UNIVERSITÉ PARIS-EST

ÉCOLE DOCTORALE UNIVERSITÉ PARIS-EST
Sciences, Ingénierie et Environnement

Damage models contributions on generation and development of failure zone around tunnels in quasi-brittle rocks

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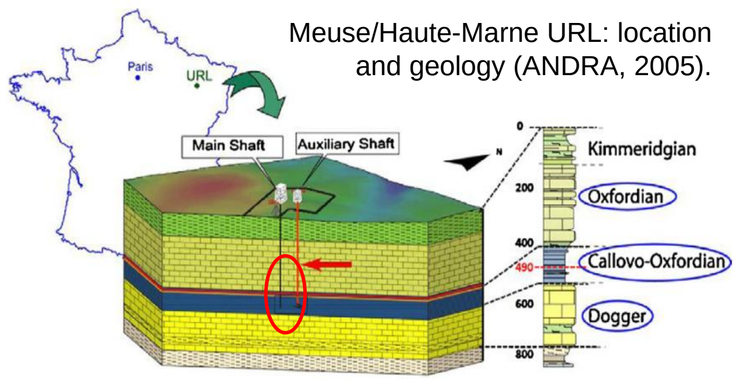
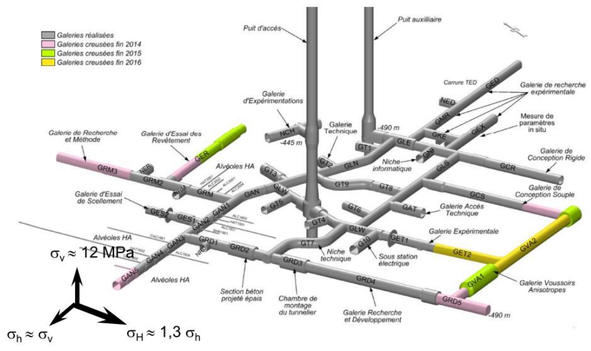
Context

Study of the impact of a possible high level nuclear waste storage in the *Callovo-Oxfordian* argillite layer (Andra, *projet Cigéo*).

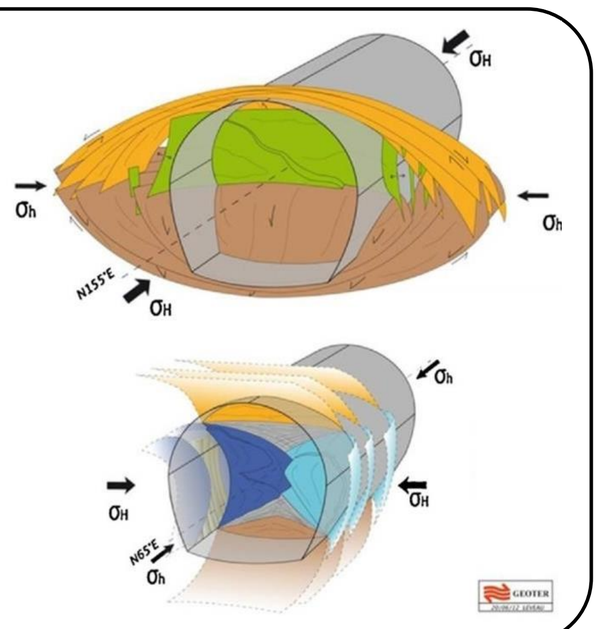
The Andra Underground Rock Laboratory (URL) in Bure has this mission.



Meuse/Haute-Marne URL: location and geology (ANDRA, 2005).

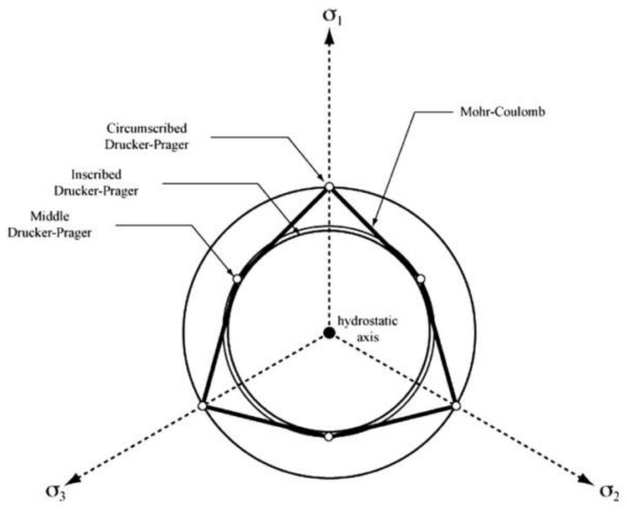


Andra URL with drifts parallel and perpendicular to the horizontal major stress. Seyedi & Armand, Andra DRD, 2016).



Modeling and Results (1)

- The simulations presented are performed with the FEM code *POROFIS* (Pouya, 2015) assuming:
  - 2D simulation on the tunnel front plane;
  - Plane strains configuration;
  - Linear isotropic elasticity (E ; v);
  - Isotropic in-plane far-field stress;
  - Drucker-Prager failure criterion with post-peak softening.



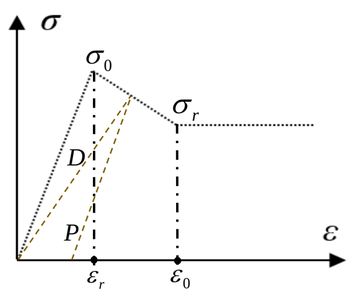
Drucker–Prager and Mohr–Coulomb failure criteria in stress space (Alejano & Bobet, 2012).

$$\sqrt{3J_2} + \sin\alpha\, I_1 - h(K) = 0$$

$$\sin\alpha = \frac{2\sin\phi}{3-\sin\phi}$$

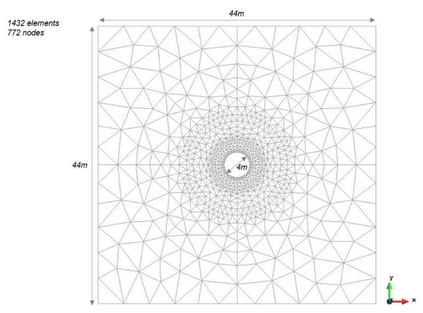
$$K = \frac{6c'\cos\phi}{3-\sin\phi}$$

Softening law variable according to the model chosen

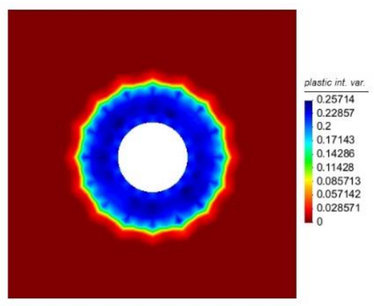


$$\eta_r = \frac{\sigma_r}{\sigma_0}$$

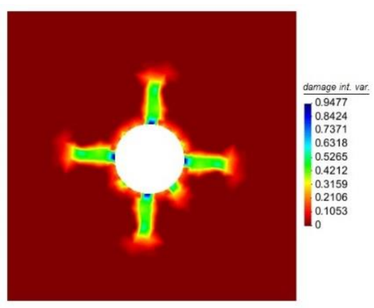
$$\beta = \frac{\varepsilon_r - \varepsilon_0}{\varepsilon_0}$$



$P \rightarrow \dot{\boldsymbol{\sigma}} = \mathbf{C} : \left(\dot{\boldsymbol{\varepsilon}} - \dot{\boldsymbol{\varepsilon}}^P\right)$



$D \rightarrow \dot{\boldsymbol{\sigma}} = (1-D) \cdot \mathbf{C} : \dot{\boldsymbol{\varepsilon}}$

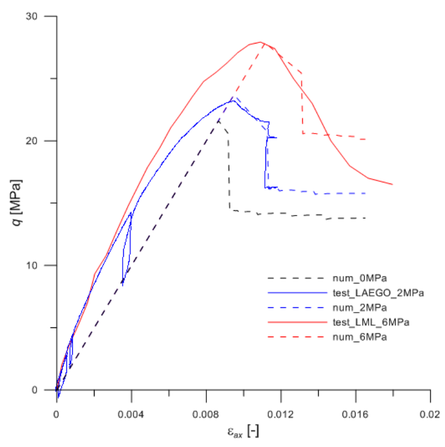


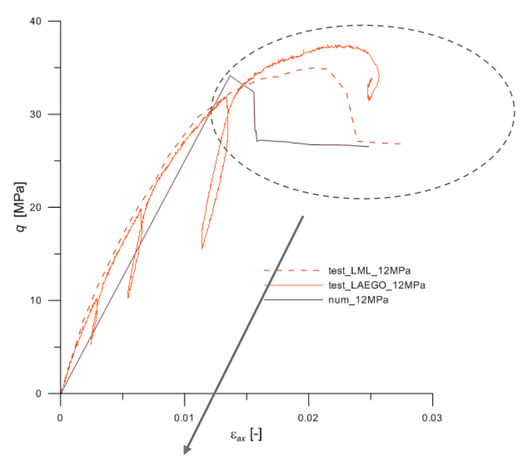
σ_{xx} (MPa)	-12
σ_{yy} (MPa)	-12
σ_{zz} (MPa)	$\nu \cdot (\sigma_{xx} + \sigma_{yy})$

E (MPa)	*v* (-)	sin*α* (-)	K (MPa)	β (-)	η_r (-)
$2 \cdot 10^3$	0.13	0.2	8.0	0.7	0.8

Modeling (2)

- Validation of the elasto-damage model with TXC tests:

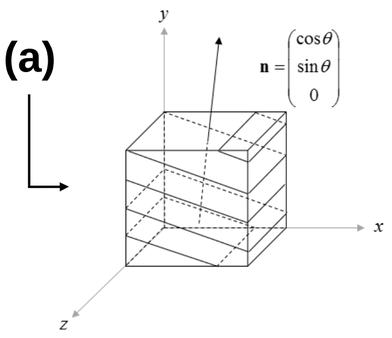




- Issues in describing the experimental behavior: if σ_c increases, the material shows a hardening phase before the resistance peak.

- Improvements: anisotropy-based model in (a) failure criterion and (b) damage evolution .

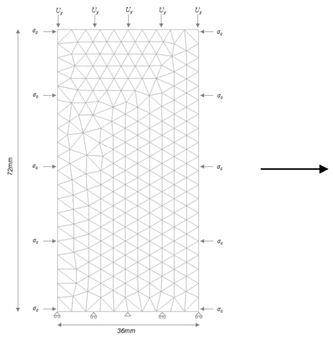
(a)

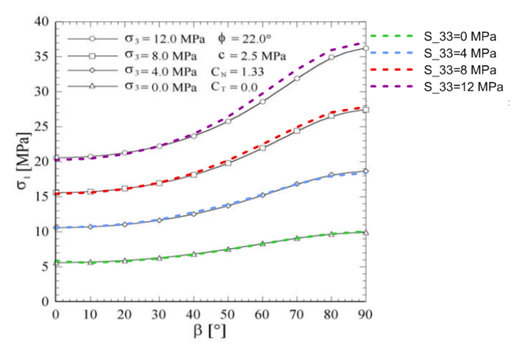


(b) →

$$\boldsymbol{\varepsilon} = \frac{1}{E}\begin{bmatrix} \frac{1}{(1-D)} & \frac{-\nu}{(1-D)} & -\nu & 0 \\ \frac{-\nu}{(1-D)} & \frac{1}{(1-D)} & -\nu & 0 \\ -\nu & -\nu & 1 & 0 \\ 0 & 0 & 0 & \frac{2(1+\nu)}{(1-D)} \end{bmatrix} \cdot \boldsymbol{\sigma}$$

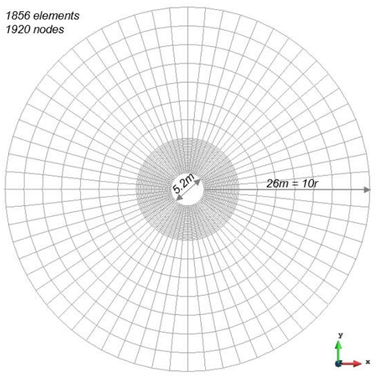
In *POROFIS,* comparison with a series of tests simulations on the same material:





Results (2) and Conclusion

- Anisotropy-based elasto-damage model on a case study (Andra URL):



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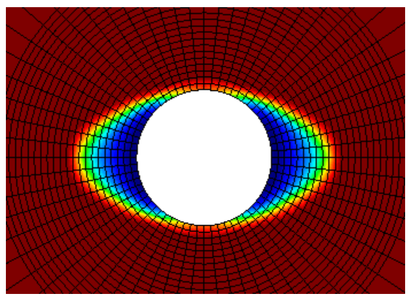
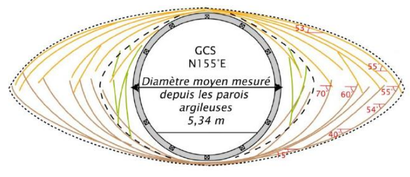


Simulated *EDZ* lateral expansion ≈ 0.6*d*

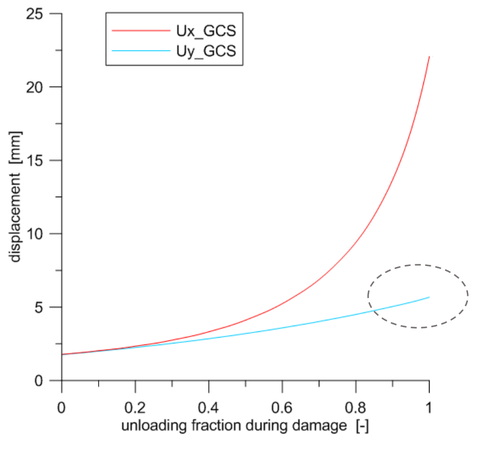
Modified from Andra report (A. Noiret, 2013)



In situ deduced *EDZ* lateral expansion ≈ 0.8*d*

E (MPa)	*v* (-)	sinα (-)	K (MPa)	β (-)	η_r (-)	h (-)	θ (°)
$1.0 \cdot 10^4$	0.2	0.25	9.5	0.2	0.95	0.25	90

σ_{xx} (MPa)	-12.5
σ_{yy} (MPa)	-12.5
σ_{zz} (MPa)	-8.0



ANDRA

Tunnel U_y 50% underestimated with respect to in-situ conditions.

- Further upgrades must include <u>elastic anisotropy</u> ($E_x = E_z > E_y$) and <u>hardening+softening behavior</u>.