRO overcoring gauge**



All six components determined from six (or more) measuremen of strain at one time.

Hydraulic fracturing

Determination of stresses through hydraulic fracturing.

Used in deep drilling.

Drilling equipment includes:

- Sealing elements
- A hydraulic pump
- An injection fluid
- A fracture orientation detection tool

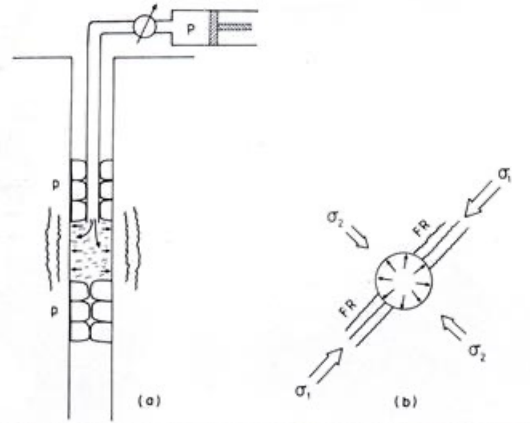
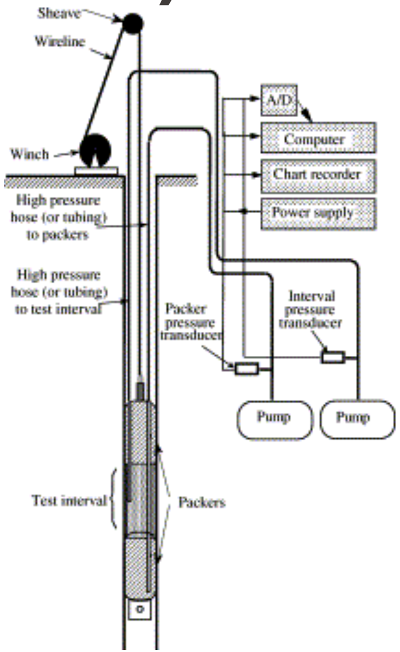


Fig. 3.51 Method of hydraulic fracturing. (a) Cross-section; *P*, packers; *p*, pressure. (b) Bird's perspective; FR, fracturing (induced).

Hydraulic fracturing

- No theoretical limit to the depth of measurement → stable borehole and **rock elastic and brittle**
- **Borehole axis** is **parallel to one of the principal stresses**
- Principal stress directions are derived from the fracture delineation on the borehole wall under the assumption that fracture attitude persists away from the hole
- Evaluation of the maximum principal stress in the plane perpendicular to the borehole axis **assumes that the rock mass is linearly elastic, homogeneous, and isotropic** (considerations of pore pressure effects, assessment of the rock tensile strength)

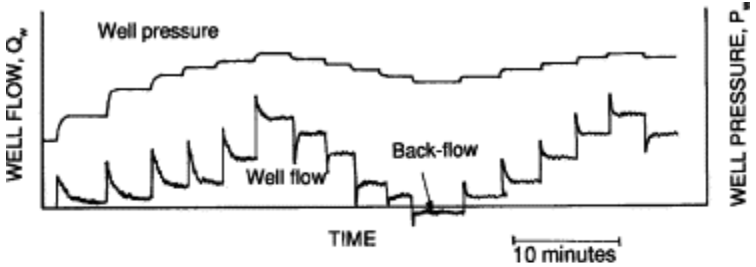
Hydraulic fracturing (ISRM – Haimson & Cornet, 2003)



Continuously record:

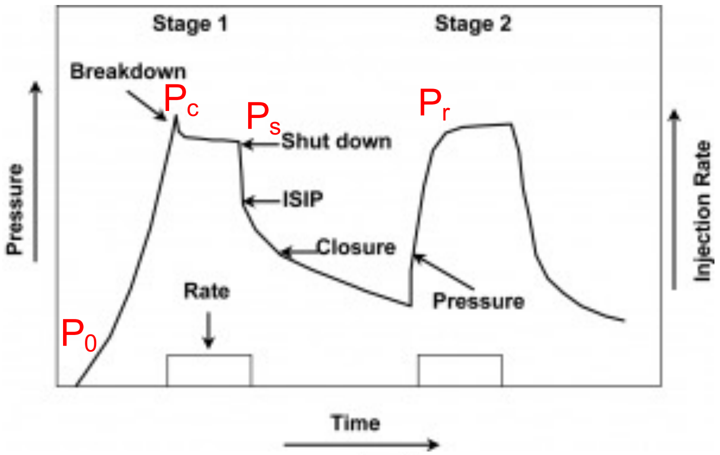
- the test interval and straddle packer pressures,
- the instantaneous injection flow rate and the total injected volume.

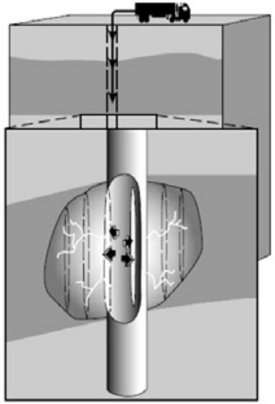
Step cycling pressure test.
The pressure is first raised, then decreased, in a stepwise manner, each step lasting 4–5 min



Hydraulic fracturing

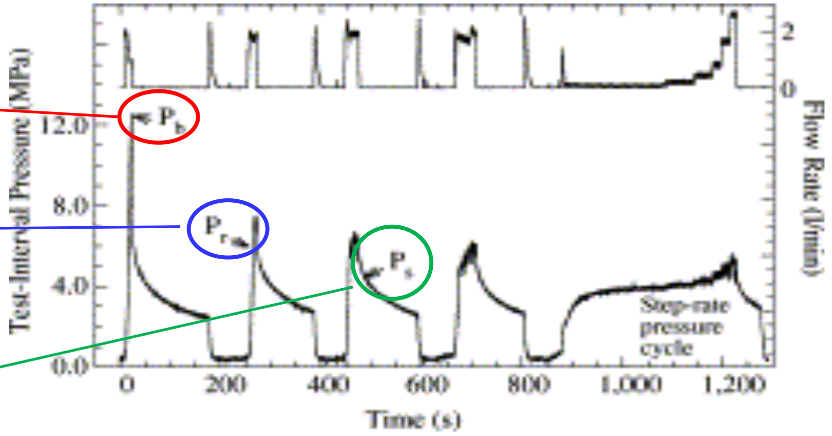
- Pressure of fracturation (P_c) (Breakdown pressure)
- The pressure needed to initiate a fracture (P_s) (shut-in pressure)
- Reopening pressure (P_r)
- Initial pressure (P_0)





Hydraulic fracturing (ISRM – Haimson & Cornet, 2003)

- Breakdown pressure (P_b) is taken as the peak pressure attained in the first pressure cycle
- Fracture reopening pressure (P_r) is the point on the ascending portion of the pressure–time curve in subsequent (usually second or/and third) cycles
- The shut-in pressure (P_s) is the pressure reached, after the pump is shut off following breakdown or fracture reopening, when the hydraulically induced or the pre-existing fracture closes back



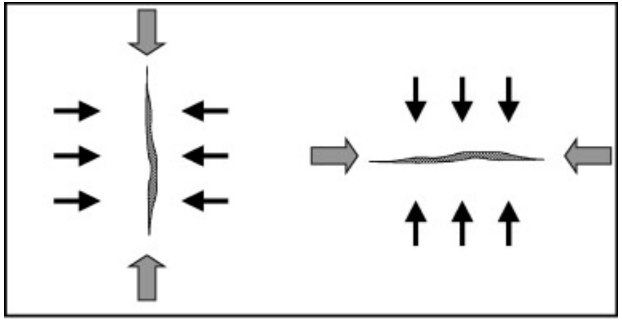
Test-interval pressure and flow rate versus time

Hydraulic fracturing

We assume:

That the induced fracture propagates in the direction perpendicular to the minimum principal stress.

- That the rock behaves elastically (stress concentration X3).
- That the rock is impermeable (no water penetration into the rock).
- That there are no fractures in the interval being tested.
- That the well is parallel to a principal stress direction.

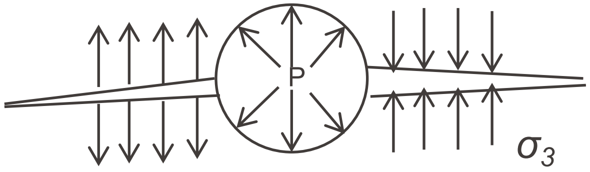


(a) $K_0 < 1$ Vertical fracture

(b) $K_0 > 1$ Horizontal fracture

Stress calculation from HF test

- Vertical stress component acts along a principal direction
- Vertical HFs are oriented perpendicular to the direction of the minimum horizontal principal stress
- Linear elasticity



- *Least horizontal stress* ($\sigma_3 = \sigma_h$)
- The **shut-in pressure (P_s)** is the pressure needed to equilibrate the fracture-normal stress, σ_h

$$\sigma_h = P_s.$$

Hydraulic fracturing

The pressure required to keep a fracture open (Ps) is equal to the minimum horizontal stress (σ_h):

$$Ps = \sigma_h$$

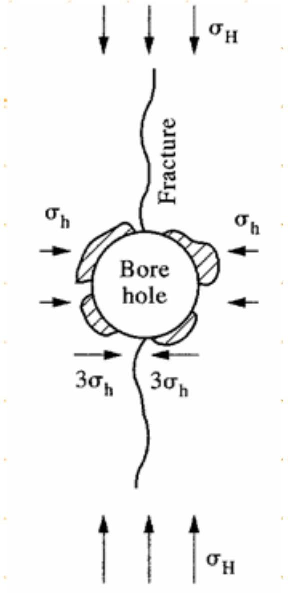
The maximum horizontal stress (σ_H) is derived from the pressures Pc and Pr. For this, it is necessary that:

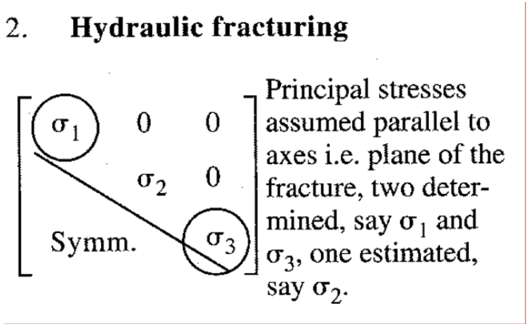
- Pc is greater than σ_h (concentrated 3 times due to the presence of the well)
- Pc is greater than the tensile strength (σ_t) of the rock

$$\sigma_H = 3\sigma_h - Pc - Po + \sigma_t$$

$$\sigma_t = Pc – Pr$$

$$\sigma_H = 3\sigma_h - Pr - Po"$$




2. **Hydraulic fracturing**

$$\begin{bmatrix} \sigma_1 & 0 & 0 \\ & \sigma_2 & 0 \\ \text{Symm.} & & \sigma_3 \end{bmatrix}$$

Principal stresses assumed parallel to axes i.e. plane of the fracture, two determined, say σ_1 and σ_3, one estimated, say σ_2.

Stress calculation from HF test

- *Vertical stress* ($\sigma_{1 \text{ or } 2} = \sigma_v$):
- **cannot be evaluated from test results**
- (unless the induced fracture is nearly horizontal → shut-in pressure = σ_v)

- σ_v is assumed to be equal to the **overburden weight per unit area at the depth of interest**

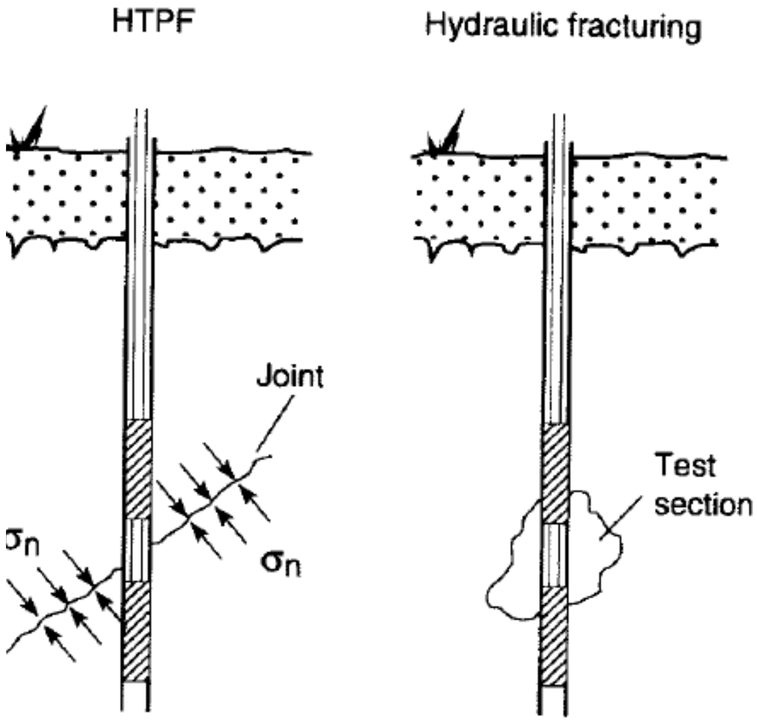
$$\sigma_v = \sum_{i=1}^{n} \rho_i g D_i$$

- ρ_l = mean mass density of rock layer *l*;
- *g* = local gravitational acceleration;
- D_l = thickness of layer *l*;
- *n* = number of rock layers overlying the test zone

Hydraulic fracturing with pre-existing fractures (HTPF)

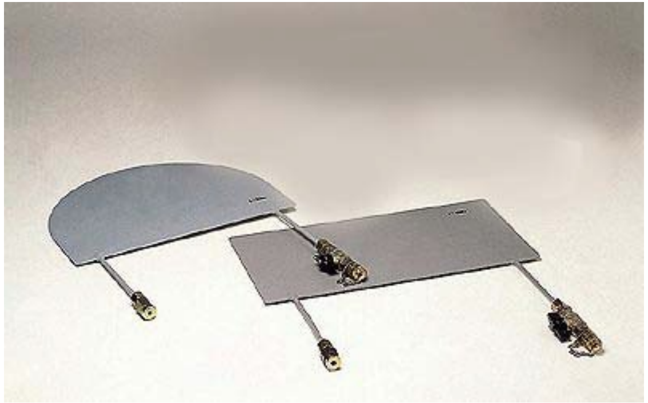
HTPF stands for Hydraulic Testing on Pre-existing Fractures.

It involves reopening pre-existing fractures isolated between two packers. A low injection rate is used. The fluid pressure that exactly balances the normal stress on the fracture is measured. This process is repeated on fractures with different orientations to determine the various components of the stress tensor.



Amadei & Stephansson (1997)

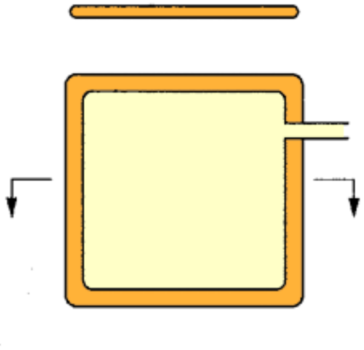
Flat Jack

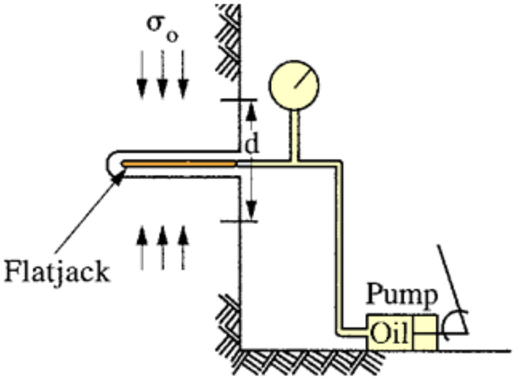


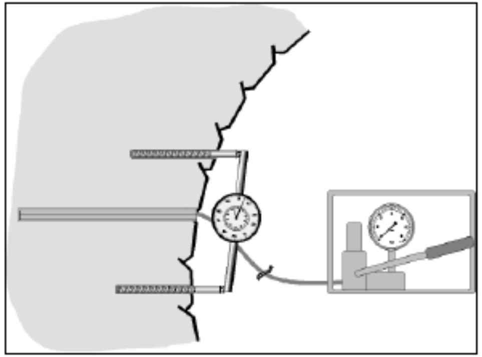
2 semi-circular metal plates welded around the perimeter.

1 feed tube allowing the system to be pressurized with water or oil.

Flat Jack

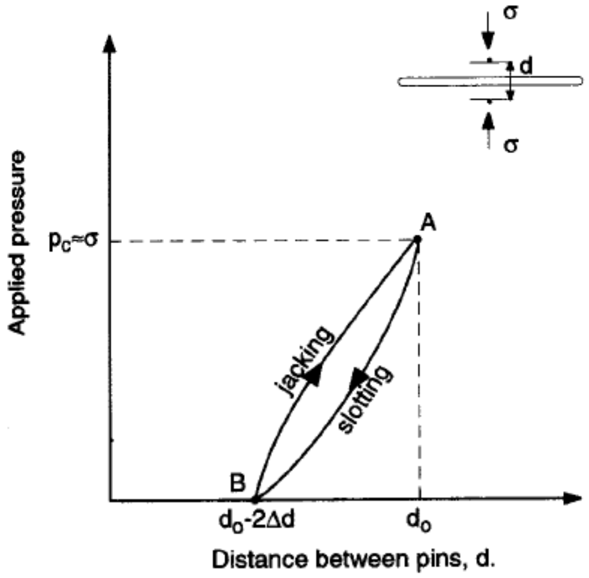


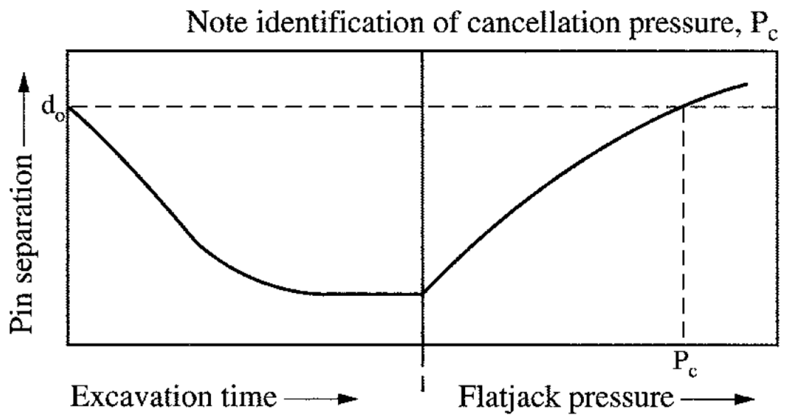




Two fixed anchors are placed in the rock. The distance (d) is measured. A groove is made in the rock. If the rock is under compression, the two anchors will move closer together. Then the flat jack is pressurized, and the anchors will move apart. It is assumed that when the distance between the anchors returns to the initial value, the force exerted by the flat jack is that of the initial stress.

Flat jack



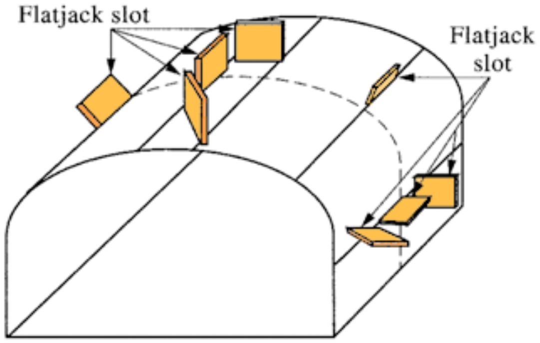


Hudson & Harrison (1997)

Flat Jack

Disadvantage of the method:

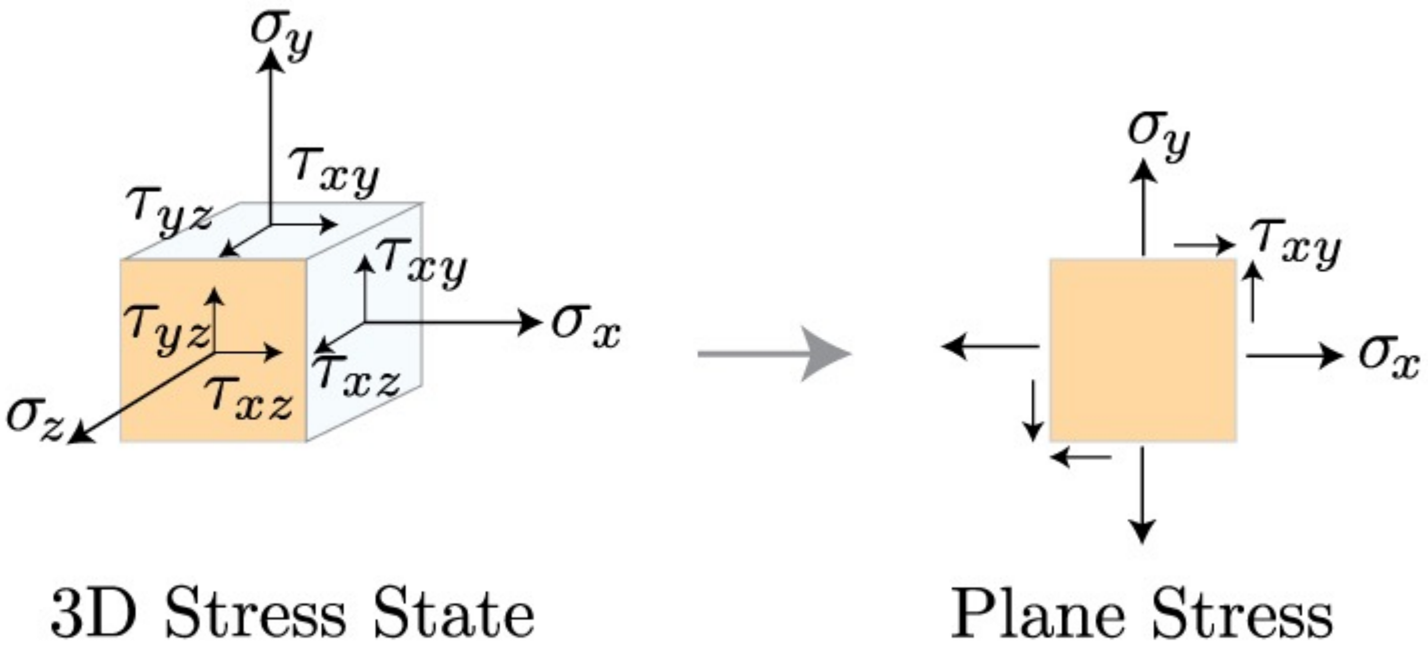
- Minimum of 6 tests with different orientations at various locations of the excavation required.
- Disturbance of the stress field during excavation, thus the redistribution of the new stresses must be taken into account.



1. **Flatjack**

$$\begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ & \sigma_{yy} & \tau_{yz} \\ \text{Symm.} & & \sigma_{zz} \end{bmatrix}$$

Stress rotation



Stress rotation

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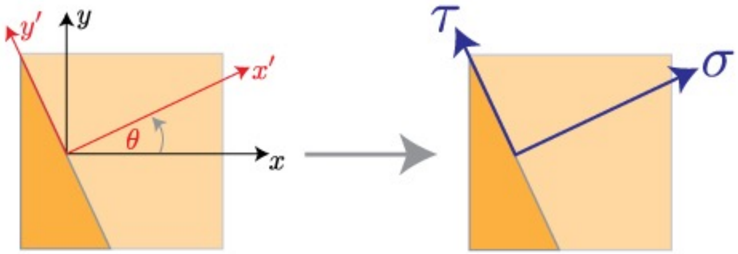
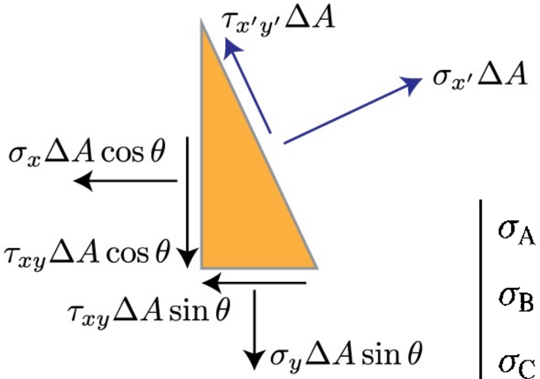


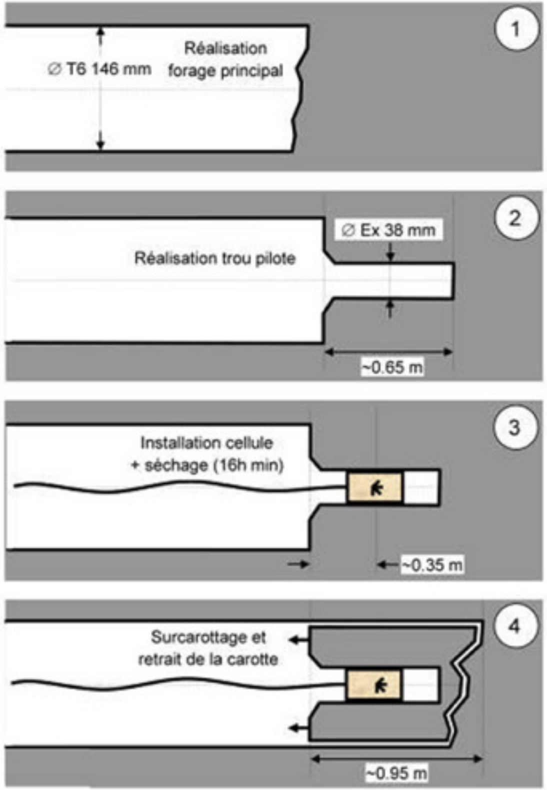


$$\begin{bmatrix}\sigma_A\\ \sigma_B\\ \sigma_C\end{bmatrix} = \begin{bmatrix}\cos^2\theta_A & \sin^2\theta_A & 2\sin\theta_A\cos\theta_A\\ \cos^2\theta_B & \sin^2\theta_B & 2\sin\theta_B\cos\theta_B\\ \cos^2\theta_C & \sin^2\theta_C & 2\sin\theta_C\cos\theta_C\end{bmatrix}\begin{bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{bmatrix} \text{ or } \boldsymbol{\sigma}_{\text{jack}} = \mathbf{R}\boldsymbol{\sigma}_{\text{global}}$$

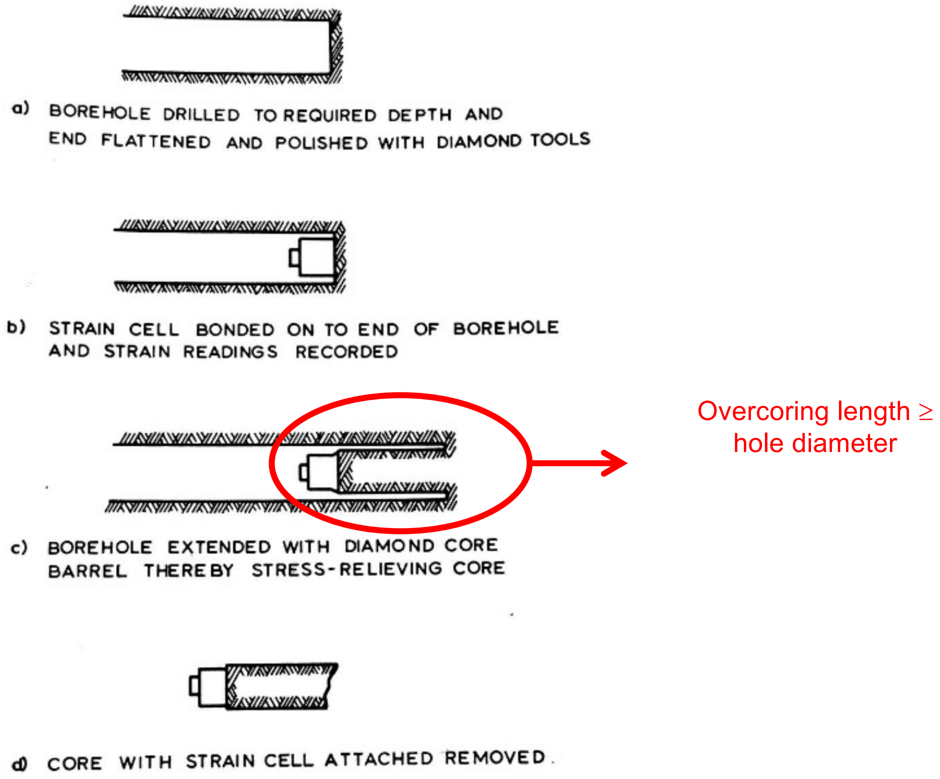
Over-coring

The method of stress measurement using the overcoring technique consists of measuring displacements or deformations at the wall of a borehole during a total relaxation of the formations achieved by coaxial coring around the borehole.

- Execution of a large-diameter access borehole to the depth at which stress measurements are desired;
- Extension for approximately 1 meter by a smaller-diameter pilot borehole, coaxial with the first one, and installation of the measurement cell according to a given orientation
- Resumption of the large-diameter borehole with a thin-walled coring tool, to overcore the formations around the measurement cell, releasing them from any stress.
- At the end of this operation, the overcored ring containing the measurement cell is retrieved.
- Then, a triaxial test is carried out on a sample to determine the geomechanical properties of the rock: Young's modulus, Poisson's ratio(s), and its degree of anisotropy.



Overcoring method (Hoek 1996, Leeman 1964)



Overcoring method (Hoek 1996, Leeman 1964)

- The **strain difference** are used **to back-calculate the stresses** acting on the rock cylinder prior to overcoring assuming *continuous, homogeneous, isotropic, and linear-elastic rock behaviour*

  → **Elastic properties of the rock** (Young's modulus and Poisson's ratio) determined by tests on the overcored rock cylinder on-site

  → Depending on the strain-measuring instrument, either the stresses in the two-dimensional plane orthogonal to the borehole axis, or the complete three-dimensional stress tensor (magnitudes and orientations) at the borehole wall, can then be determined.

Over coring

- Various measurement cells have been developed since the emergence of this technique.
- Bidirectional cells

- Doorstopper (South Africa)
- US-BM (USA)T

- Tridirectional cells

- LNEC
- CSIR (Australia)

Over-coring USBM

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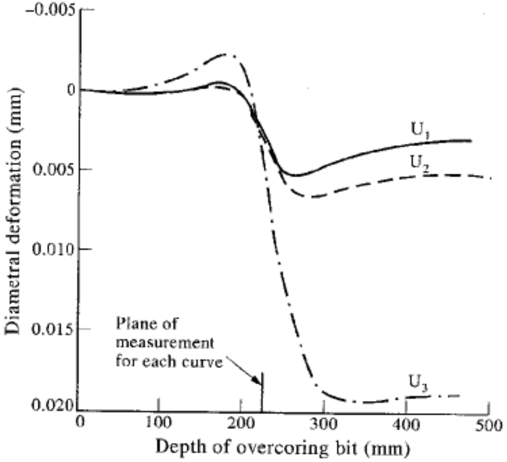
The traces are the electrical output from the device plotted against time during overcoring and hence illustrate the evolution of diametral change during overcoring.

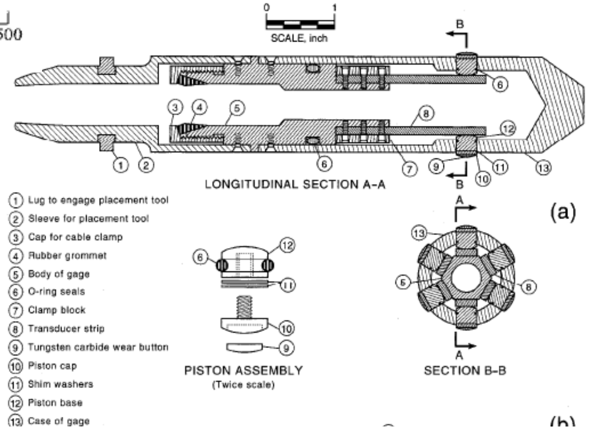


$$\varepsilon = A\sigma$$

3. USBM overcoring torpedo

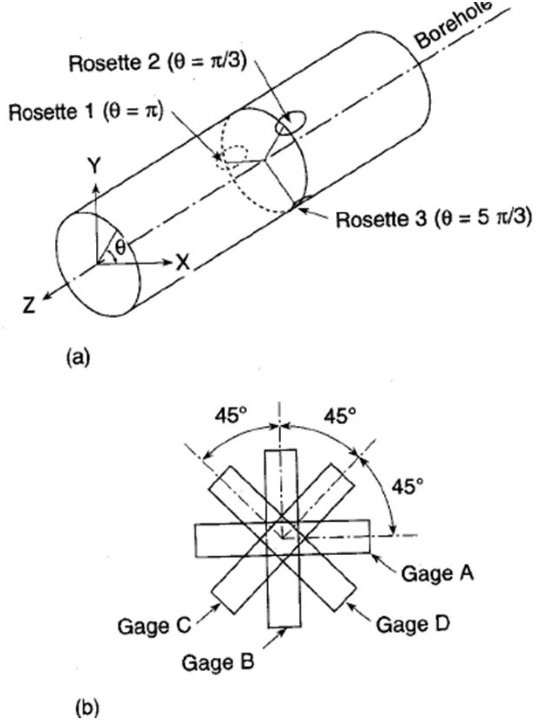
$$\begin{bmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ & \sigma_{yy} & \tau_{yz} \\ \text{Symm.} & & \sigma_{zz} \end{bmatrix}$$

Three components in 2-D determined from three measurements of borehole diameter change.

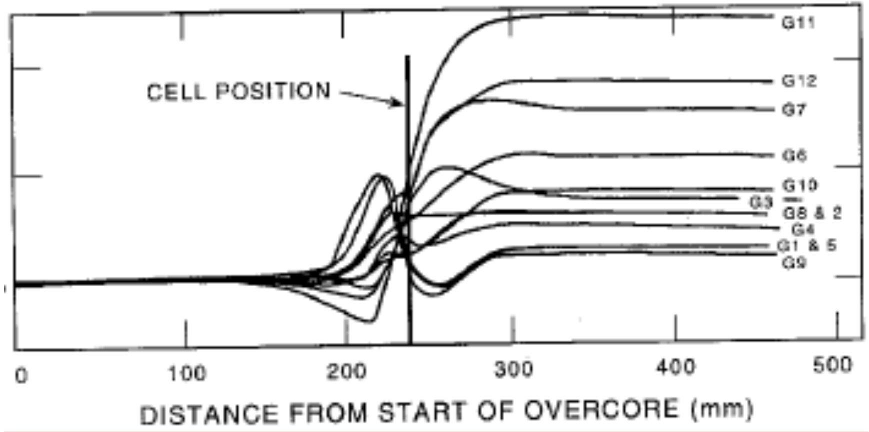


Over coring USBM (CSIRO)

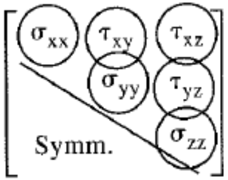
A technique similar to USBM plus a strain gauge glued inside the well to measure normal deformations in the well.



Overcoring USBM (CSIRO)



4. **CSIRO overcoring gauge**



All six components determined from six (or more) measureme[nts] of strain at one time.

Complete stress tensor

Seismic waves

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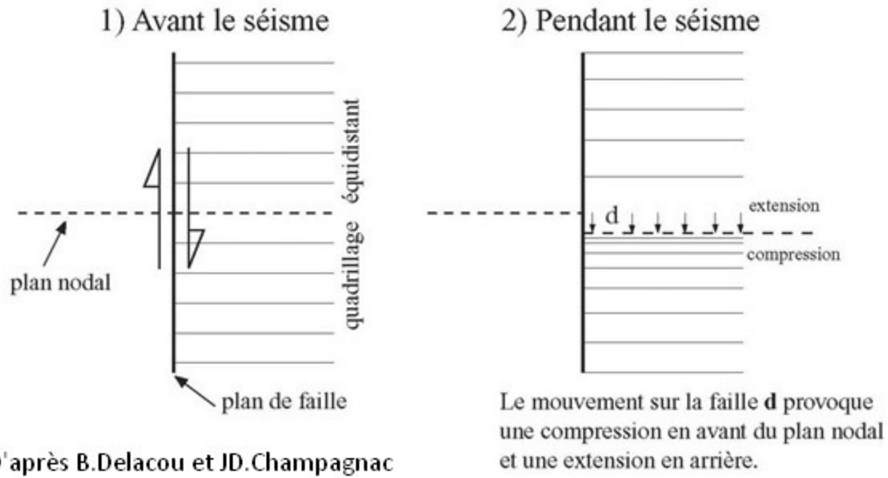
Studying the focal mechanism of an earthquake allows us to account for the relative movement between the two compartments of rock at the moment of rupture along the fault plane separating them. Seismologists have studied ground motions observed at different stations. It is noted that for motions contemporaneous with the arrival of P-waves, two situations are possible:

particles move towards the focus: thus, there is dilation at the station.

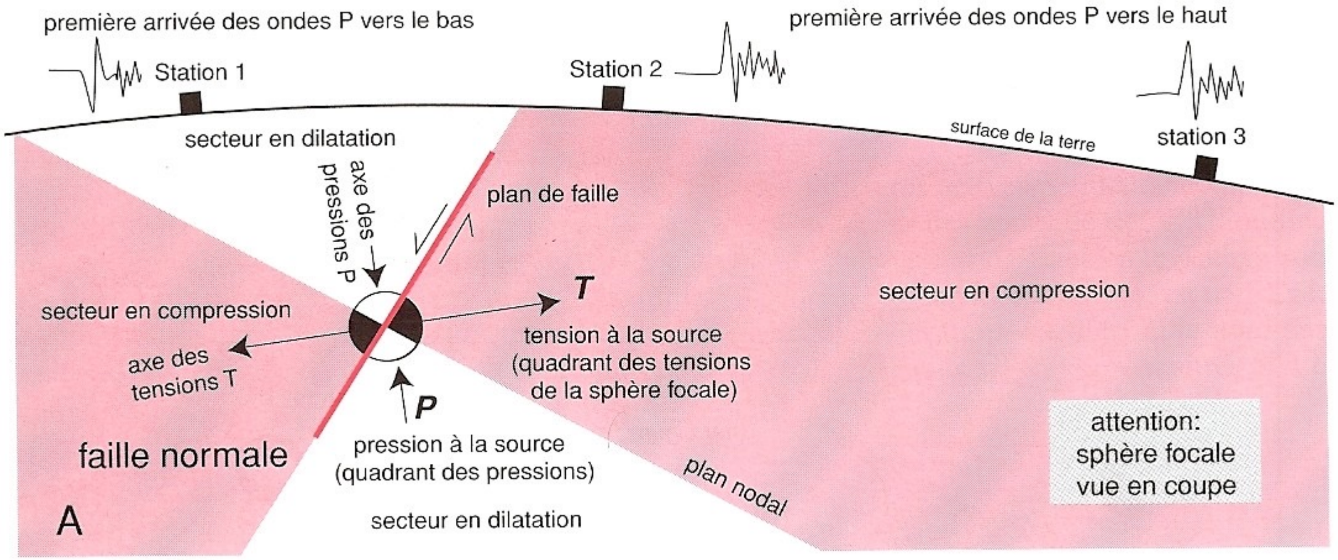
particles appear to move away from the focus: thus, there is compression at the station.



D'après B.Delacou et JD.Champagnac

Seismic waves

A network of stations thus allows for the establishment of a map of areas on the globe that have experienced compression (these stations are then represented by the "+" sign) or dilation (represented by the "-" sign).



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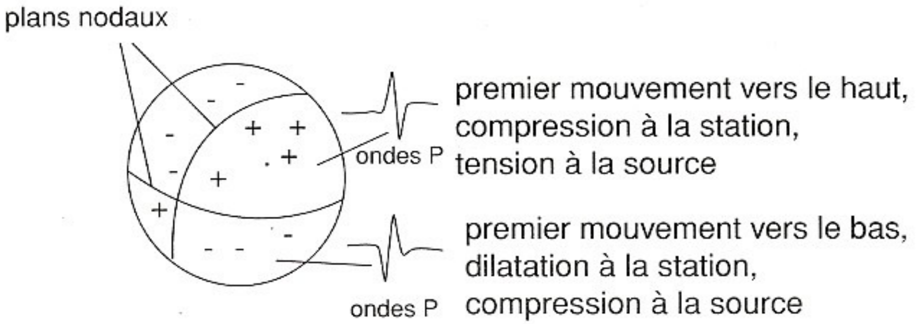
Seismic waves

To determine the focal mechanism of an earthquake, the Earth is assimilated to a sphere with the center being the earthquake focus (this is the focal sphere). Stations that have recorded the earthquake are projected onto this sphere, indicating the direction of the initial movements associated with P-waves (compression or dilation). This establishes four sectors of compression-dilation, delimited by nodal planes. By convention, the following representation mode is used:

- For sectors where the initial movements are compression (+), the focal mechanism is tension: the quadrant is represented in black.
- For sectors where the initial movements are dilation (-), the focal mechanism is compression: the quadrant is represented in white.



Reverse fault

Seismic waves

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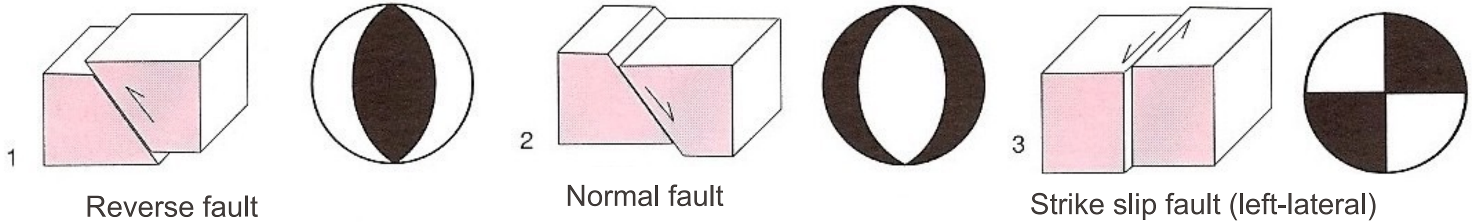
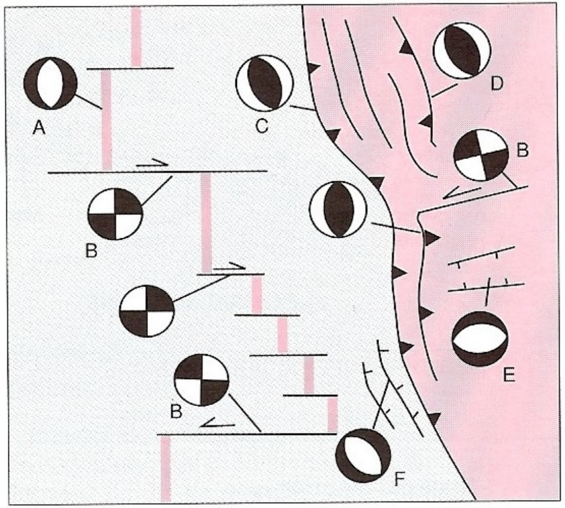
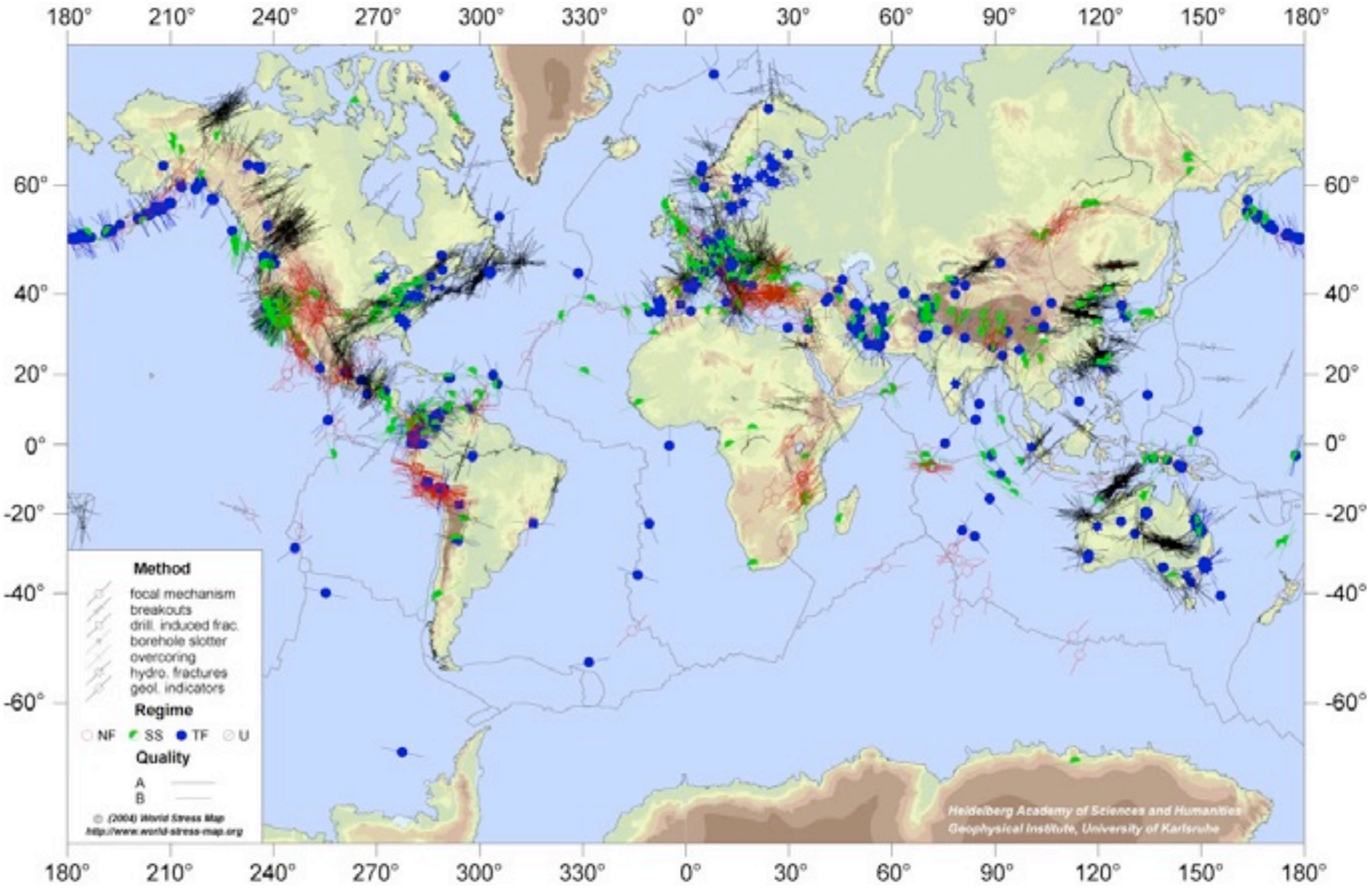


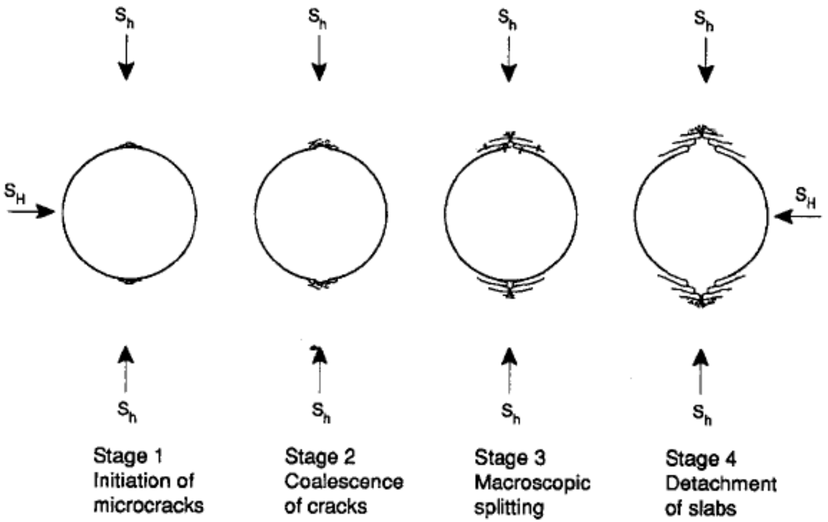


http://eduterre.ens-lyon.fr/thematiques/terre/montagnes/extension/meca%20foyer

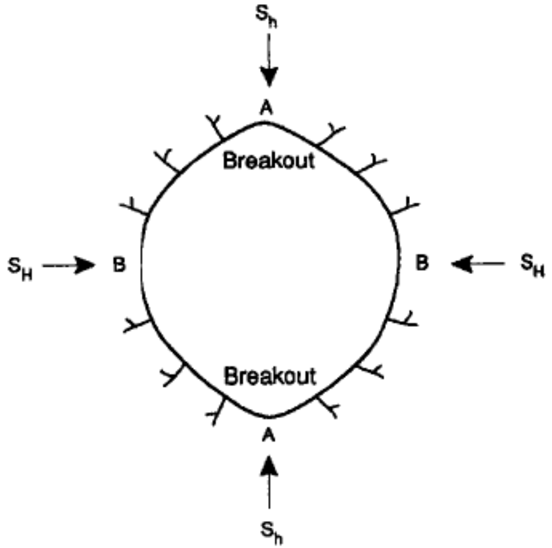


180° 210° 240° 270° 300° 330° 0° 30° 60° 90° 120° 150° 180°
60° 40° 20° 0° -20° -40° -60°
Method
focal mechanism
breakouts
drill. induced frac.
borehole slotter
overcoring
hydro. fractures
geol. indicators
Regime
NF SS TF U
Quality
A
B
© (2004) World Stress Map
http://www.world-stress-map.org
Heidelberg Academy of Sciences and Humanities
Geophysical Institute, University of Karlsruhe

Breakout

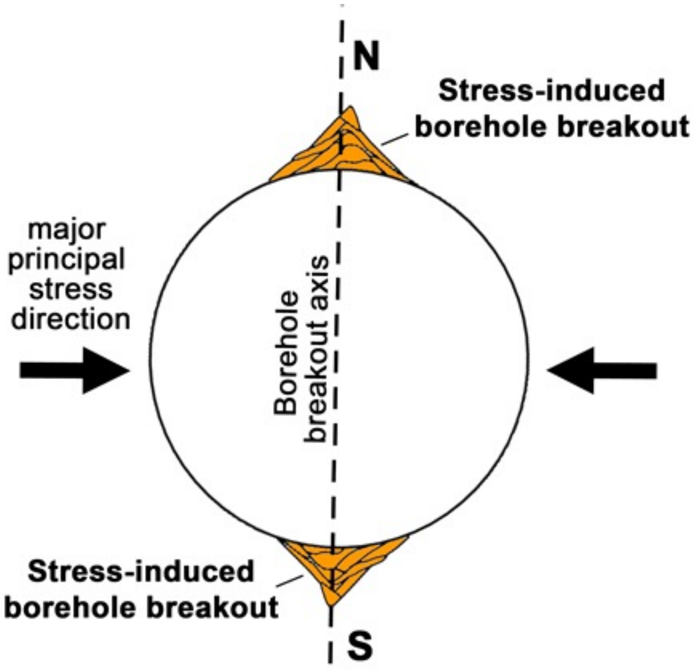


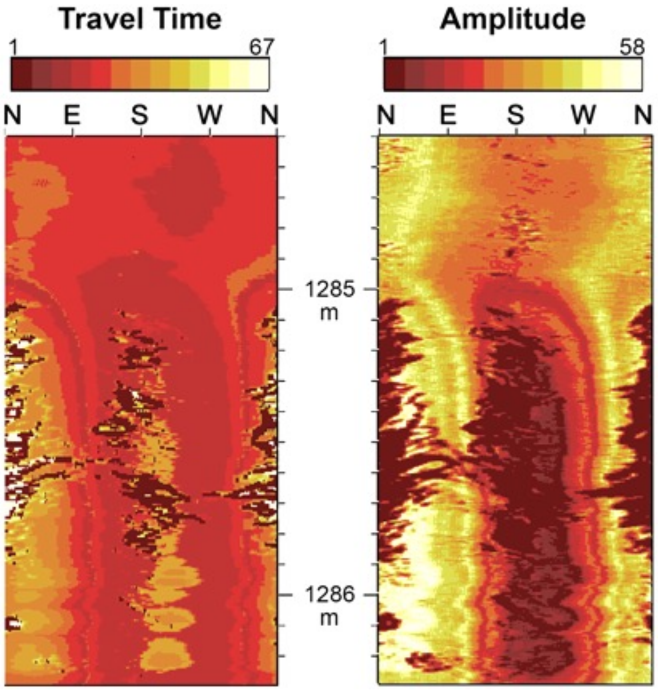
S_h
S_H
S_H
S_h
Stage 1
Initiation of
microcracks
Stage 2
Coalescence
of cracks
Stage 3
Macroscopic
splitting
Stage 4
Detachment
of slabs



S_h
A
Breakout
S_H
B
B
S_H
Breakout
A
S_h

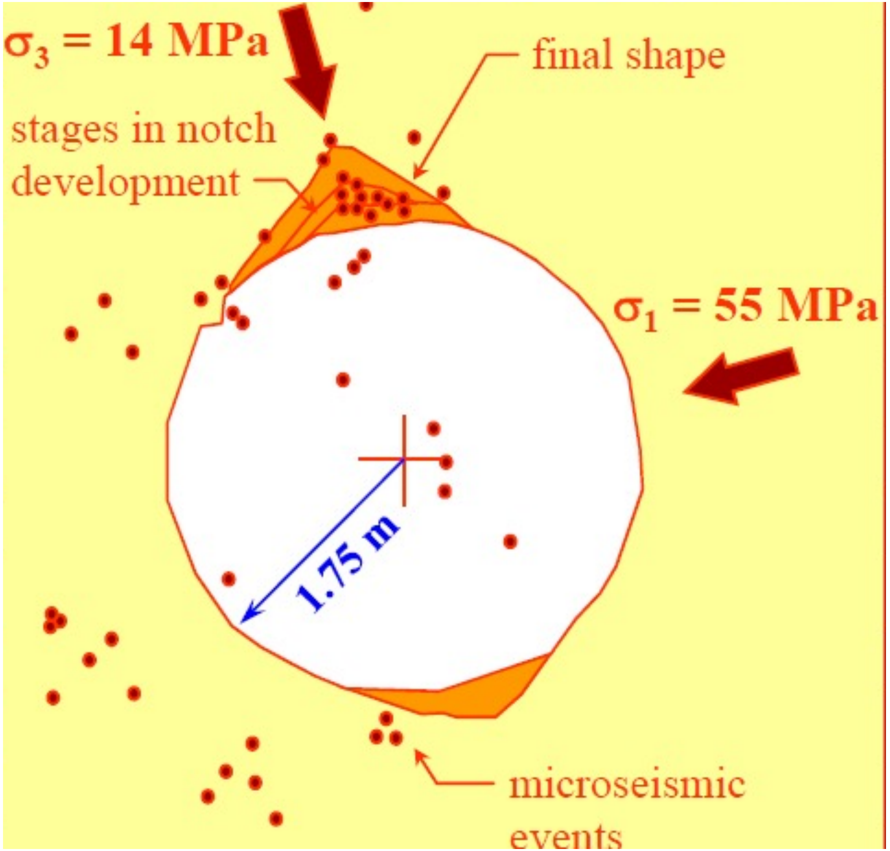
Breakout





Televiewerm INCO's Totten mine

Breakout (tunnels)

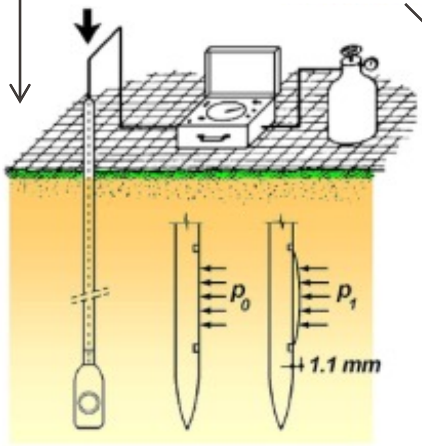


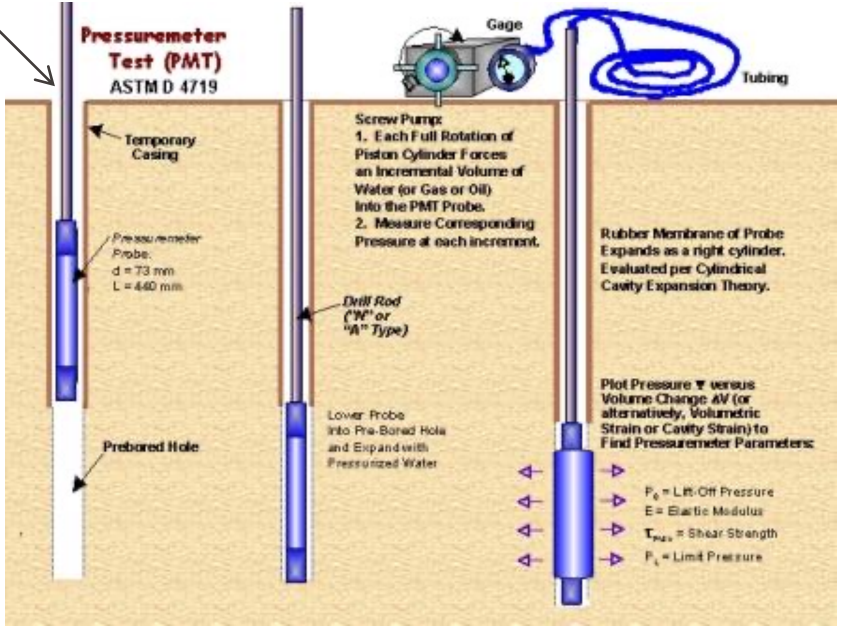
Field investigations (Downhole & In Situ Testing)

Prof. M. VIOLAY

In situ modulus

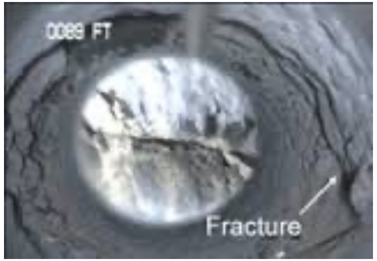
Flat Dilatometer	Measure deformation with applied pressure
Pressuremeter	Measure strain with applied pressure





Discontinuities

Joints orientation

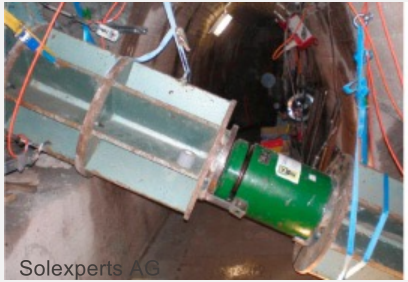


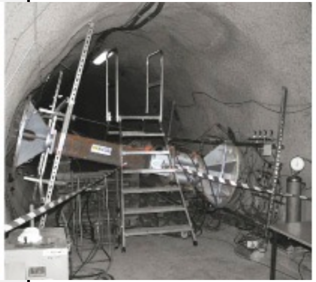
Impression packer	Plastic rubber packered against borehole wall → impression of fractures and orientation
Borehole camera	Views directly through a camera into the hole → systematic mapping of discontinuities
Borehole acoustic imaging	Pulsed acoustic signal and reflection → impression of fractures and orientation

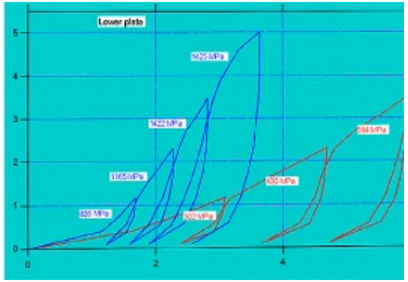
Field investigations (Downhole & In Situ Testing)

In situ modulus

P- and S-wave velocities	Measures P- and S-wave velocities →dynamics elastic and shear moduli
Plate load test	Applies load at a plate normal to rock surface and measure deformation with load







! Large scale tests can be quite expensive and difficult to be realised

Indirect determination of rock properties (ex. Schmidt Hammer) + Laboratory tests

Method	Avantages	Limitations	Where/when
Hydraulic fracture	Existing wells, fast, accurate	only 2 D	Shallow and deep wells
Overcoring	3 D	Need of a well	Fairly unreliable for high-stress areas
HTPF	3 D	Need for pre-existing fractures with varied orientations	Used when hydraulic fracturing and over-core data do not work
Flatjack	Inexpensive	At least 6 measurements	In tunnels
Focal mechanisms	Information obtained from earthquakes	Very great depth	In seismically active zones
Break out	fast	Orientation only (no magnitudes)	Deep wells
Geological indicators	Inexpensive	Large uncertainties	At the beginning of the project