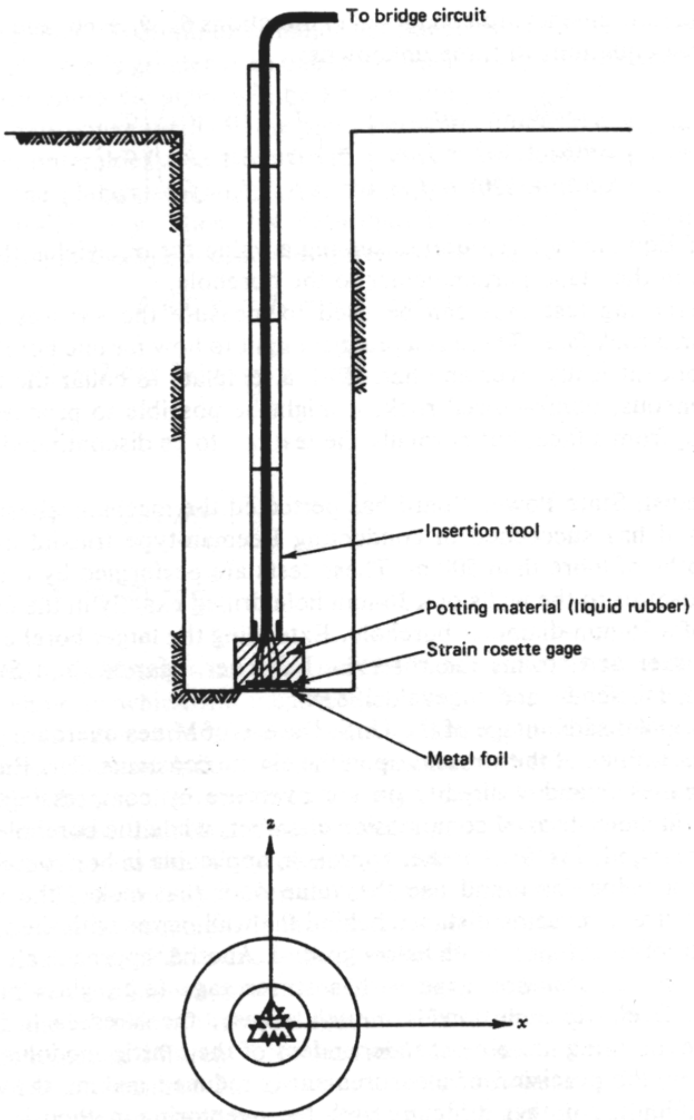
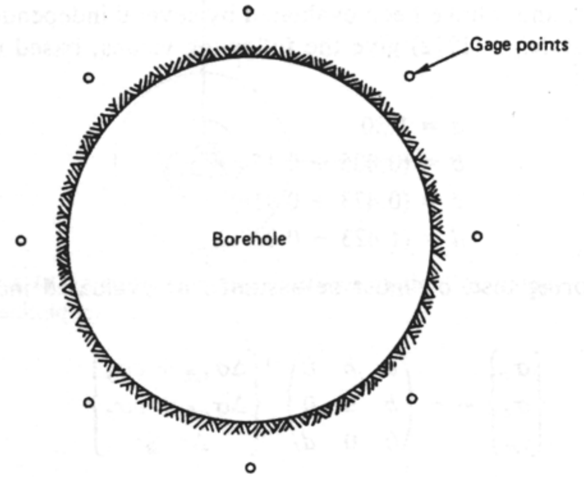
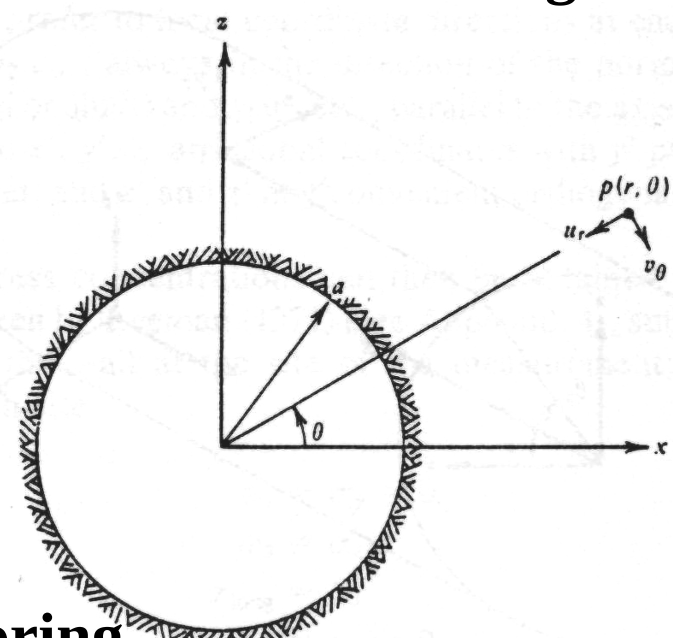
Surface relief (measure displacement or strain)



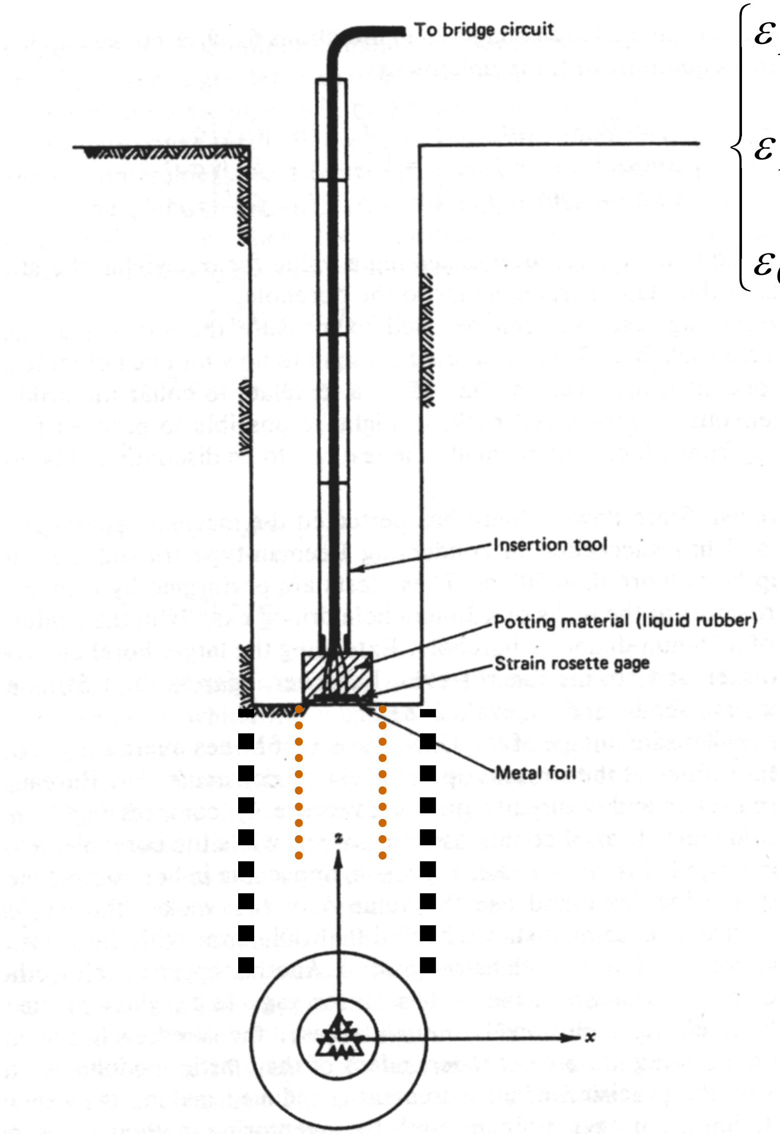


Pin ⟶ Undercoring



Doorstopper biaxial strain cell ⟶ Overcoring

Surface relief



Doorstopper biaxial strain cell

$$\begin{Bmatrix} \varepsilon_A \\ \varepsilon_B \\ \varepsilon_C \end{Bmatrix} \rightarrow \begin{Bmatrix} \varepsilon_{x'} \\ \varepsilon_{z'} \\ \gamma_{x'z'} \end{Bmatrix}$$

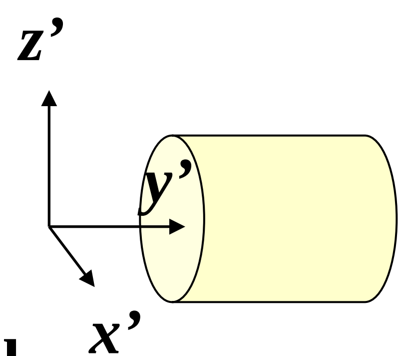
Strain analysis (coordinate transformation)

$$\begin{Bmatrix} \varepsilon_{x'} \\ \varepsilon_{z'} \\ \gamma_{x'z'} \end{Bmatrix} \rightarrow \begin{Bmatrix} \Delta\sigma_{x'} \\ \Delta\sigma_{z'} \\ \Delta\tau_{x'z'} \end{Bmatrix}$$

Elastic relation

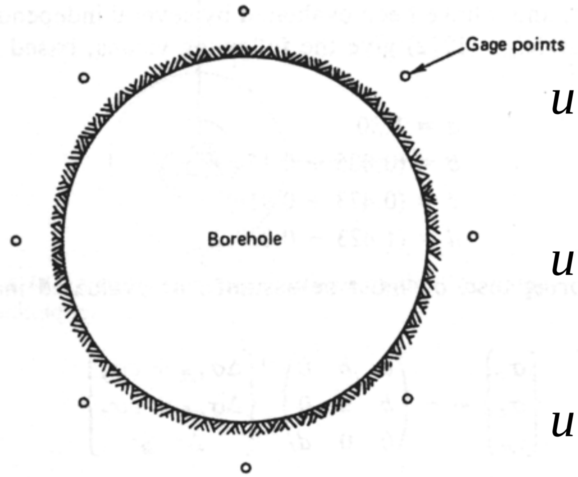
Finite element analysis

$$\begin{Bmatrix} \Delta\sigma_{x'} \\ \Delta\sigma_{z'} \\ \Delta\tau_{x'z'} \end{Bmatrix} \rightarrow \begin{Bmatrix} \sigma_{x'} \\ \sigma_{y'} \\ \sigma_{z'} \\ \tau_{y'z'} \end{Bmatrix}$$



At surface, $\sigma_{y'} = 0$

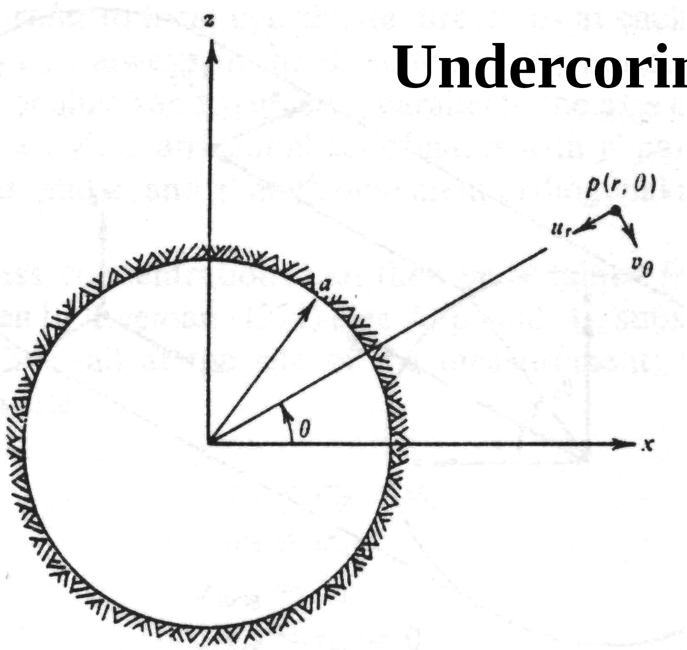
Surface relief



$$u_{r,1} = -\frac{a^2}{2Gr}\left[\frac{\sigma_h+\sigma_v}{2} + \frac{\sigma_h-\sigma_v}{2}\cdot\{4\cdot(1-\nu) - \frac{a^2}{r^2}\}\cdot\cos 2(\theta+\theta_1)\right]$$

$$u_{r,1} = -\frac{a^2}{2Gr}\left[\frac{\sigma_h+\sigma_v}{2} + \frac{\sigma_h-\sigma_v}{2}\cdot\{4\cdot(1-\nu) - \frac{a^2}{r^2}\}\cdot\cos 2(\theta+\theta_2)\right]$$

$$u_{r,1} = -\frac{a^2}{2Gr}\left[\frac{\sigma_h+\sigma_v}{2} + \frac{\sigma_h-\sigma_v}{2}\cdot\{4\cdot(1-\nu) - \frac{a^2}{r^2}\}\cdot\cos 2(\theta+\theta_3)\right]$$

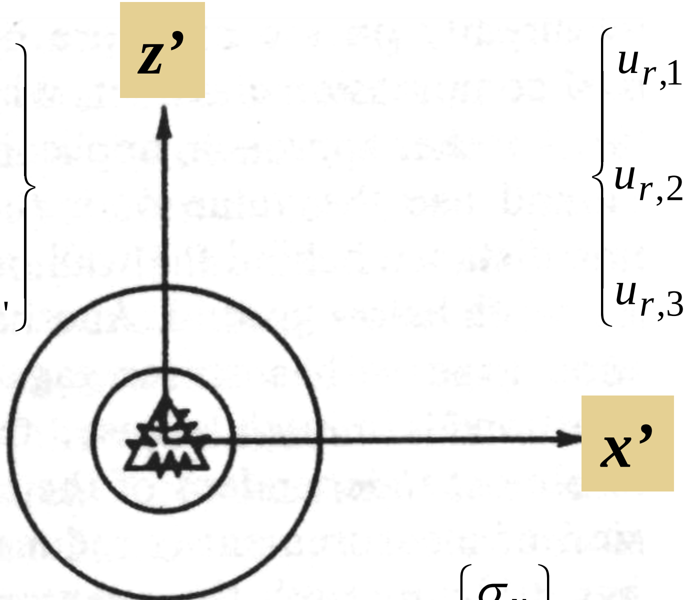


Undercoring

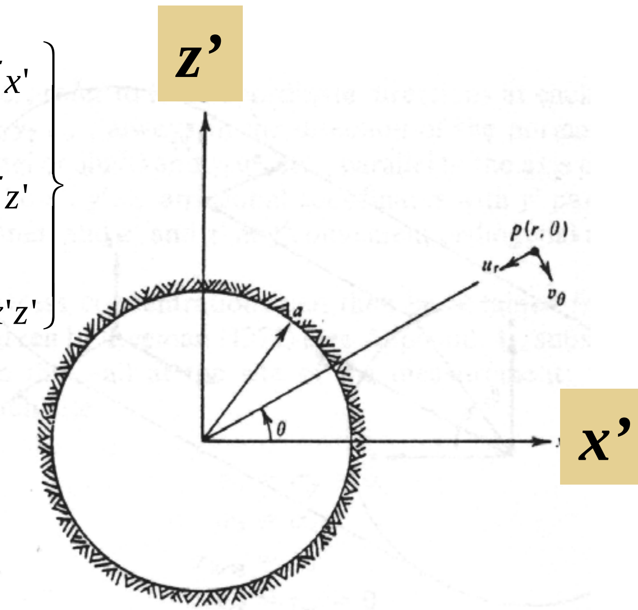
$$\begin{Bmatrix} u_{r,1} \\ u_{r,2} \\ u_{r,3} \end{Bmatrix} \rightarrow \begin{Bmatrix} \sigma_{x'} \\ \sigma_{z'} \\ \tau_{x'z'} \end{Bmatrix}$$

Modification of stress concentration

$$\begin{Bmatrix}\varepsilon_A\\ \varepsilon_B\\ \varepsilon_C\end{Bmatrix} \rightarrow \begin{Bmatrix}\sigma_{x'}\\ \sigma_{z'}\\ \tau_{x'z'}\end{Bmatrix}$$



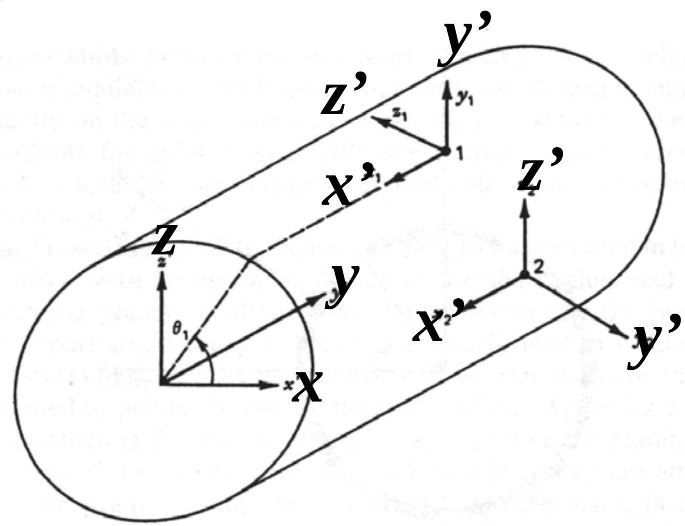
$$\begin{Bmatrix}u_{r,1}\\ u_{r,2}\\ u_{r,3}\end{Bmatrix} \rightarrow \begin{Bmatrix}\sigma_{x'}\\ \sigma_{z'}\\ \tau_{x'z'}\end{Bmatrix}$$



General Kirsch formulas (Leeman,1971)

$$\begin{Bmatrix}\sigma_{x'}\\ \sigma_{z'}\\ \tau_{x'z'}\end{Bmatrix} = \begin{bmatrix} \mathrm{d} & 0 & e & 0 & 0 & f\\ g & 1 & h & 0 & 0 & i\\ 0 & 0 & 0 & n & p & 0\end{bmatrix} \begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\\ \tau_{xy}\\ \tau_{yz}\\ \tau_{zx}\end{Bmatrix}$$

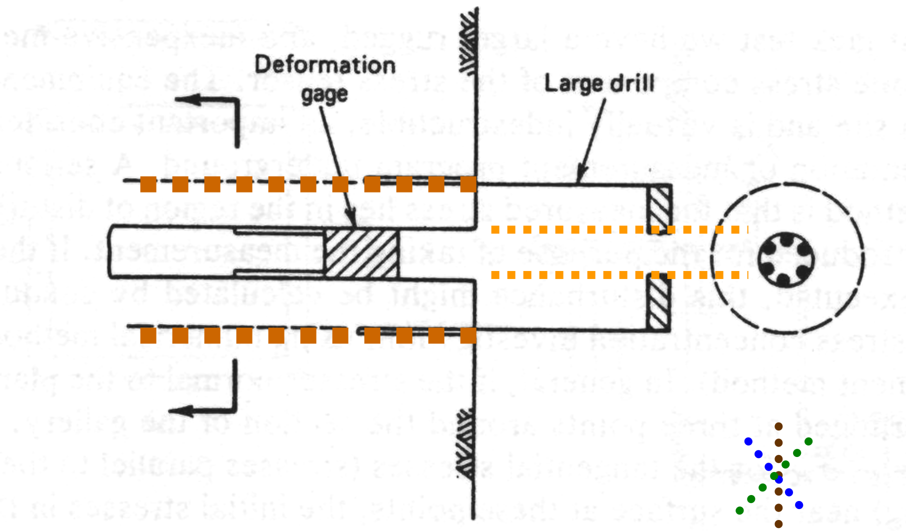
Function of θ



$$\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\\ \tau_{xy}\\ \tau_{yz}\\ \tau_{zx}\end{Bmatrix} = ?$$

Borehole relief (measure displacement or strain)

$$\Delta d(\theta) = \sigma_{x'} \cdot f_1(\theta) + \sigma_{y'} \cdot f_2(\theta) + \sigma_{z'} \cdot f_3(\theta) + \tau_{x'z'} \cdot f_4(\theta)$$



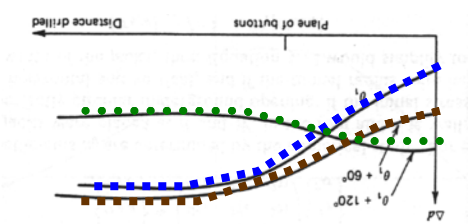
$$f_1(\theta) = d \cdot (1 + 2\cos 2\theta)\frac{1-\nu^2}{E} + \frac{d \cdot \nu^2}{E}$$

$$f_2(\theta) = -\frac{d \cdot \nu}{E}$$

$$f_3(\theta) = d \cdot (1 - 2\cos 2\theta)\frac{1-\nu^2}{E} + \frac{d \cdot \nu^2}{E}$$

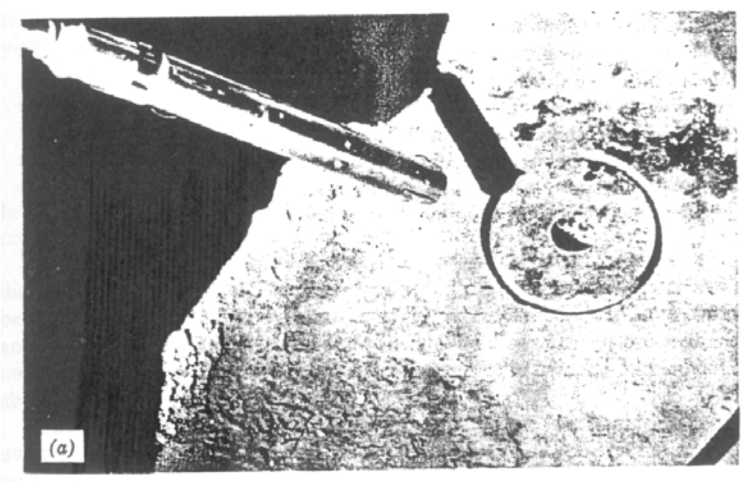
$$f_4(\theta) = d \cdot (4\sin 2\theta)\frac{1-\nu^2}{E}$$

USBM gage

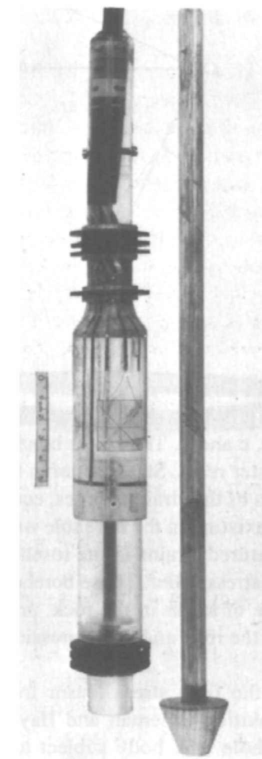


$$\sigma_{y'} \text{ is assumed} \longrightarrow \left.\begin{matrix} \sigma_{x'} \\ \sigma_{z'} \\ \tau_{x'z'} \end{matrix}\right\} \text{can be solved}$$

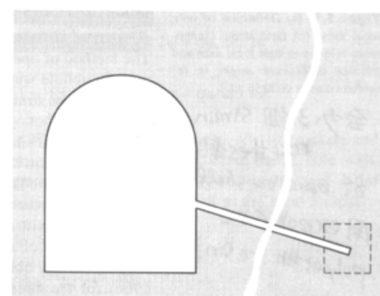
Borehole relief

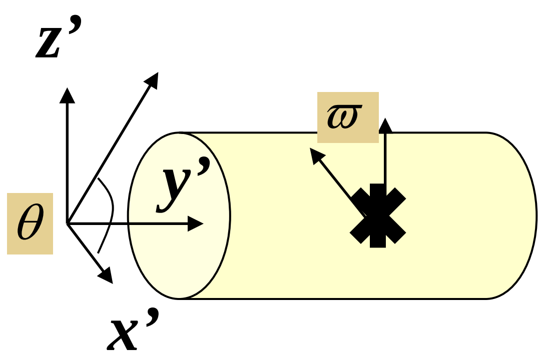


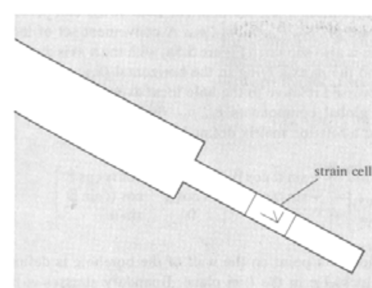
$$\varepsilon(\theta,\varpi) = A_{xx}\cdot\sigma_{x'} + A_{yy}\cdot\sigma_{y'} + A_{zz}\cdot\sigma_{z'} + A_{xz}\cdot\tau_{x'z'} + A_{xy}\cdot\tau_{x'y'} + A_{yz}\cdot\tau_{y'z'}$$

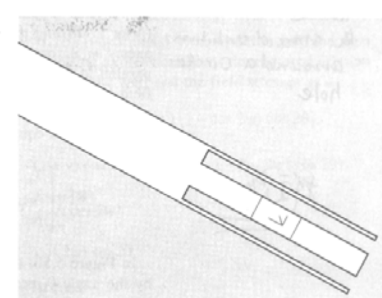


CSIRO triaxial strain cell









HW4

- Ch 5, problem 2 and problem 3

In-situ stress measurement

- Hydraulic method **(measure stress at failure)**
  - Hydraulic fracture
  - Sleeve fracture
  - Hydraulic test on pre-existing fracture
- Flat jack method **(measure compensate stress)**
- Relief method **(measure displacement or strain)**
  - Surface relief **(pin, Doorstopper biaxial strain cell)**
  - Borehole relief **(USBM gage, CSIRO triaxial strain cell)**

An overview of rock stress measurement method