UMONS
Université de Mons

Master's thesis – June 2010

Characterization of the mechanical behavior of interfaces casing / cement of injection wells in the geological context of CO_2 storage

Experimental study and numerical modeling

Caroline DUBOIS

Under the direction of Professor
Jean-Pierre TSHIBANGU

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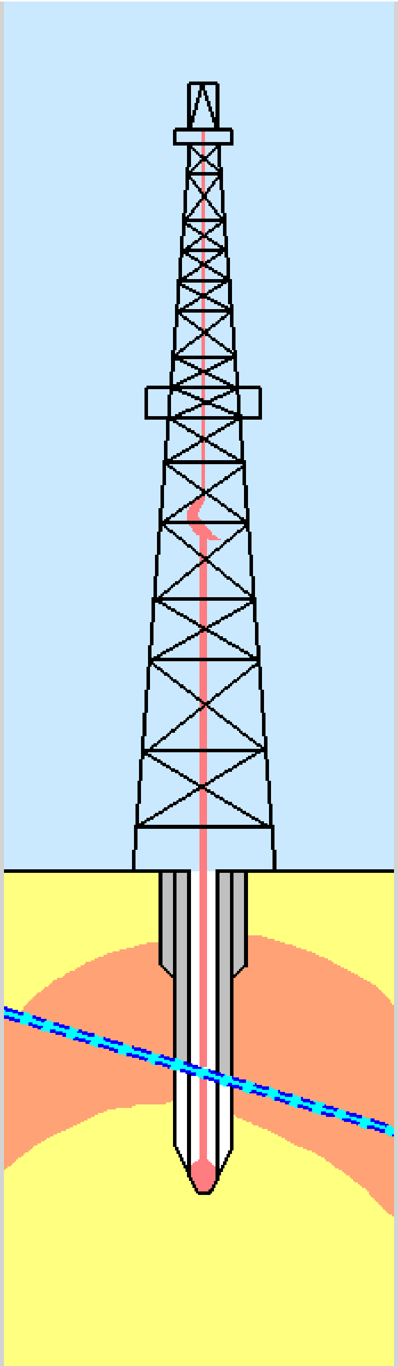

Outline

Introduction

Mechanical characterization of interfaces

→ **Tests of single and double shearing assemblies**

Numerical modeling with Abaqus™

→ **Simulating the behavior of interfaces in a test called Push-Out**

Conclusions

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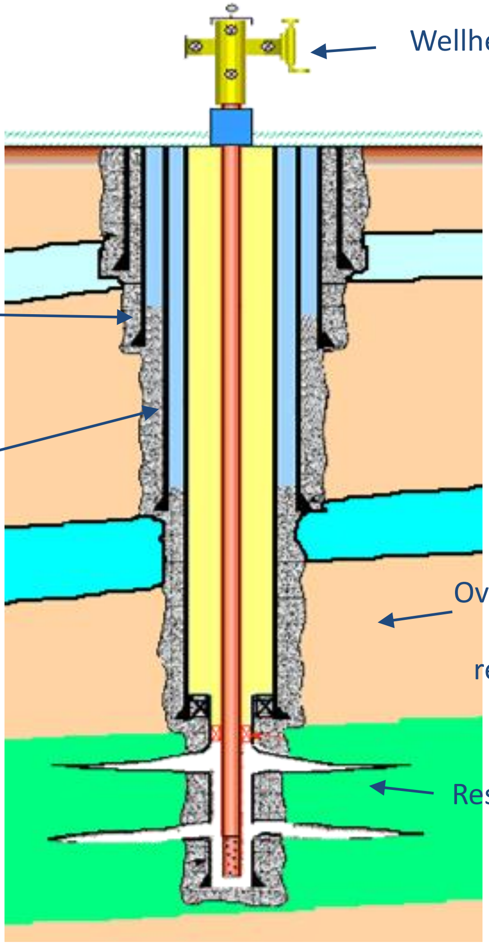
Problematic of CO_2 geological storage

Method to significantly reduce the amount of CO_2 in the atmosphere



→ Ensure the well seal

Weakness zones = Junctions

- Formation / Cement
- Cement / Steel

→ Carbonation of cement

Portlandite Water + CO_2 Calcium carbonates

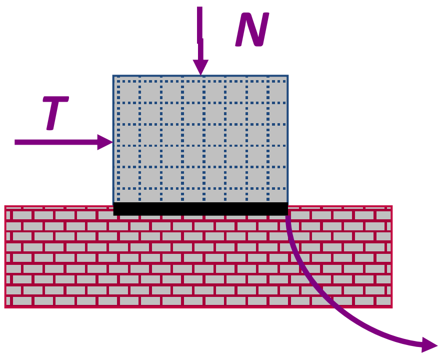
$$\boxed{Ca(OH)_2 + H^+ + HCO_3^- \rightarrow CaCO_3 + 2\,H_2O}$$

↘ Mechanical properties

↘ Porosity

Behavior of the interfaces

Example of an interfacial law

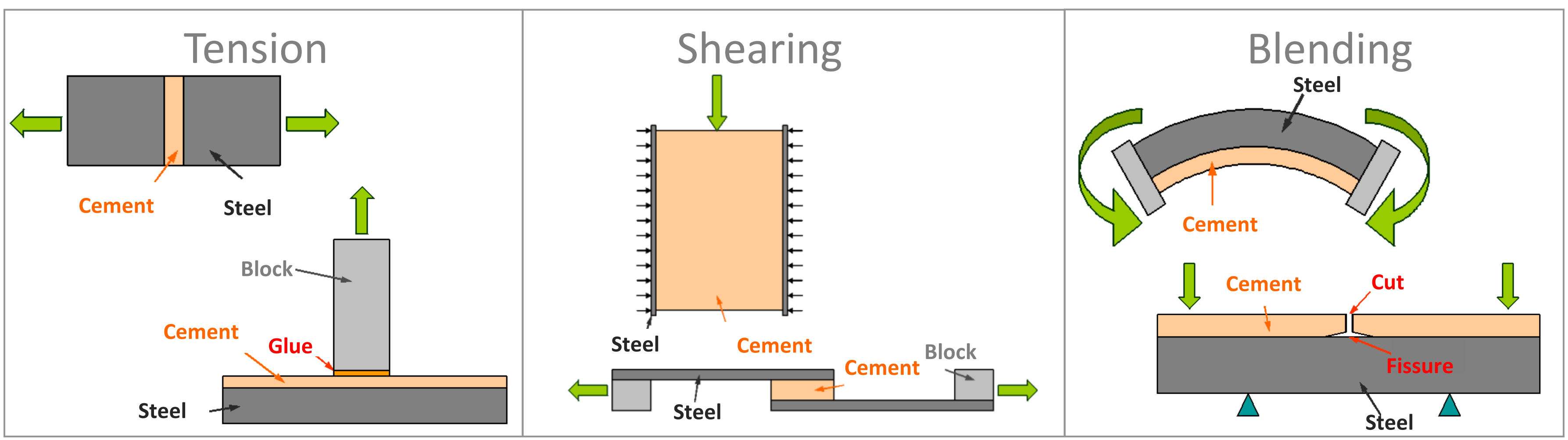


Coulomb law

$$T \le \mu N + c \begin{cases} < \longrightarrow \text{No motion} \\ = \longrightarrow \text{Sliding} \end{cases}$$

Interface :
c : cohesion
μ : friction factor

Example of failure characterization :



Characterization of the behavior of steel-cement interfaces

in configurations of mechanical loading that may occur:

- **in well**
- **in carbonation conditions**

Overall framework

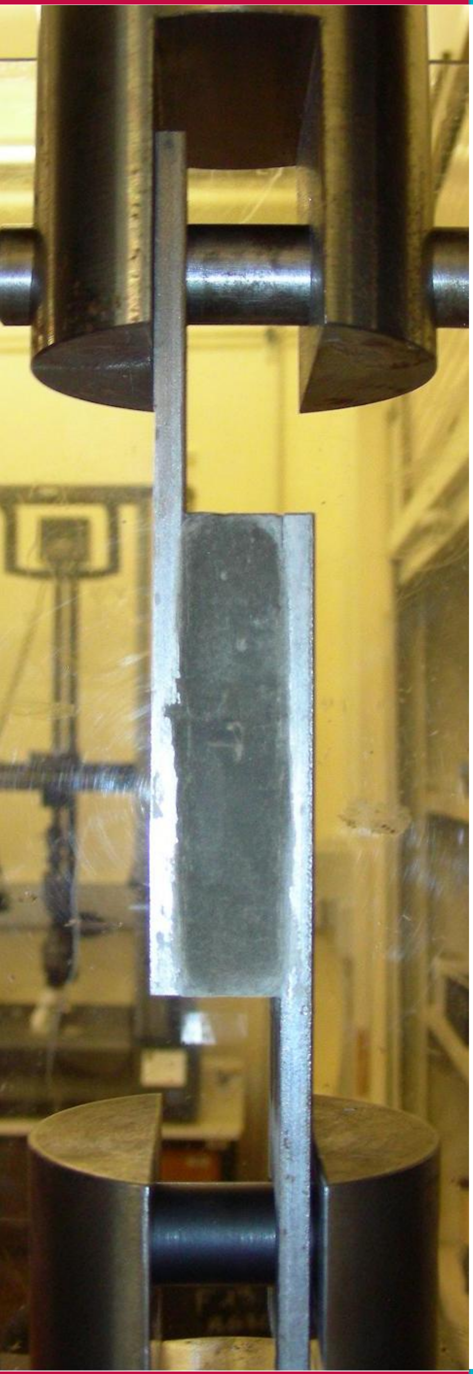
Experimentation

Mechanical characterization tests on cement / steel assemblies

Modeling

Numerical modeling of the interfaces behavior

Understand the phenomena
Determine the model parameters
Build a database for various loading



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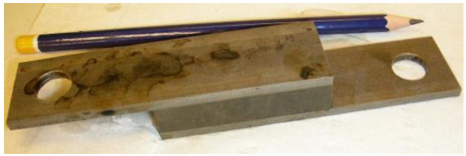
Types of tests

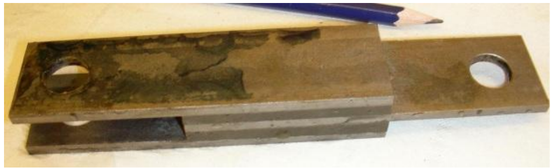
Assemblies

Cement block

Simple shearing



Double shearing



Ageing

(1) 7 days setting

+

4 weeks ageing

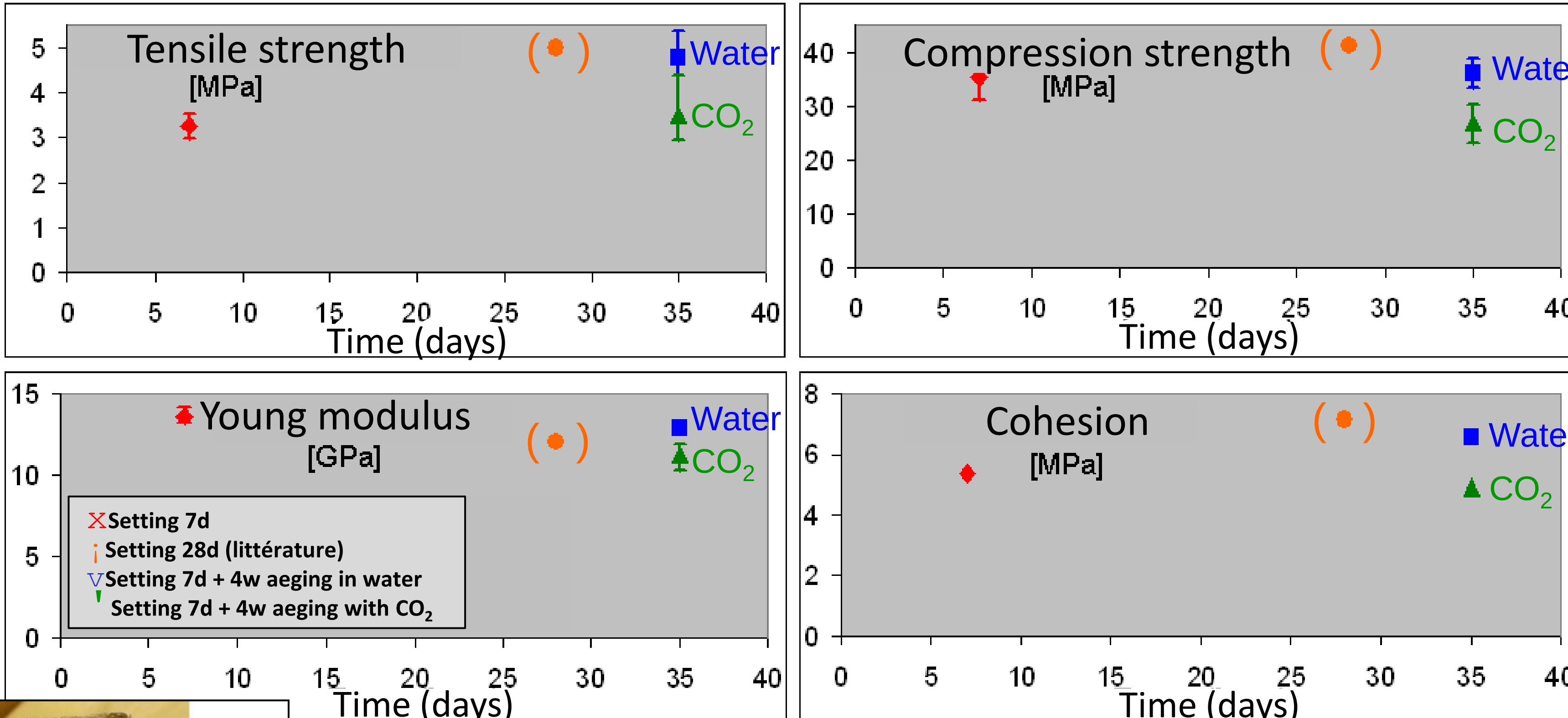
(2) in water

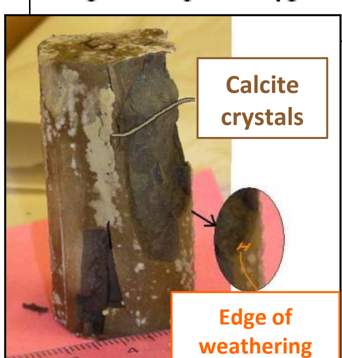
(3) in water saturated in CO_2

Influence of the imposed conditions

- Speed
- Extend of the interface

Cement blocks



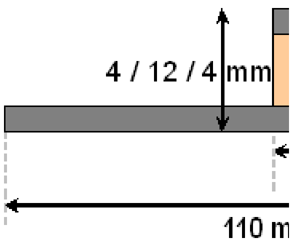


Carbonation of the blocks → Heterogeneity

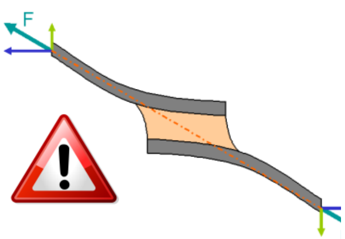
!!! Attention to the quantitative evaluation of the experimental results!!!

Simple sheari

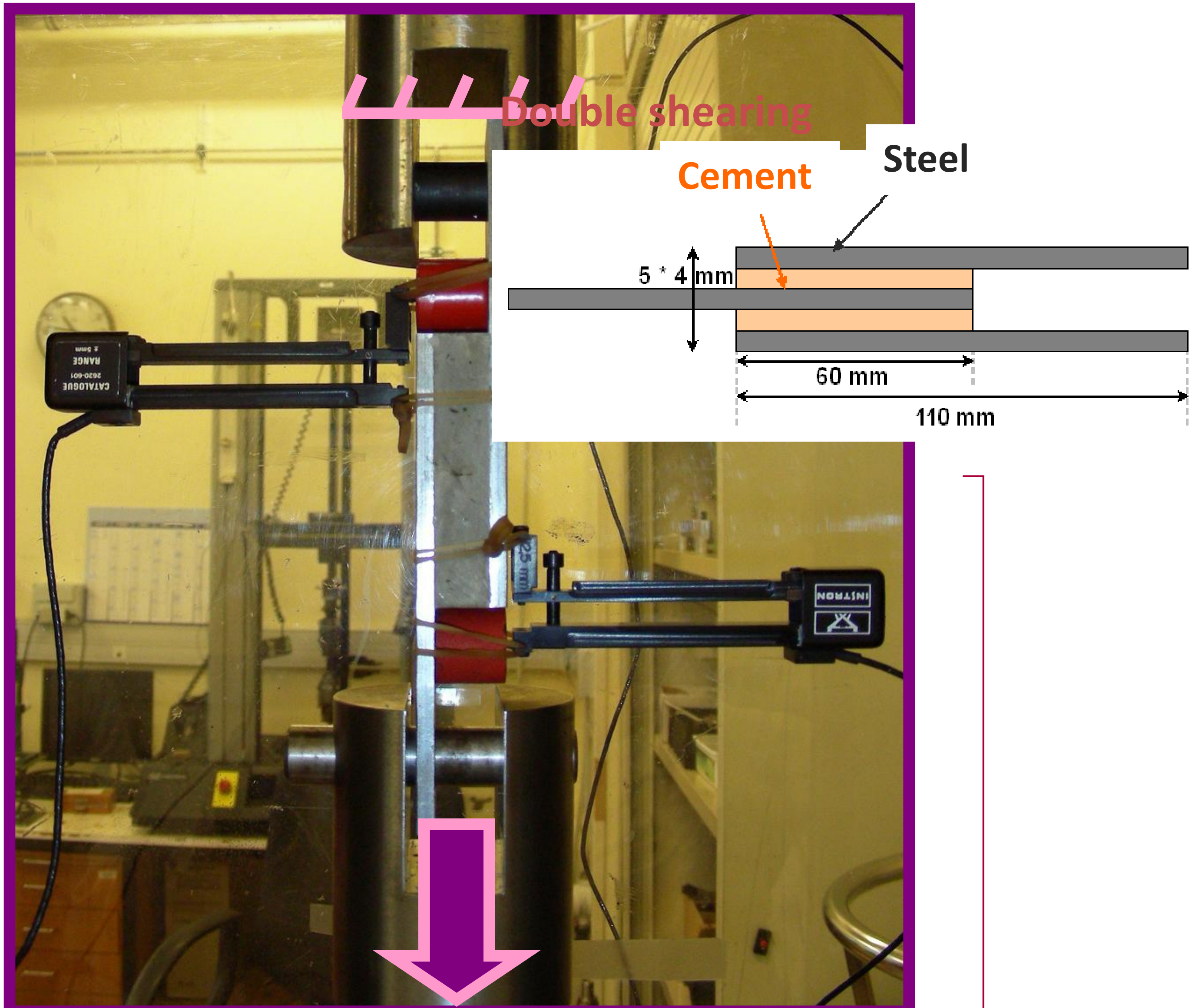
Cer



Moment

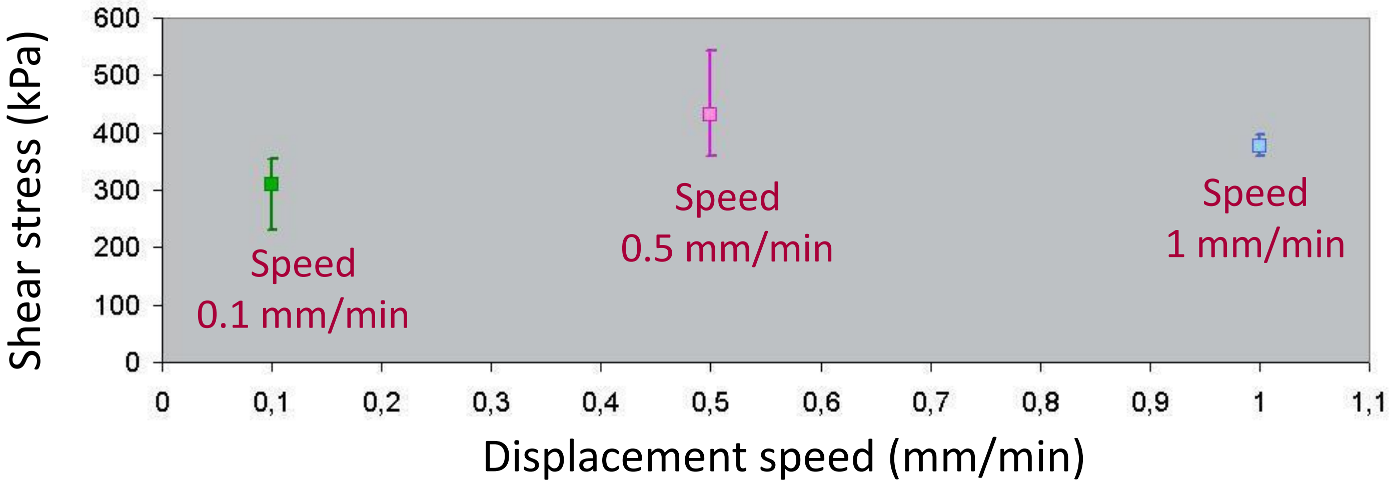


Double shearing

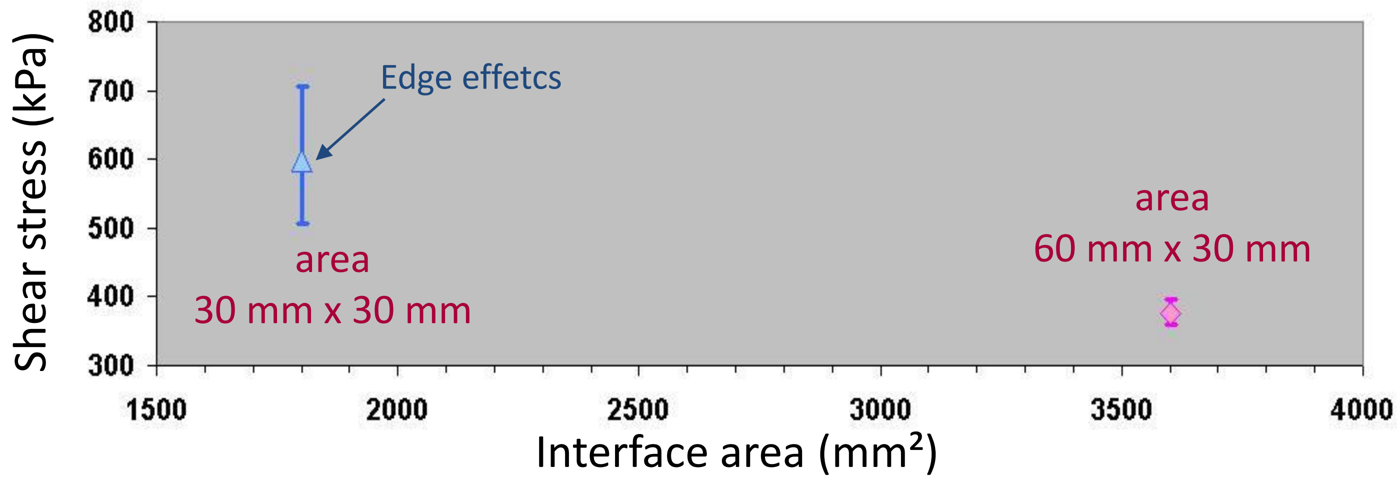


Influence of the setted conditions

Influence of the fixed displacement speed



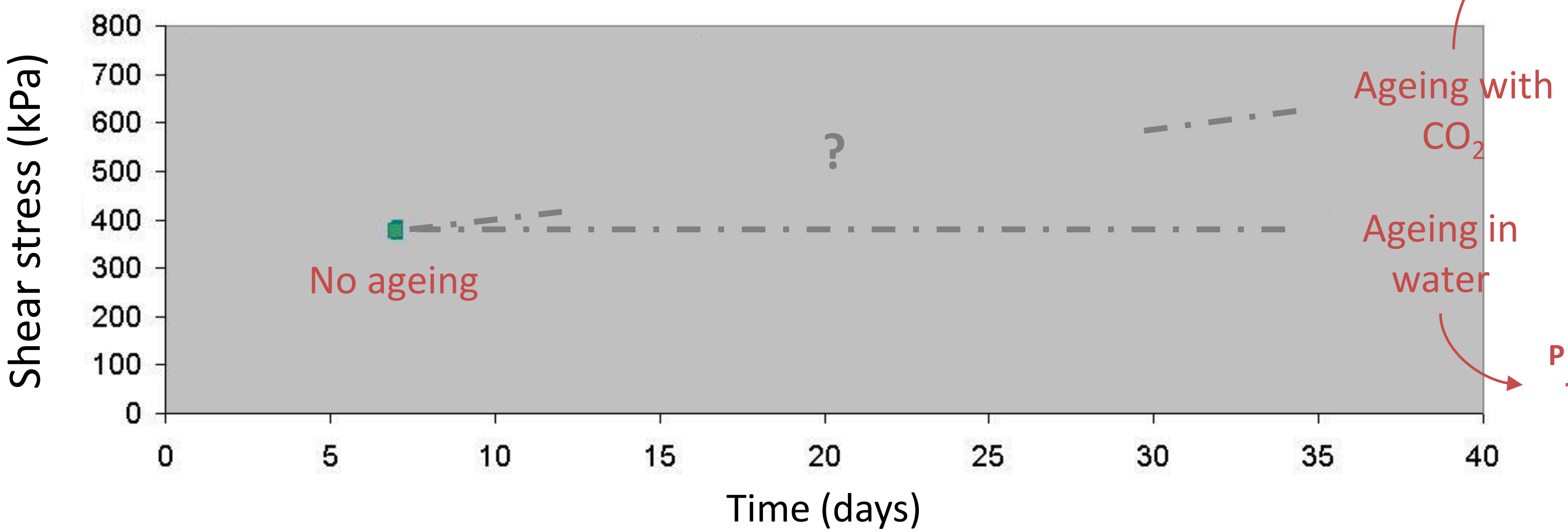
Influence of the interface area



Behavior of interfaces in contact with CO_2

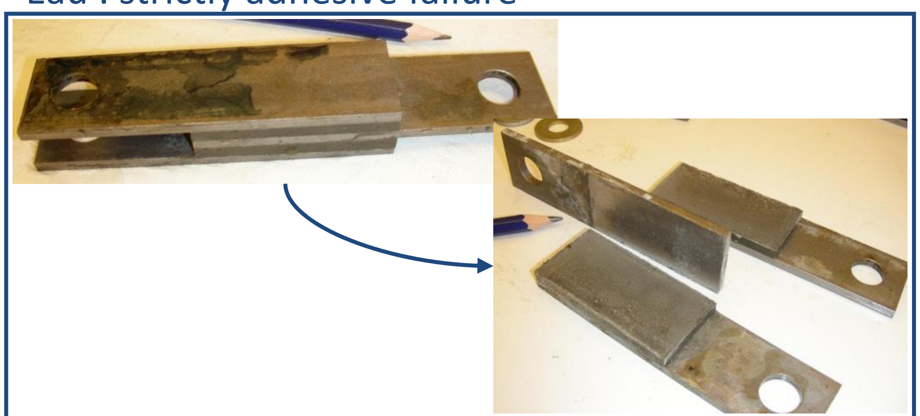
Setting : 7 days
Ageing : 4 weeks

P = 40 bars
T = 80 C
Water saturated in CO_2

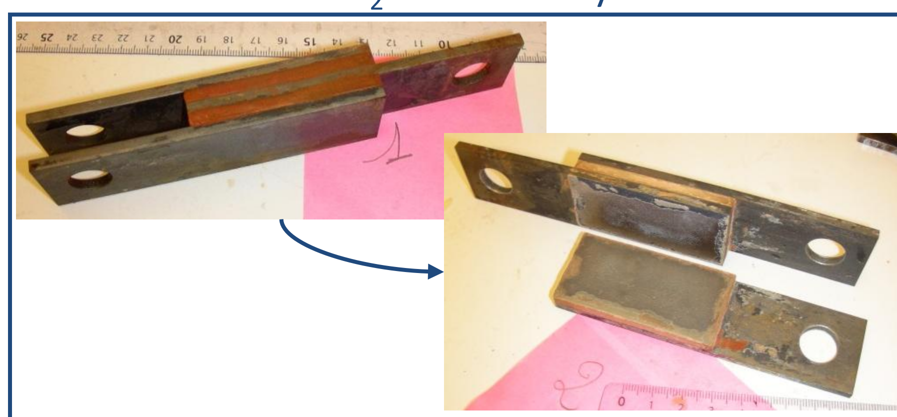


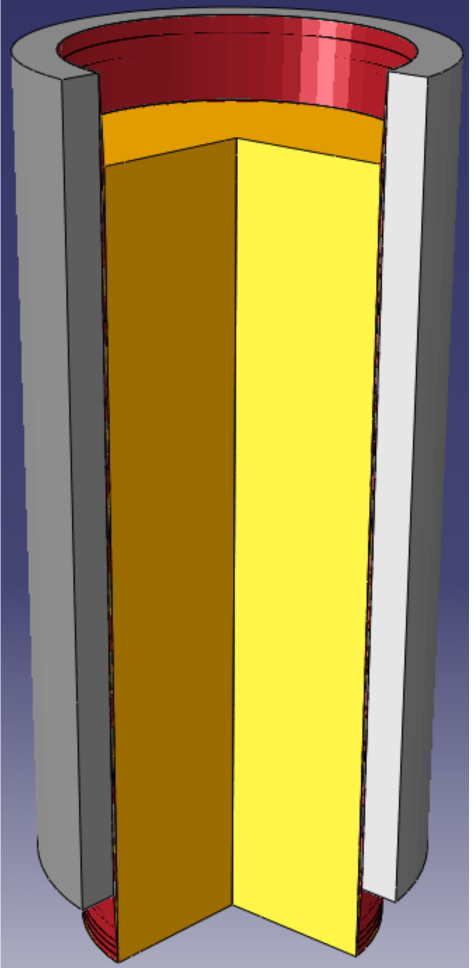
P = 40 bars
T = 80 C
Water

Eau : strictly adhesive failure



CO_2 : non-strictly adhesive failure





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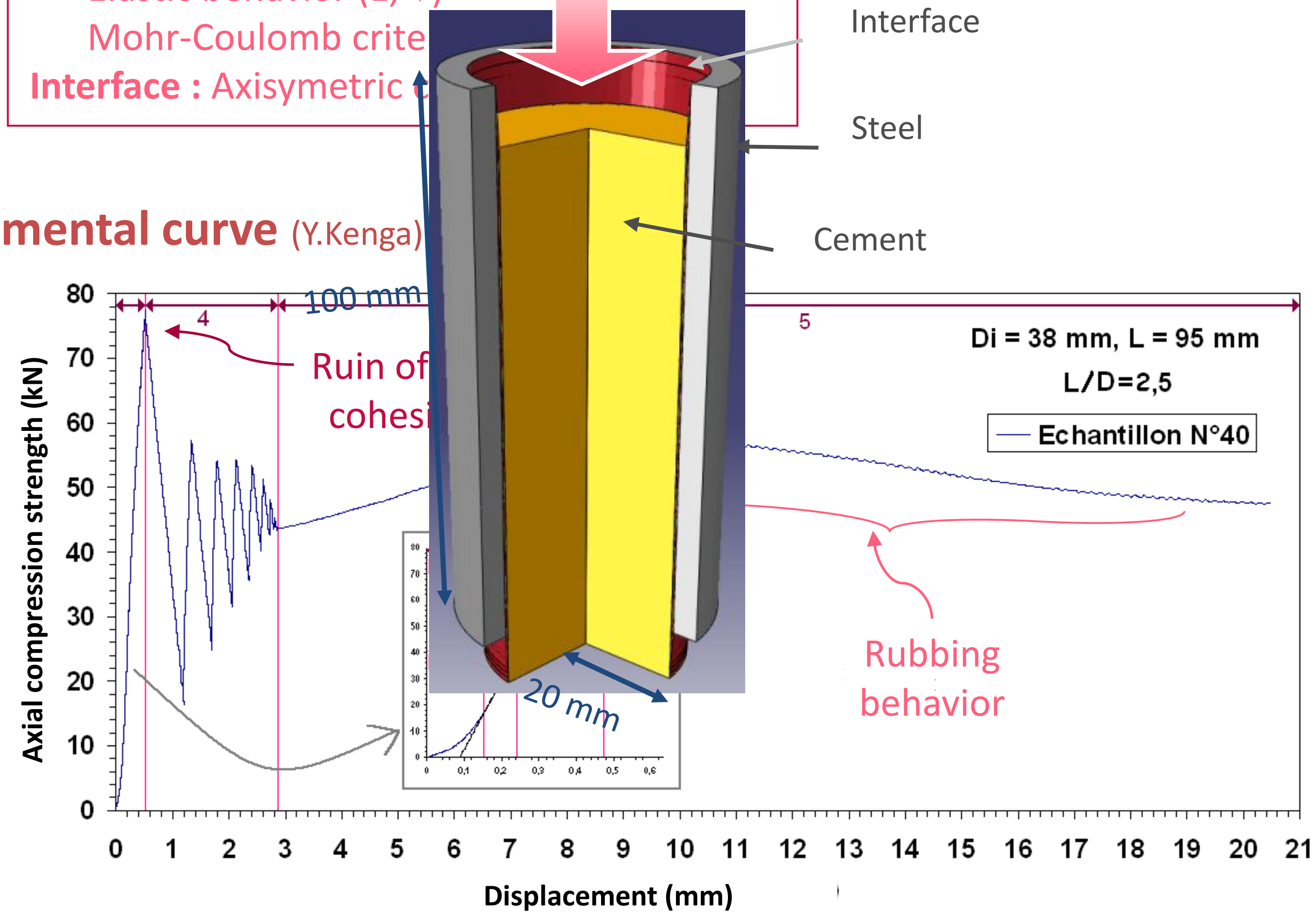
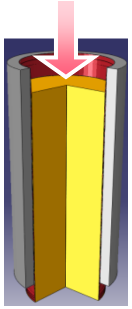
Push-Out

Steel : Axisymetric continious elements
Elastic behavior (E, ν)
Cement : Axisymetric continious elements
Elastic behavior (E, ν)
Mohr-Coulomb crite
Interface : Axisymetric

Experimental curve (Y.Kenga)



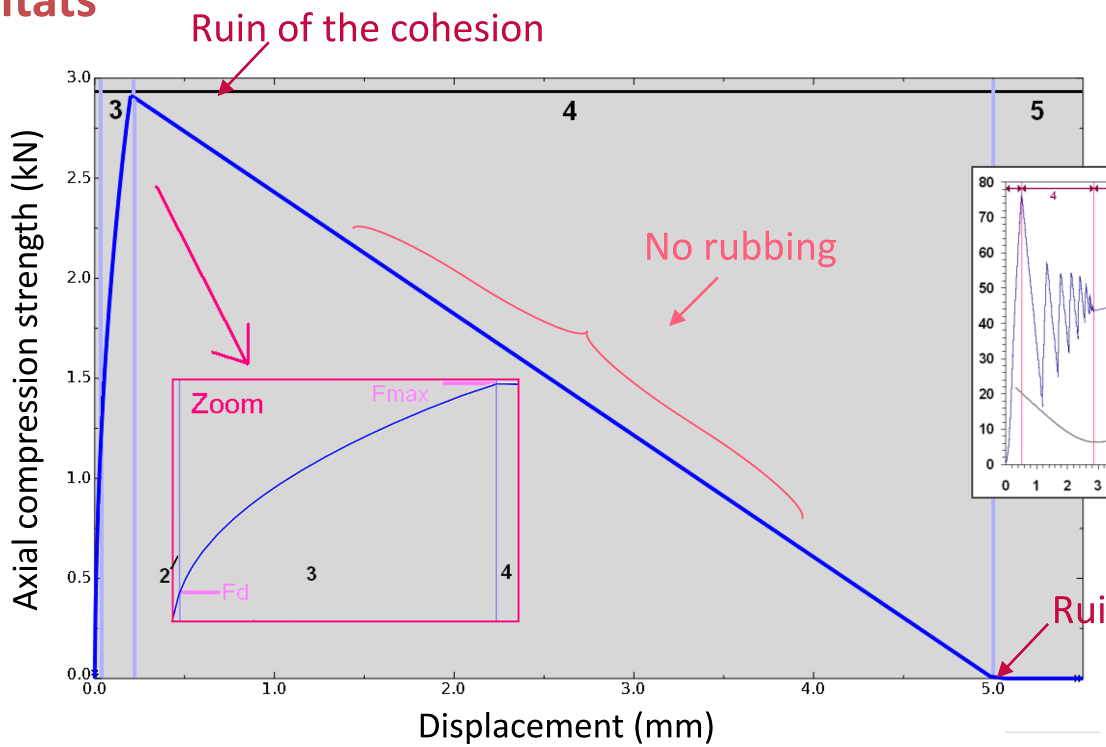
Interfacial law available in Abaqus™

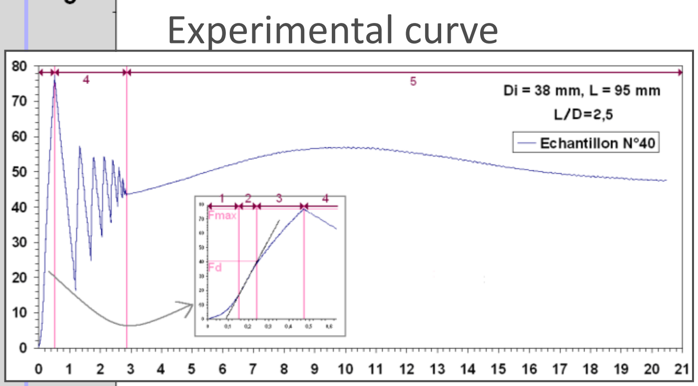


Parameters of the interfacial law:

Elastic behavior (K_{NN}, K_{SS})
Failure initiation: strain from which damage begins (10^{-3})
Failure propagation: displacement reached the ruin of material (5 mm)

Résultats





➔ **Parameters can not predict the behavior of the interface**

User interfacial law

Adhesion-friction law (Cangémi 1997)

Normal-adhesion law → Perpendicular behavior of the interface

$$\begin{cases} R_N - K_N \cdot [u_N] \cdot \beta^2 \geq 0 \ , \ [u_N] \leq 0 \\ (R_N - K_N \cdot [u_N] \cdot \beta^2) \cdot [u_N] = 0 \end{cases}$$

Adhesion-friction law → Tangential behavior of the interface

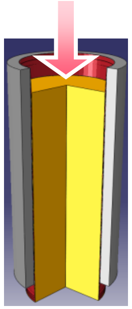
$$\begin{cases} \left| R_T - K_T \cdot [u_T] \cdot \beta^2 \right| < \mu \left| R_N - K_N \cdot [u_N] \cdot \beta^2 \right| \Rightarrow [u_T] = 0 \\ \left| R_T - K_T \cdot [u_T] \cdot \beta^2 \right| = \mu \left| R_N - K_N \cdot [u_N] \cdot \beta^2 \right| \Rightarrow [u_T] > 0 \end{cases}$$

Non-reversible adhesion → degradation of the adhesion of the contact

$$\dot{\beta} = f(w)$$

R : reaction force at contacts
[*u*] : displacement
β : adhesion intensity ➔ $\beta \in [0,1]$
K : stiffness
w : adhesion energy of Dupré
μ : coefficient of friction

User interfacial law

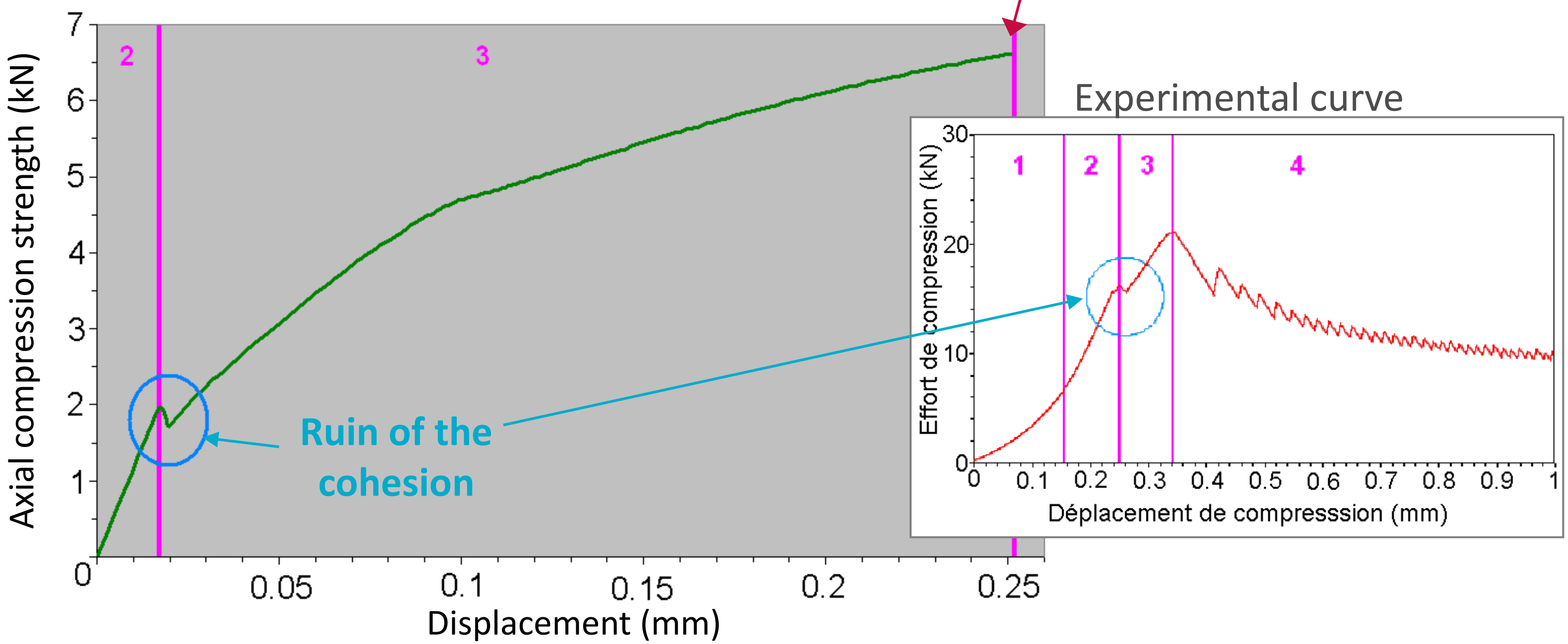


Implementation of a specific law that pairs adhesion and friction
(Cangémi 1997)

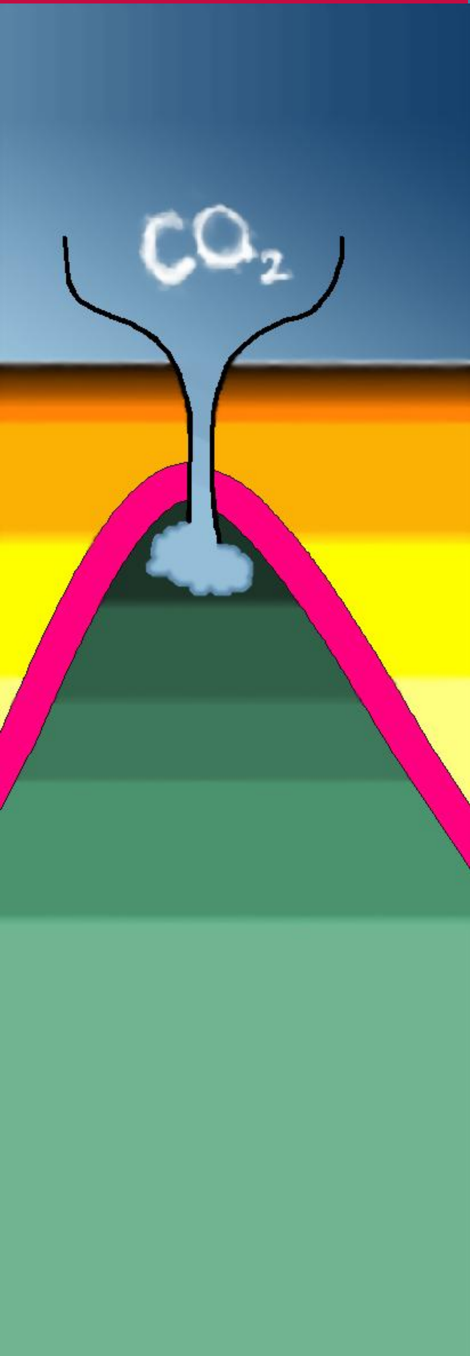
Parameters:

Elastic behavior (K_{NN}, K_{SS})
Failure and degradation (w)

Results



➔ **Perform a parametric analysis to calibrate the model to the experimental results**



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Trials

Mechanical characterization of interfaces cement / steel

→ Development of a protocol for shear tests

→ Characterization of interfaces aged in water + CO_2

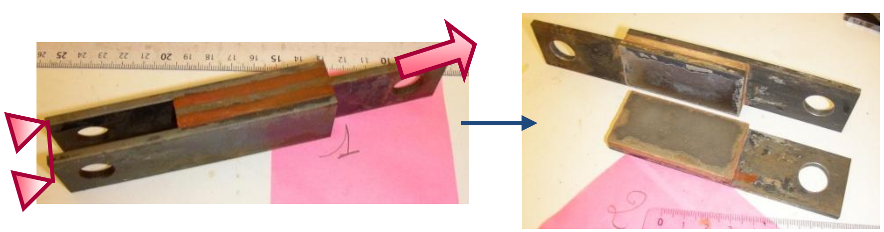
→ Reverence on cement blocks

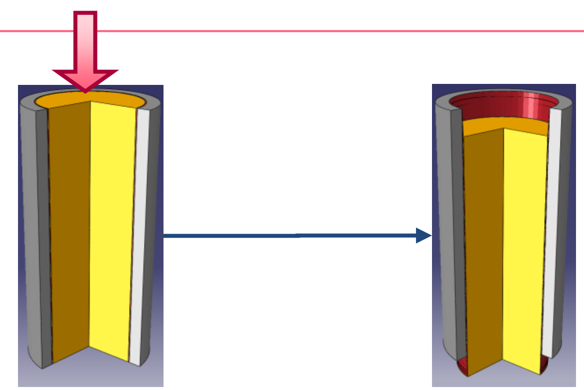
Modeling

Specific law for modeling the behavior of interfaces cement / steel

→ Testing a law available in Abaqus™

→ Implementation of a specific law that paires adhesion and friction (Cangémi 1997)





Thank you for your attention