15TH ISRM CONGRESS 2023

FLUID INJECTION EFFECT ON FRACTURE PROPAGATION NEAR AN UNDERGROUND DRIFT

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Introduction

- Excavation of underground galleries in the Callovo-Oxfordian claystone

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Fracture network around the tunnel wall (EDZ)

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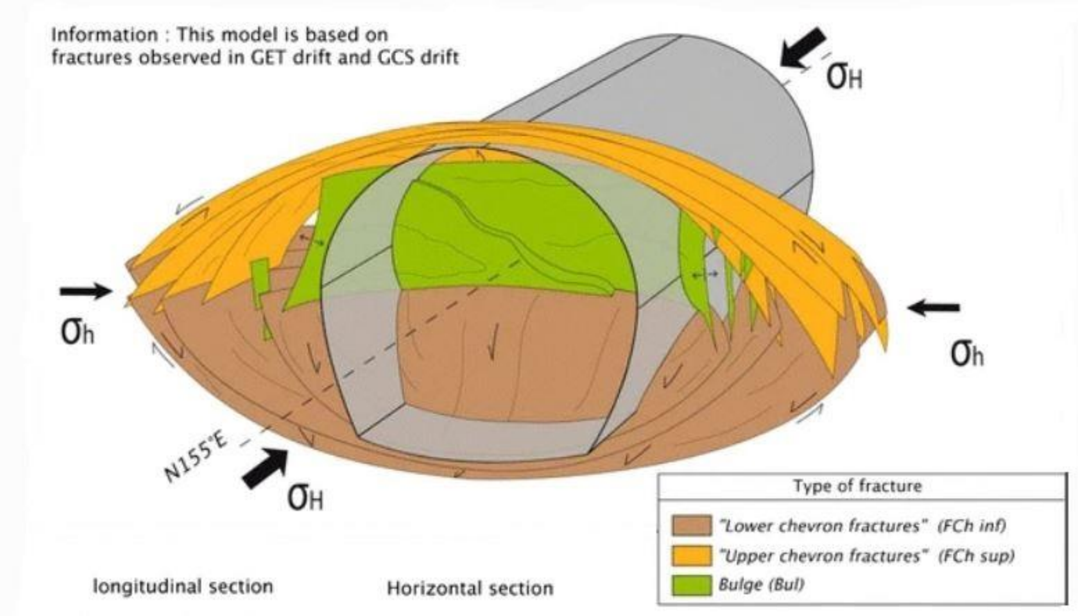
Mechanical and hydraulic disturbances (creation of damaged and fractured zones)

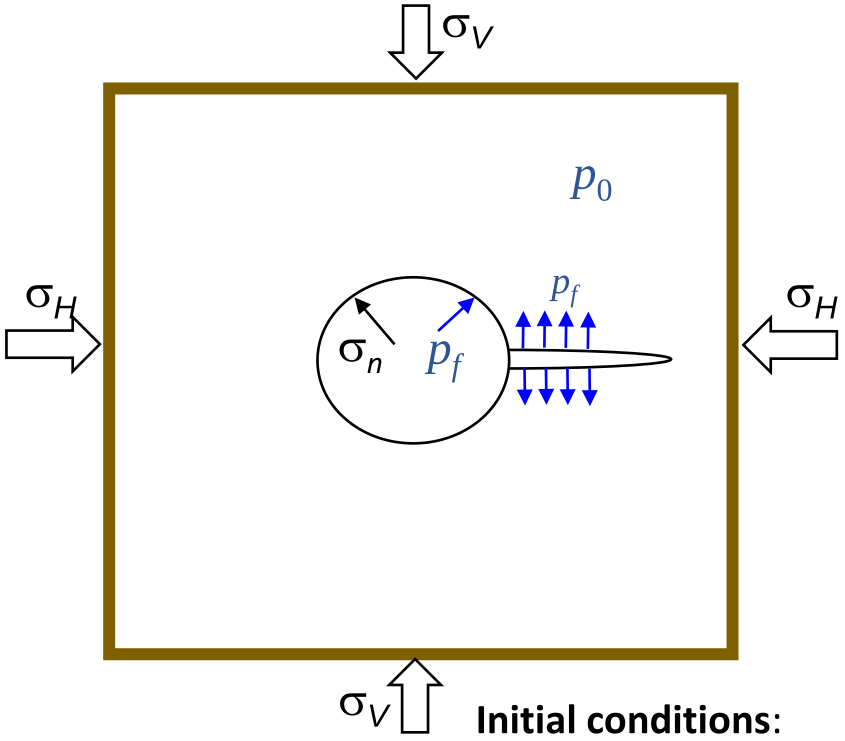
- Over the long term: additional stress from gases, particularly hydrogen, resulting from corrosion of the metals used in the casing of radioactive waste packages

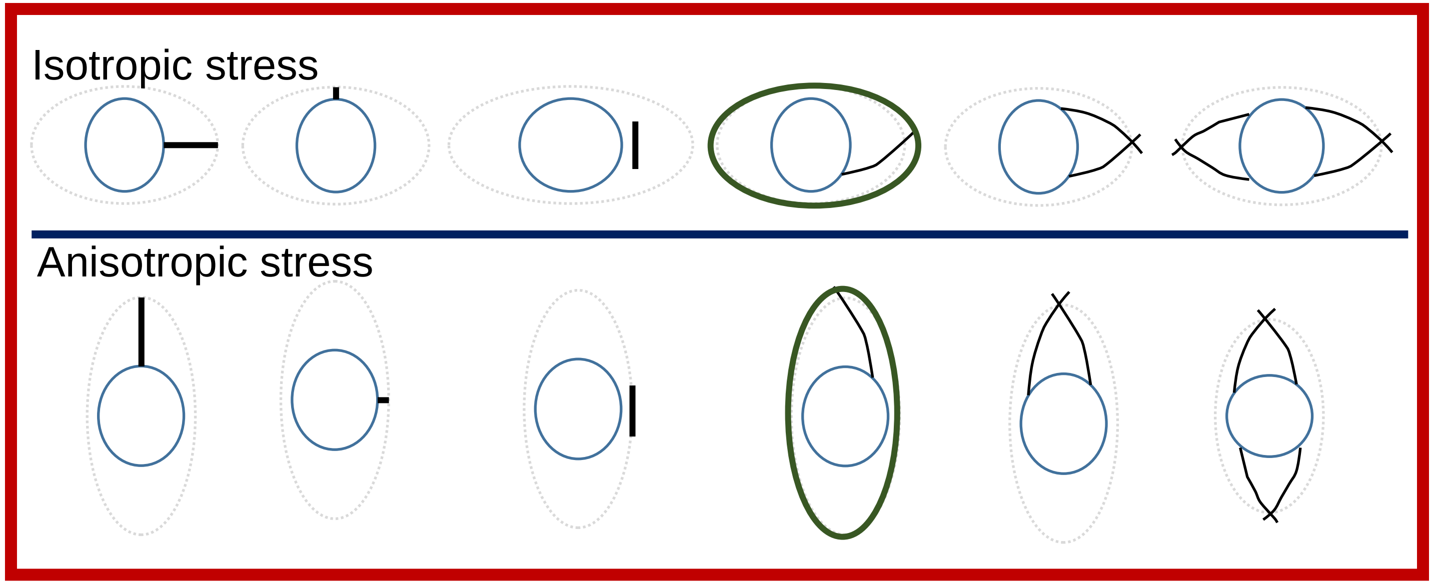


Armand et al. 2013

Fracture propagation from the extremity of existing fractures under fluid injection action

Simple cases of existing fractures around the gallery





Initial conditions:

- σ_H , σ_V: in-situ stresses
- p_0 : initial pore pressure

Load actions:

- p_f : injected fluid pressure
- σ_n : $-p_f$: fluid mechanical action

Theoretical framework

Rock behavior ➡ ***Poroelastic medium***

Hydraulic constitutive model

$$C_M \frac{\partial p}{\partial t} = div(K\nabla p) + (-\rho_f b \frac{\partial \varepsilon_v}{\partial t})$$

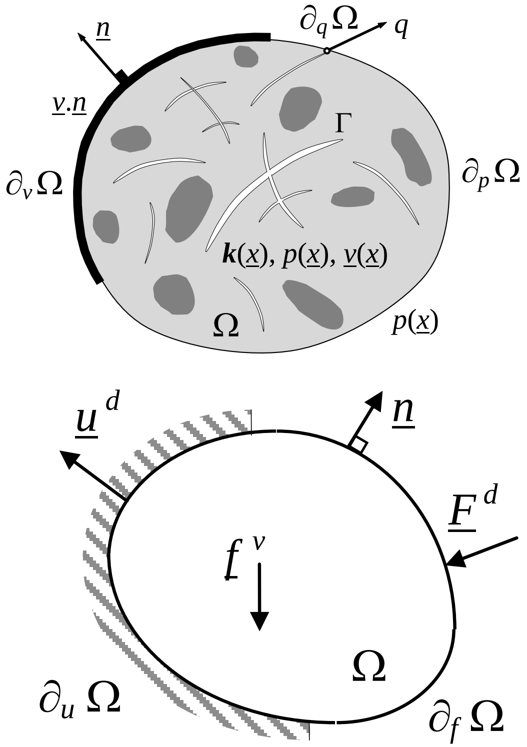
$$\boldsymbol{K} = \frac{\rho_f}{\mu} \boldsymbol{k} \qquad C_M = \frac{\rho_f}{M}$$

Mechanics constitutive model

$$div\sigma(\underline{x}) + \underline{f}^v(\underline{x}) = 0$$

$$\sigma(\underline{x}) = \sigma^i(\underline{x}) + \mathbb{C}(\underline{x}, \varepsilon(\underline{x}), \mathbf{D}) : [\varepsilon(\underline{x}) - \varepsilon^{ir}(\underline{x})]$$

$$\boldsymbol{\sigma}^i = -bp\boldsymbol{\delta}$$

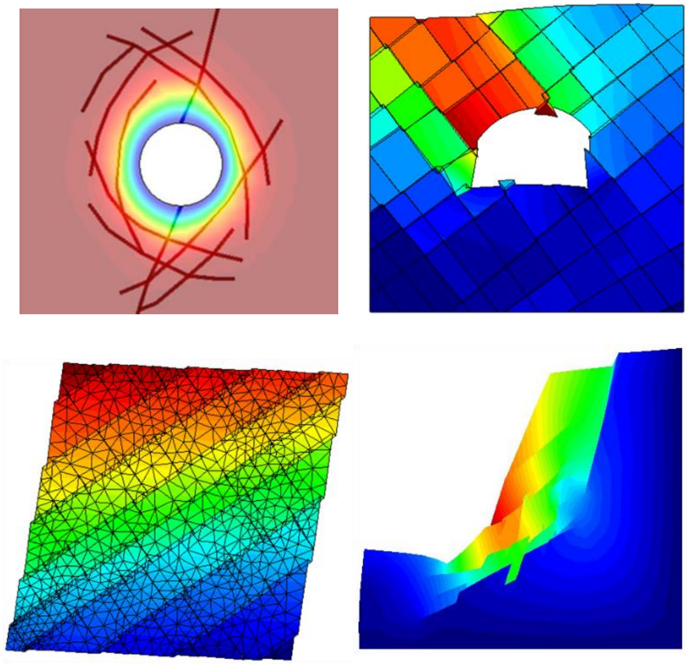


(Catalogue des Matériaux du code Disroc (2023), http://www.fracsima.com/DISROC/Materials-Catalog.PDF)

Numerical modeling

- Disroc code (Fracsima – A. Pouya)
- Finite Element Code enriched with joint elements
- Coupled thermo-hydro-mechanical phenomena in materials and structures in the presence of fracturing
- Analyze fracture propagation
- Under the effect of incompressible fluid injection
- Evaluate the equivalence of numerical modeling results and analytical solutions (Tada et al. 2000)

DISROC

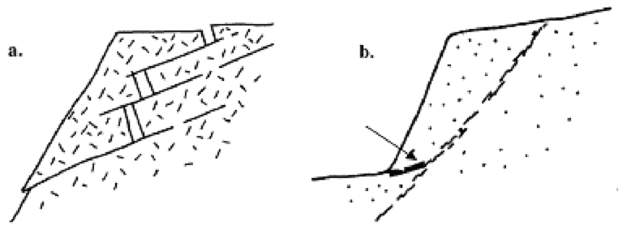


https://www.fracsima.com/DISROC

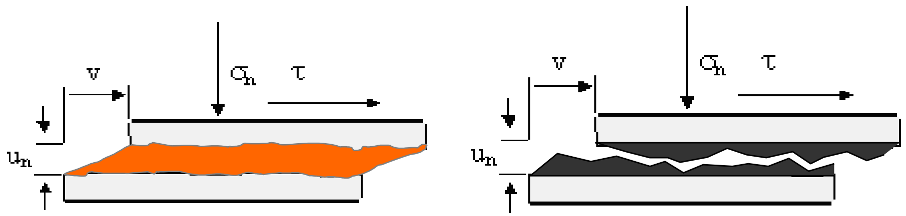
Cohesive fracture model

Damage-Plasticity of rock joints

(Pouya & Bemani 2014)



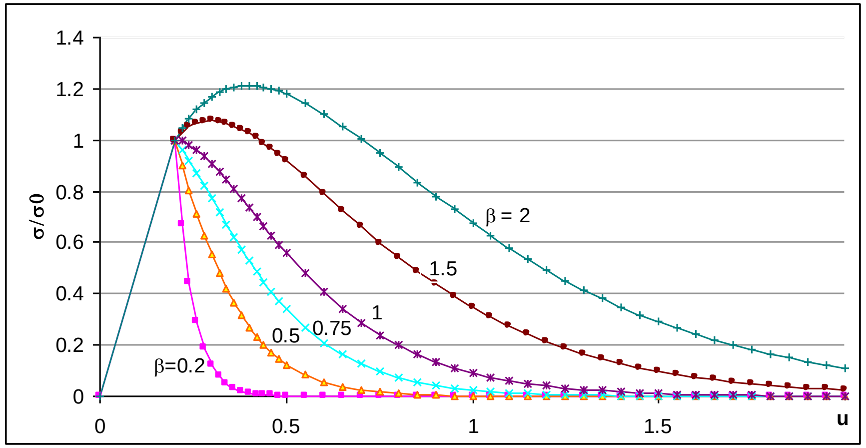
$$\underline{\sigma} = (1 - D)\ \mathbf{k}\ (\underline{u} - \underline{u}^p)$$



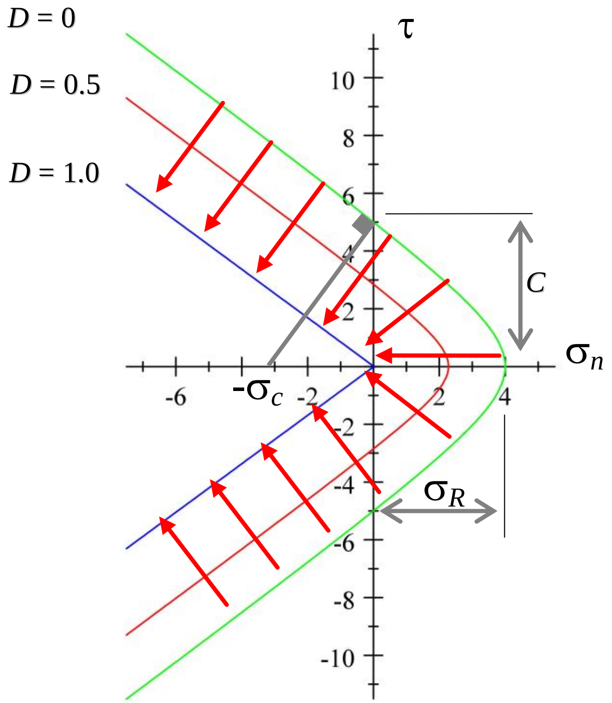
Plasticity and damage criterion:

$$F(\underline{\sigma}, D) = \quad \tau^2 - \sigma_n^2 \tan^2\varphi + 2g(D)\sigma_c\sigma_n - g^2(D)C^2$$

$$g(D) = (1 - D)(1 - \beta \ln(1 - D))$$



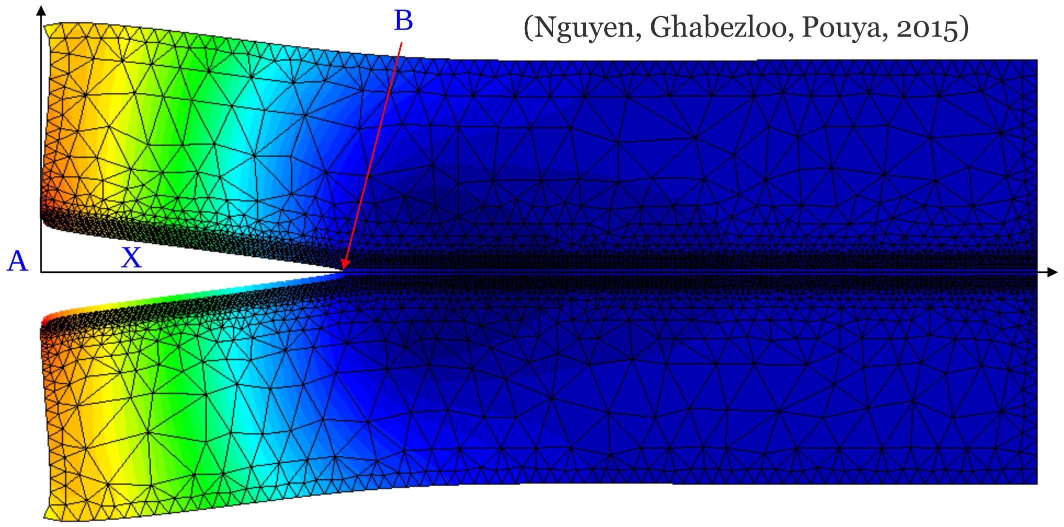
Traction-Separation law for different values of the parameter β.

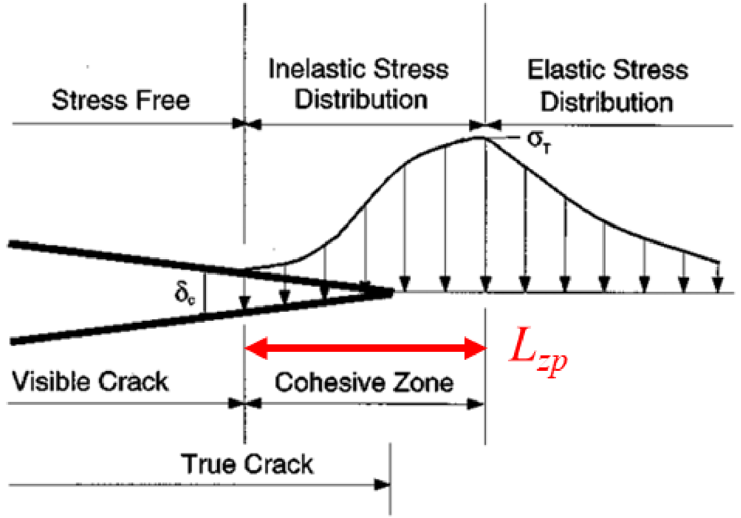


Evolution of the criterion from the intact condition (green) to a frictional law (blue) during the damage process (red arrows)

(Catalogue des Matériaux du code Disroc (2023), http://www.fracsima.com/DISROC/Materials-Catalog.PDF)

Comparison CZ-Fracture- Linear Elastic Fracture Mechanics - Fracture in a half-space





Mesh size $L_j << L_{zp}$ ➡

$$K_{IC} = \sqrt{\frac{E}{1-\nu^2}\left[\frac{1}{2}+\beta(\beta+1)\right]\frac{\sigma_R^2}{k_n}}$$

Mesh size $L_j >> L_{zp}$ ➡

$$\sigma_R = \sqrt{\frac{2}{\pi L_j}}\, K_{Ic}$$

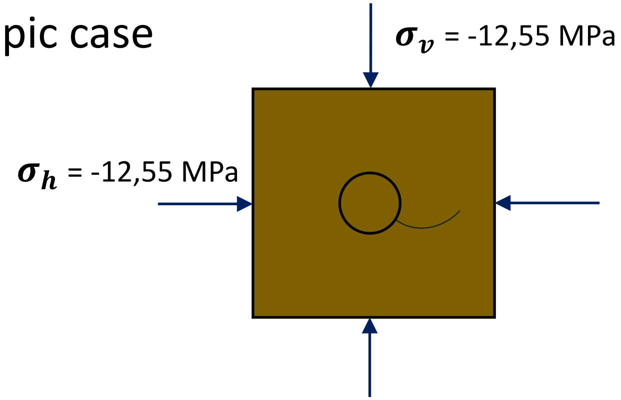
$$L_{zp} = \frac{\pi}{8}\cdot\frac{E}{k_n.(1-\nu^2)}\cdot\left[\frac{1}{2}+\beta(\beta+1)\right]$$

Process zone size L_{zp}

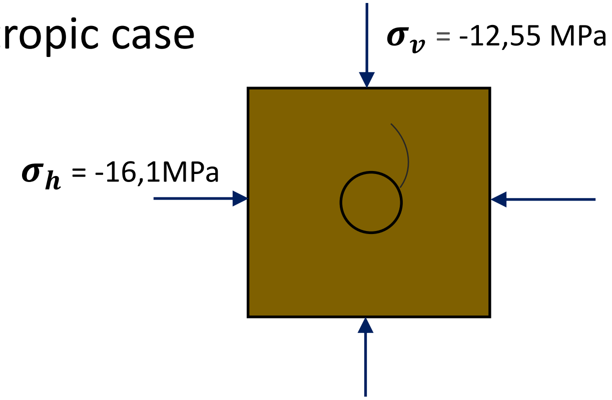
Claystone: $L_{zp} \approx$ 2 mm

Geometries and parameters

Isotropic case



Anisotropic case



Mechanical parameters applied to the pre-existing fracture

Parameter	Value
k_n	***3×10^{05} MPa/m***
k_t	***3×10^{05} MPa/m***
e	***0.00001 m***
σ_R	***5.05 MPa***
C	***50 MPa***
φ	***27°***
h_r	***1***
β	***0.1***
β'	***1***
k_{0t}	***3×10^{04} MPa/m***
k_{0n}	***3×10^{04} MPa/m***

Hydraulic conductivity of pre-existing fracture is **2.7×10^{-17} *m^3***

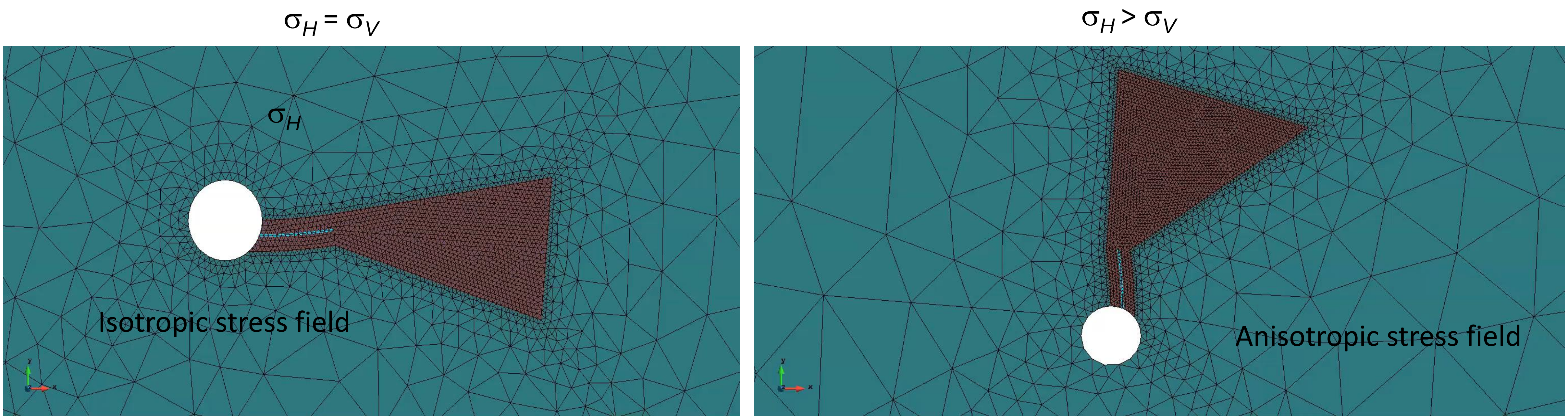
The mechanical parameters for the undamaged zone are the same as the pre-existing fracture except for the following parameters :

Parameter	Value
e	***0.001 m***
k_{0t}	***300 MPa/m***
k_{0n}	***300 MPa/m***

The hydromechanical parameters of the Rock (COx)

Parameter	Value
E	***5200 MPa***
ν	***0.3***
k	***2.7×10^{-20} m^2***
C_M	***2.8×10^{-04} MPa^{-1}***
b	***0.8***

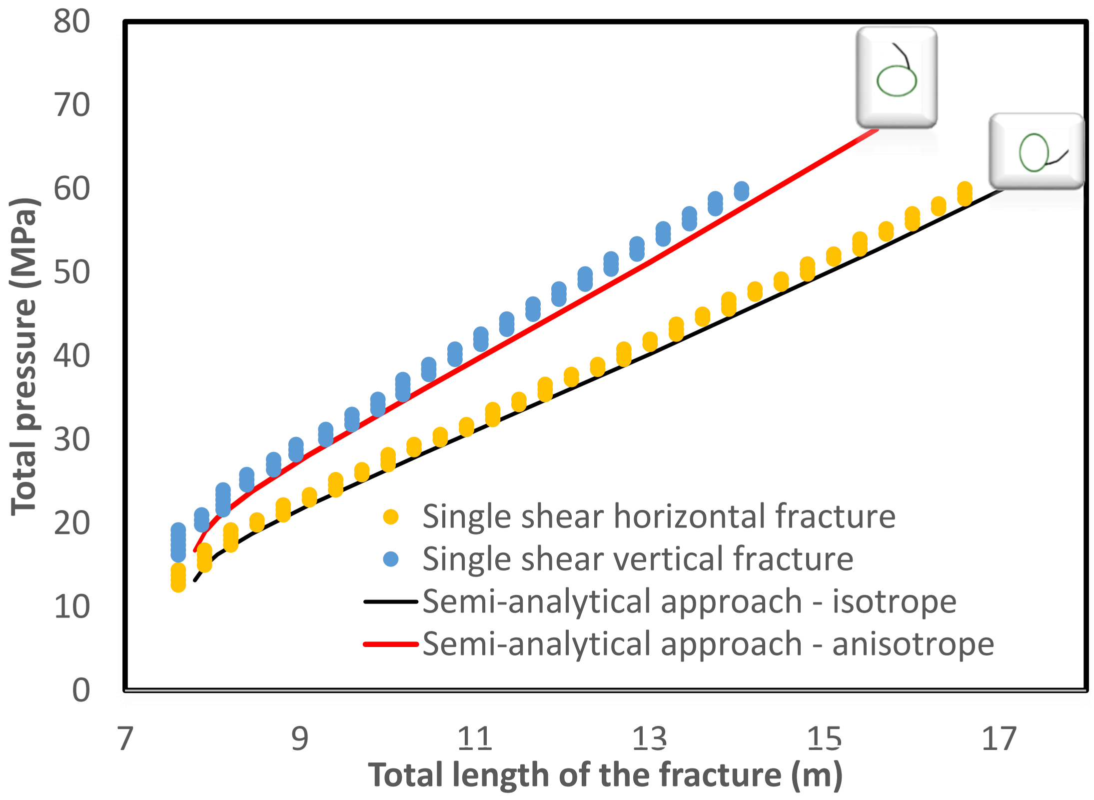
Results - Effect of stress anisotropy



Geometry of the fracturing, for the cases of isotropic and anisotropic in-situ stresses.

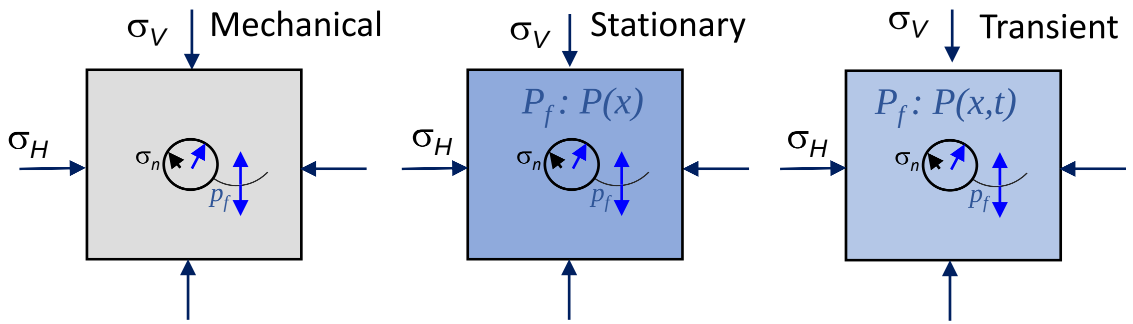
Results - Effect of stress anisotropy

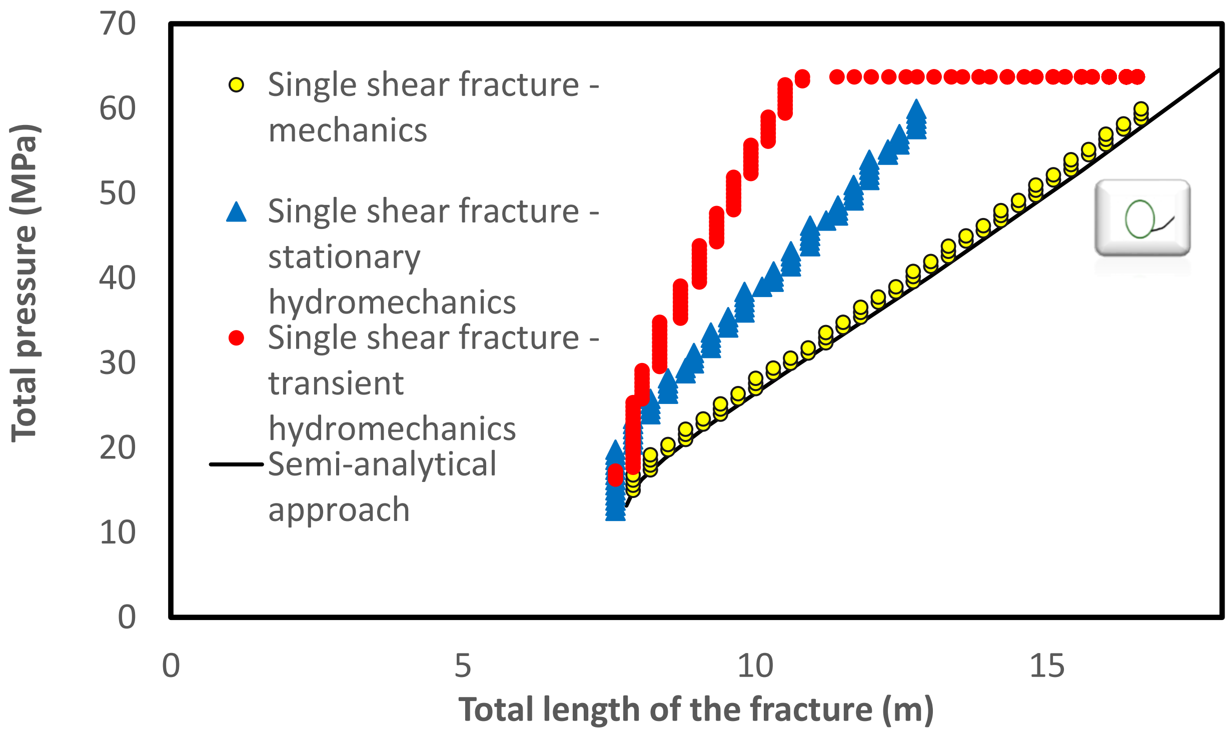
- Purely mechanical loading
- Approximation of a short time scale
- Les propagation in the anisotropic case.
- Propagation toward the radial path
- The propagation is primarily controlled by fluid pressurization



Results - Effect of fluid flow

- Stationary flow and transient flow
- The hydro-mechanical couplings
- The hydromechanical coupling H ⇨ M
- The stationary calculation: Less propagation than the mechanical calculation
- The transient calculation: The effect of time of diffusion, the same propagation as for the mechanical calculation





Conclusion

- The in-situ stress anisotropy essential for reactivation and propagation
- The fracture follows the radial path favored by the fluid loading
- The poromechanical coupling in the rock exposed to the stationary pressure field tends to act against fracture propagation
- For transient conditions, before any significant fluid diffusion (1s) the propagation is even smaller than for the stationary case, but after 1 day (diffusion in the fracture but not in the rock) one recovers the simple mechanical case

On-going work and perspectives

- Unsaturated flow and poromechanical coupling in the fracture
- Dissolution of gas in the liquid phase and advective transport

- Criterion for fracture propagation in unsaturated porous medium ?
- Crack propagation in viscoplastic?
- Rate of gas production ?

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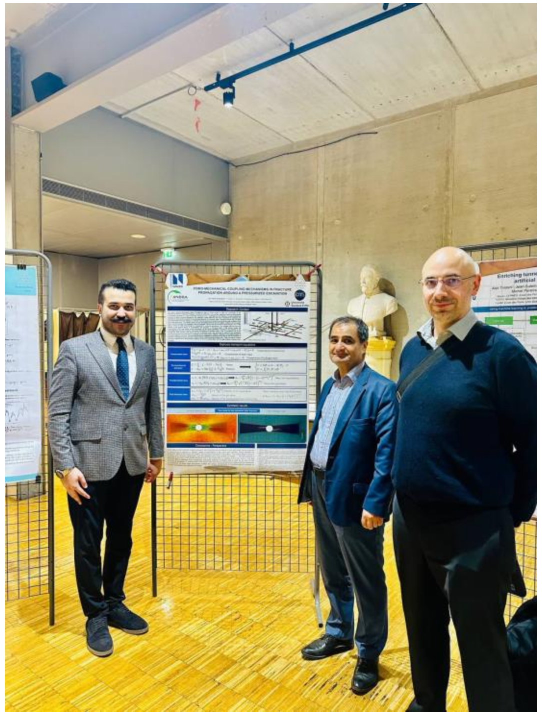
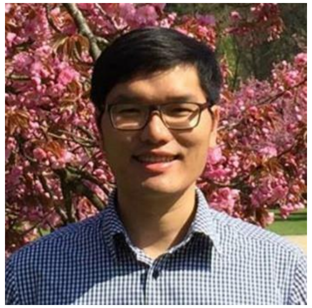
Thank you for your attention





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