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European Joint Programme on Radioactive Waste Management

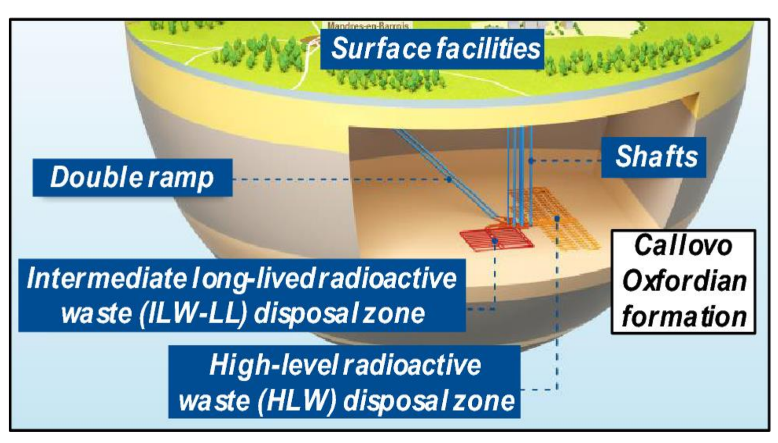
A thermal-mechanical constitutive modelling for Callovo-Oxfordian Claystone in the context of nuclear waste disposal

Hangbiao Song and Frédéric Collin
Université de Liège, Urban and Environmental Engineering, Liège, Belgium (hangbiao.song@uliege.be)

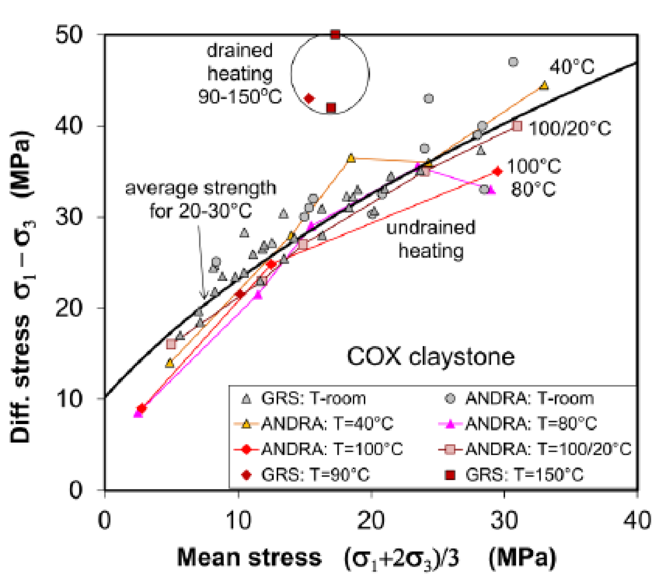
1. Context

Deep geological disposal

- Multi-barrier confinement
- Long-term management
- T-H-M-C coupling process



Cigéo project overview (Andra) (Alonso, 2024)



Comparison of drained and undrained thermal strengths of the COx claystone (Zhang, 2018).

Thermal effects on

- Volume change behavior (elastic expansion vs. plastic contraction depending on the OCR)
- Strength (preconsolidation pressure, compression and swelling index, and shear strength)
- Thermal pressurization behavior

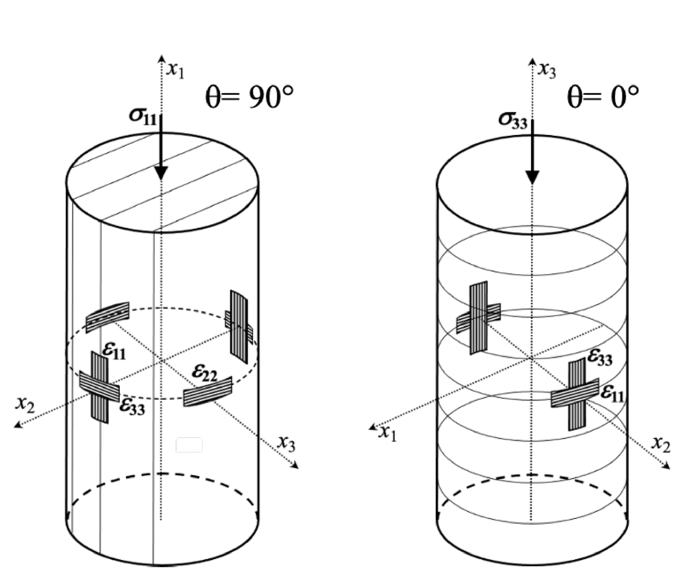
Objective

Introduce the thermal-mechanical coupling in constitutive model (thermal plasticity) and apply it to large-scale ALC1605 heater test.

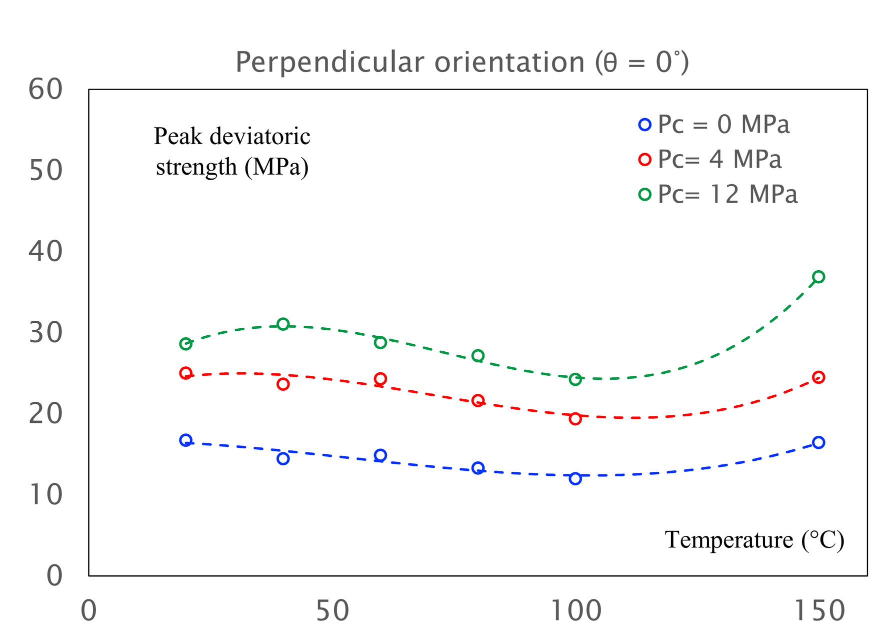
2. Experimental test

Triaxial compression tests by ULorraine (EURAD, 2019)

- 20 mm diameter and 40 mm high samples
- Different confining pressure (0 MPa, 4 MPa, and 12MPa)
- Different temperatures (from 20 to 150°C)
- perpendicular (θ = 0°) and parallel (θ = 90°) to bedding planes



Sample geometry



Strength vs. temperature (Gbewade, 2023)

3. Numerical modelling

Experimental $c-T$ data

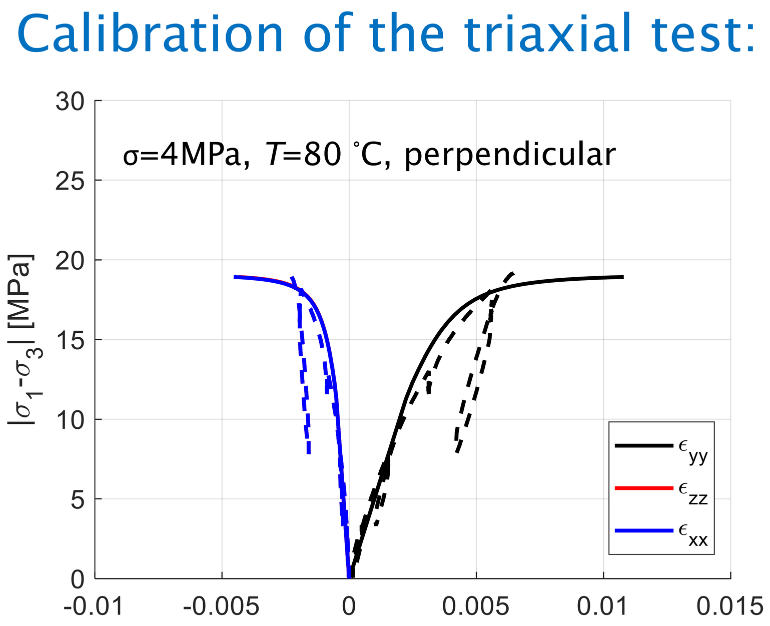
Temperature /°C	cohesion/MPa
20	4.27
40	4.06
60	3.74
80	3.15
100	2.29

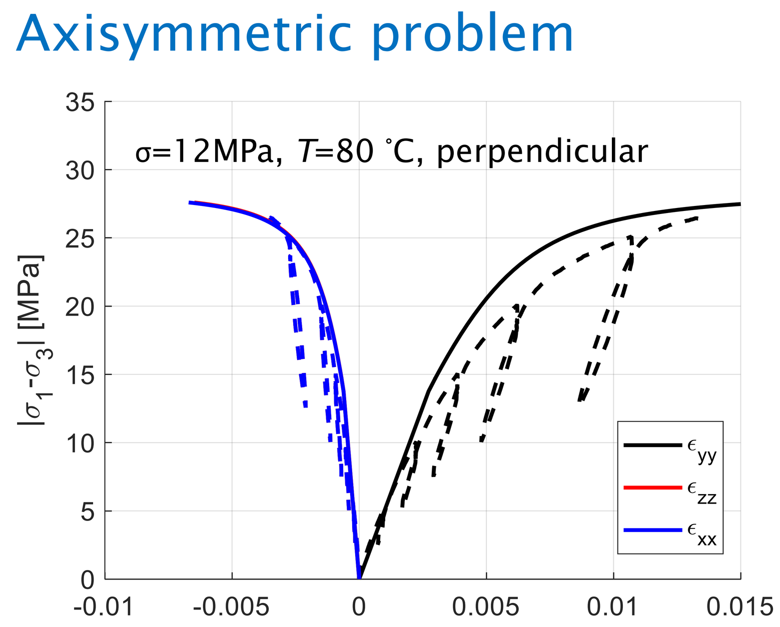
Implementation of constitutive relation between c and T

$$c = \begin{cases} 4.27, & T < 20℃ \\ c_0[1-\beta(T-T_0)^2], & 20℃ \le T \le 100℃ \\ 2.29, & T > 100℃ \end{cases}$$

$(T_0 = 20\ ℃)$

Calibration of the triaxial test: 2D Axisymmetric problem





4. Application

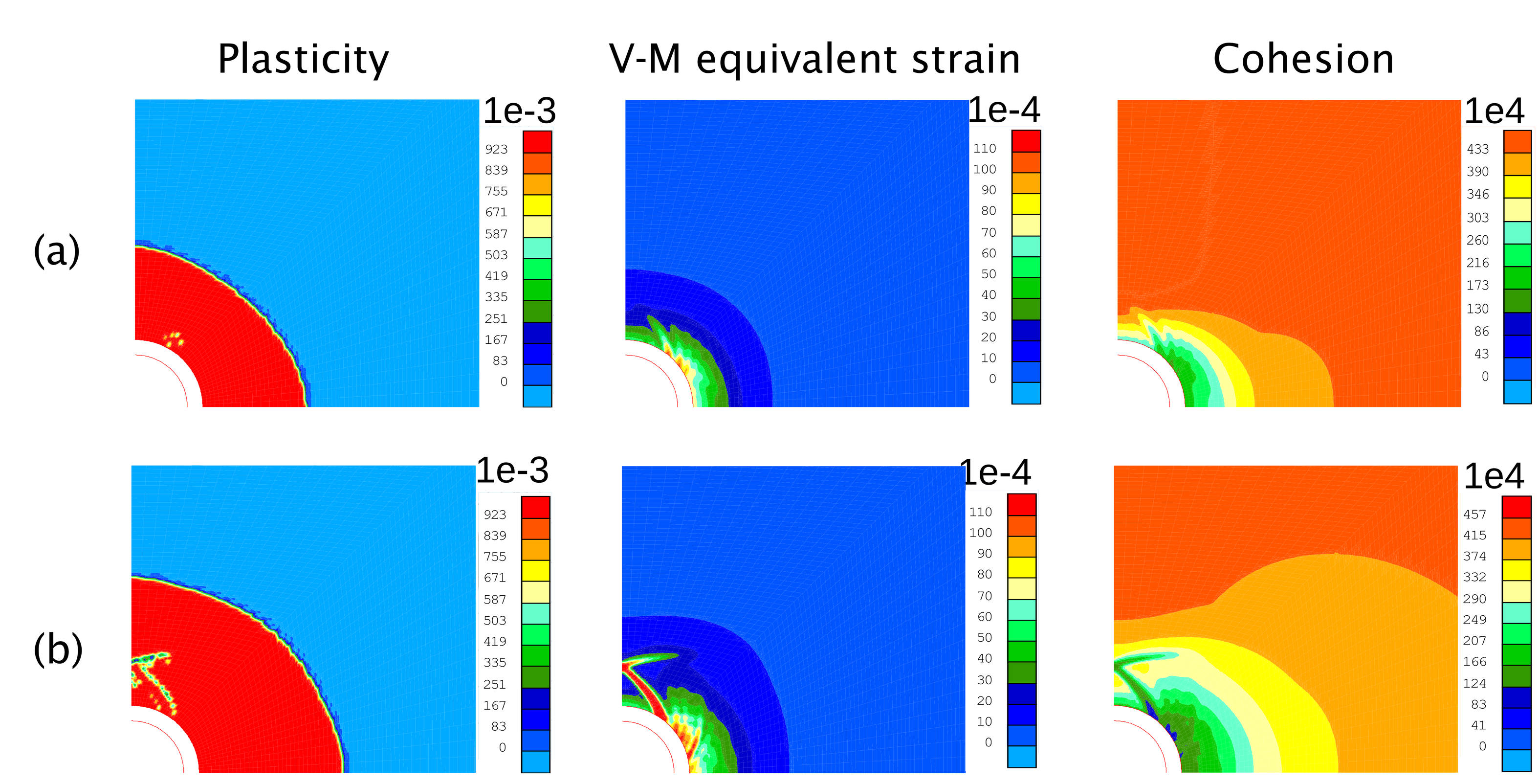
Modelling of In-situ *ALC1605* heater test (EURAD, 2019)

- 2D plane strain problem (Excavation + Injection + Heating)
- Fully THM coupling code: LAGAMINE (ULiege)
- HSsmall strain stiffness model (Brinkgreve, 2007)
- Elastoplastic model: $c=f(\kappa, I_2, T)$

Callovo-Oxfordian claystone parameters

Elastic parameters		Plastic parameters		T-H parameters	
$E_{//0}$ (GPa)	16	$\psi_c = \psi_e$ (°)	5	c_s (J/kg/K)	790
$E_{\perp 0}$ (GPa)	10	$\phi_{c,0}$ (°)	10	c_s (J/kg/K)	790
$E_{//f}$ (GPa)	8	$\phi_{c,f}$ (°)	23	α_s (K^{-1})	1.25E^{-5}
$E_{\perp f}$ (GPa)	5	$\phi_{e,0}$ (°)	7	c_w (J/kg/K)	4180
$\nu_{////}$ (-)	0.21	$\phi_{e,f}$ (°)	23	$\lambda_{//}$ (W/m/K)	1.88
$\nu_{//\perp}$ (-)	0.35	c_0 (MPa)	4.27	$\lambda_{\perp}$ (W/m/K)	1.25
$G_{\perp}$ (GPa)	2.5	$A_{//}$ (-)	0.117	$k_{//}$ (m²)	3.9E^{-20}
$b_{//}$ (-)	0.82	b_1 (-)	14.24	$k_{\perp}$ (m²)	1.3E^{-20}
$b_{\perp}$ (-)	0.86	β (-)	7.3E^{-5}	χ_w^{-1}(MPa^{-1})	4.5E^{-4}

Results: (a) without/(b) with *c (T)* after heating



5. Conclusions

1. The cohesion dependency on temperature is introduced, and the parameters are calibrated based on triaxial test results.
2. The increase of the plastic zone after heating is observed, which is induced by the degradation of the cohesion.
3. The strain localisation phenomenon is observed, and the evolution of V-M equivalent strain is of the same pattern as cohesion evolution.

6. References

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4. EURAD WP HITEC (2019) – Milestone report 49 – Selection of benchmark exercises for task 2.1, 2.2 and 2.3.
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