IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

# Xper: a software dedicated to the fracture of nonlinear heterogeneous materials. Coupling with MFront using MGIS

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MEMBRE DE
ETSON
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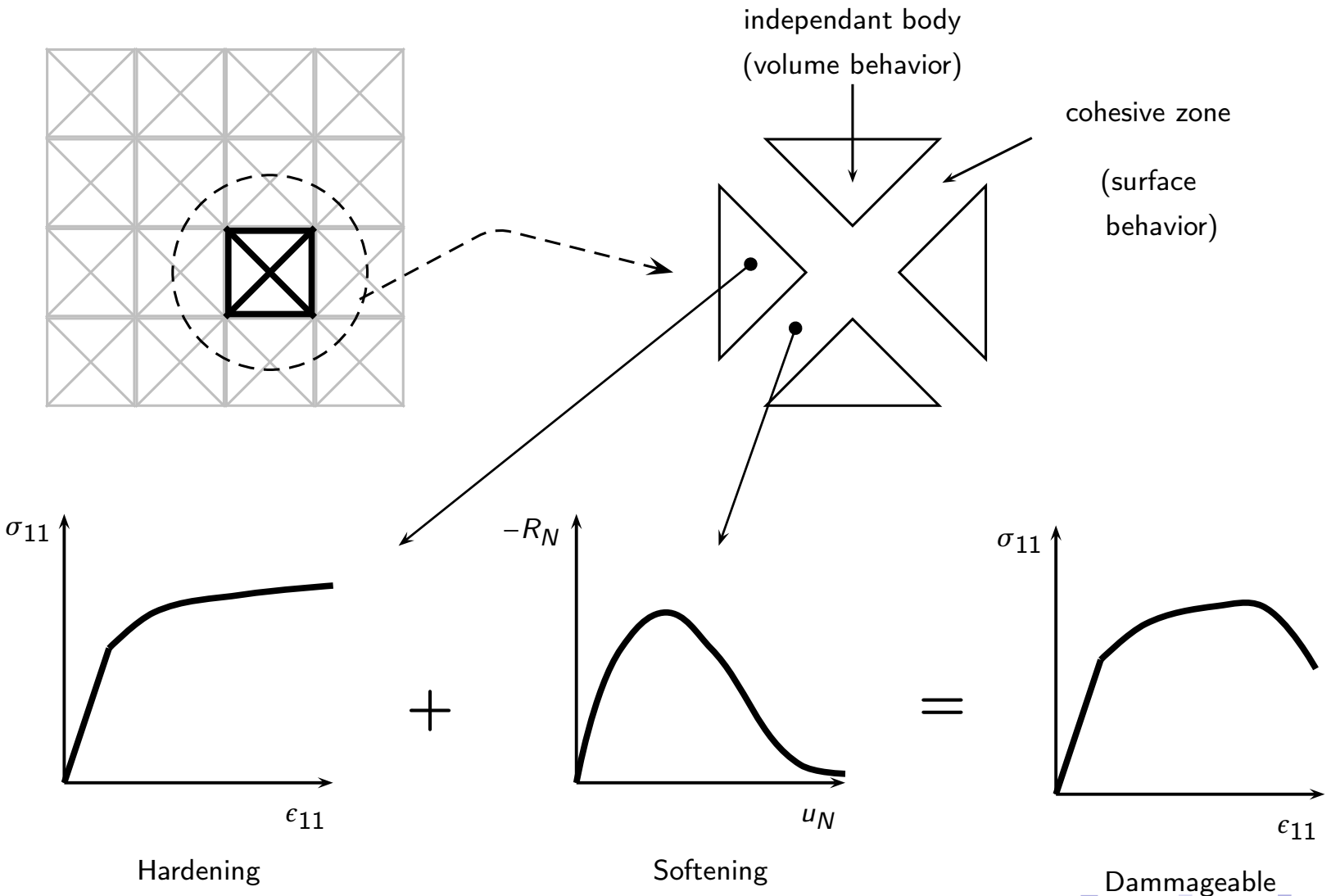
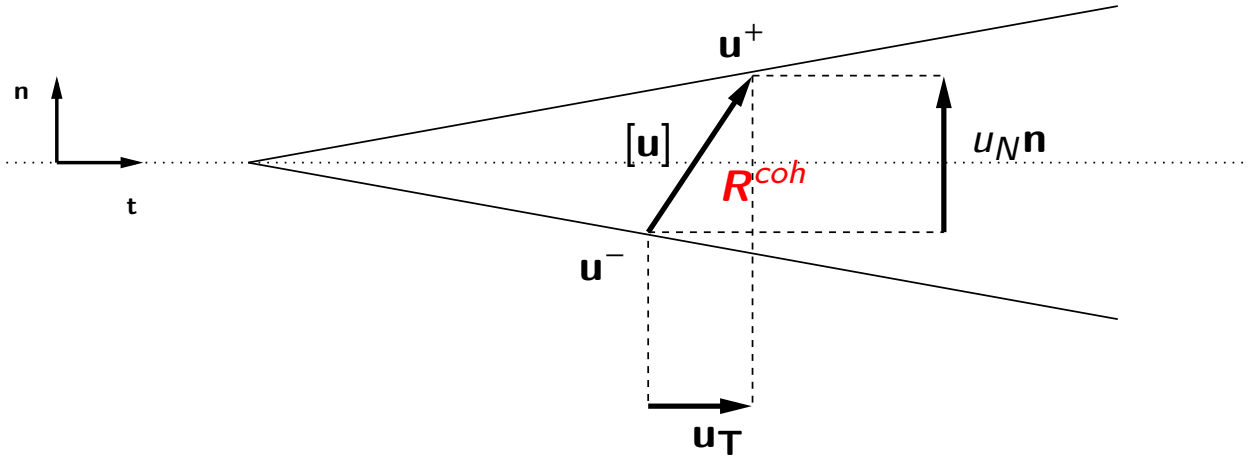
# Multibody approach



# Surface behavior : FCZM (1)

- Cohesive Zone Model (CZM)



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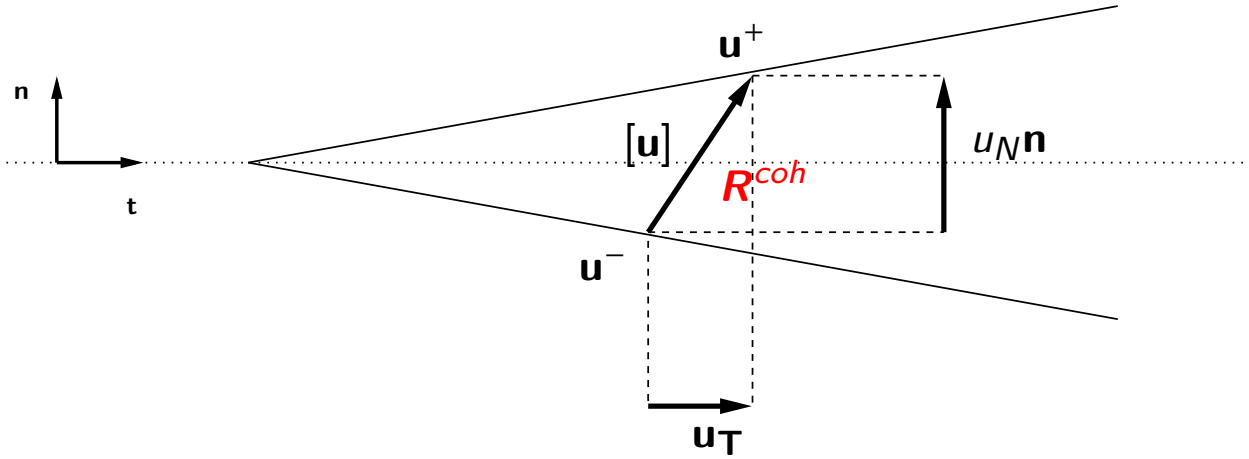


- FZCM = damage ($\boldsymbol{R}^{coh}$) + contact ($R_N$) + friction ($R_T$)

  - Contact
    $-(R_N + R_N^{coh}) \in \partial I_{\mathbb{R}^+}(u_N)$
  - Friction
    $(R_T + R_T^{coh}) \in \partial(\mu|R_N + R_N^{coh}| \parallel \boldsymbol{v}_T \parallel)$

# Surface behavior : FCZM (2)

- Cohesive force : $\boldsymbol{R}^{coh}$

$$\boldsymbol{R}^{coh} = K(\beta)\cdot[\mathbf{u}], \qquad K(\beta) = \beta\left(C_N \mathbf{n}\otimes\mathbf{n} + C_T \frac{\mathbf{u_T}\otimes\mathbf{u_T}}{\|\mathbf{u}_T\|^2}\right)$$

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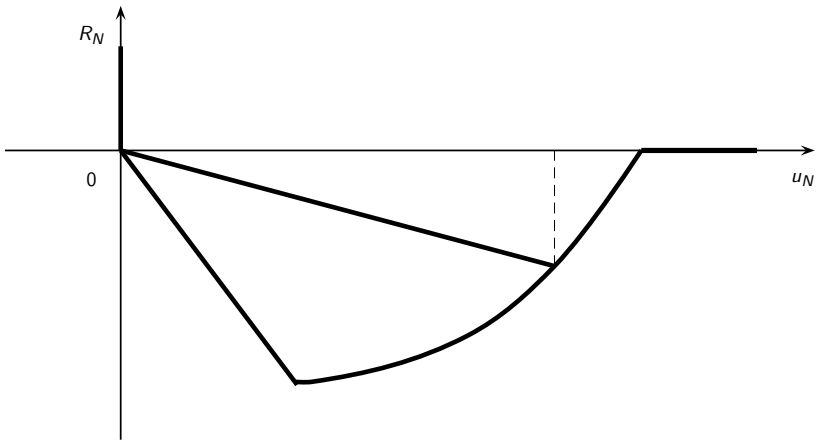
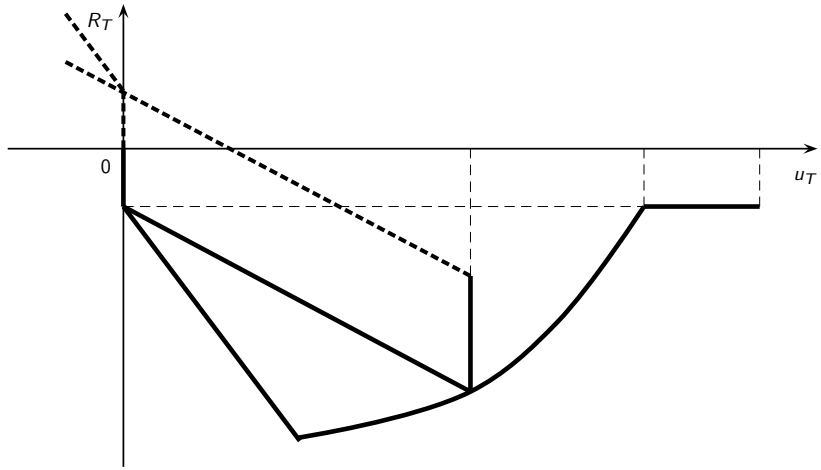
- Evolution of surface damage : $\beta = min(g(\|[u]\|), g(\|[u_{\max}]\|))$

$$g(x) = \begin{cases} \beta_0 & \text{if } x \le \delta_0 \\ 0 & \text{if } x \ge 3\delta_0 \\ \dfrac{\beta_0(3\delta_0 - x)}{\delta_0 + x} & \text{otherwise} \end{cases}, \quad \delta_0 = \sqrt{\frac{w(C_N + C_T)}{(9 - 4ln4)C_N C_T}}$$



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$\delta_0$

$\delta_0$

e

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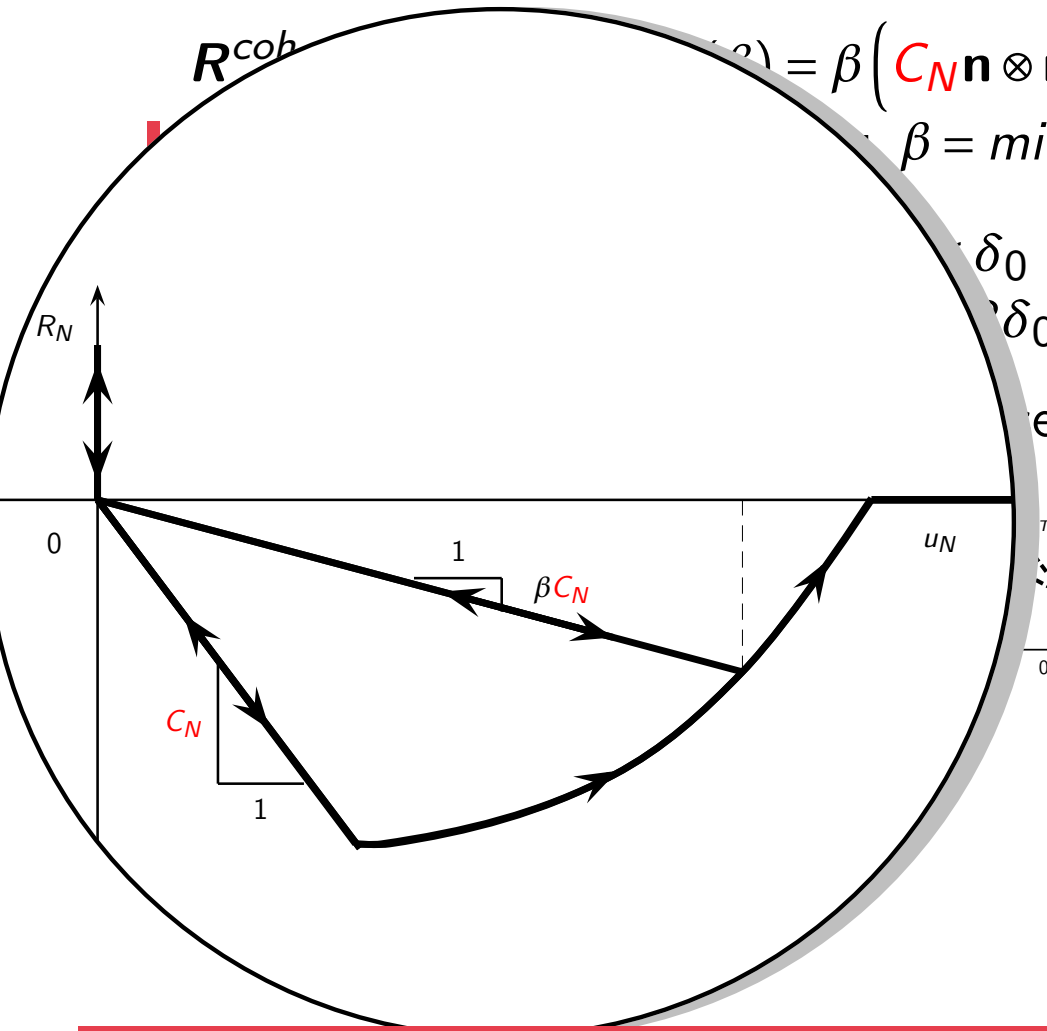


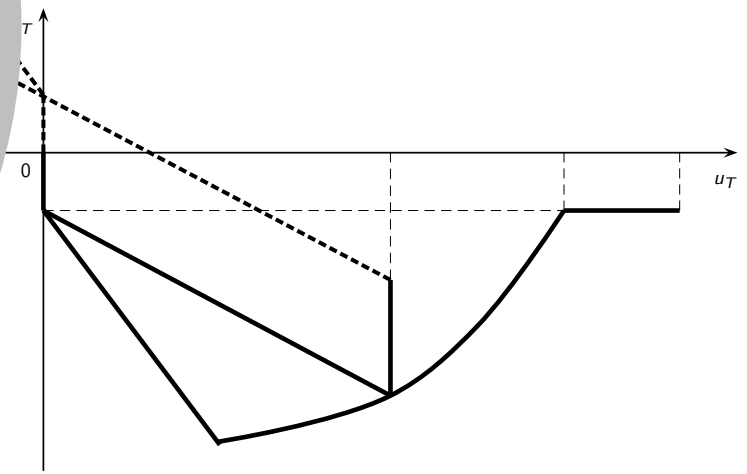

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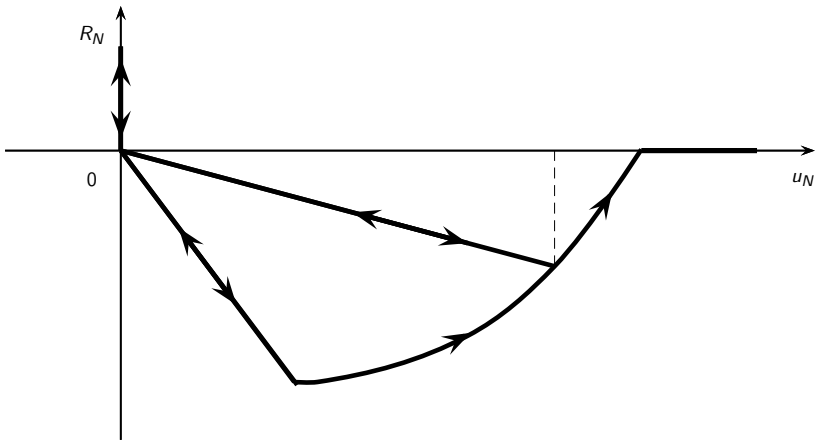
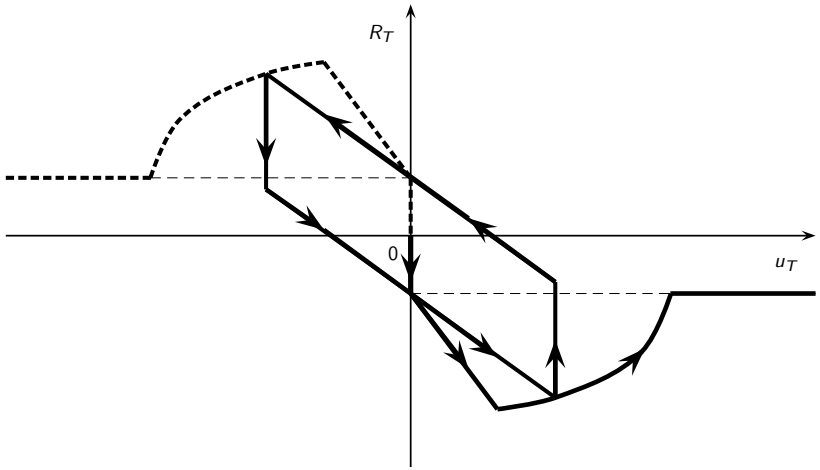
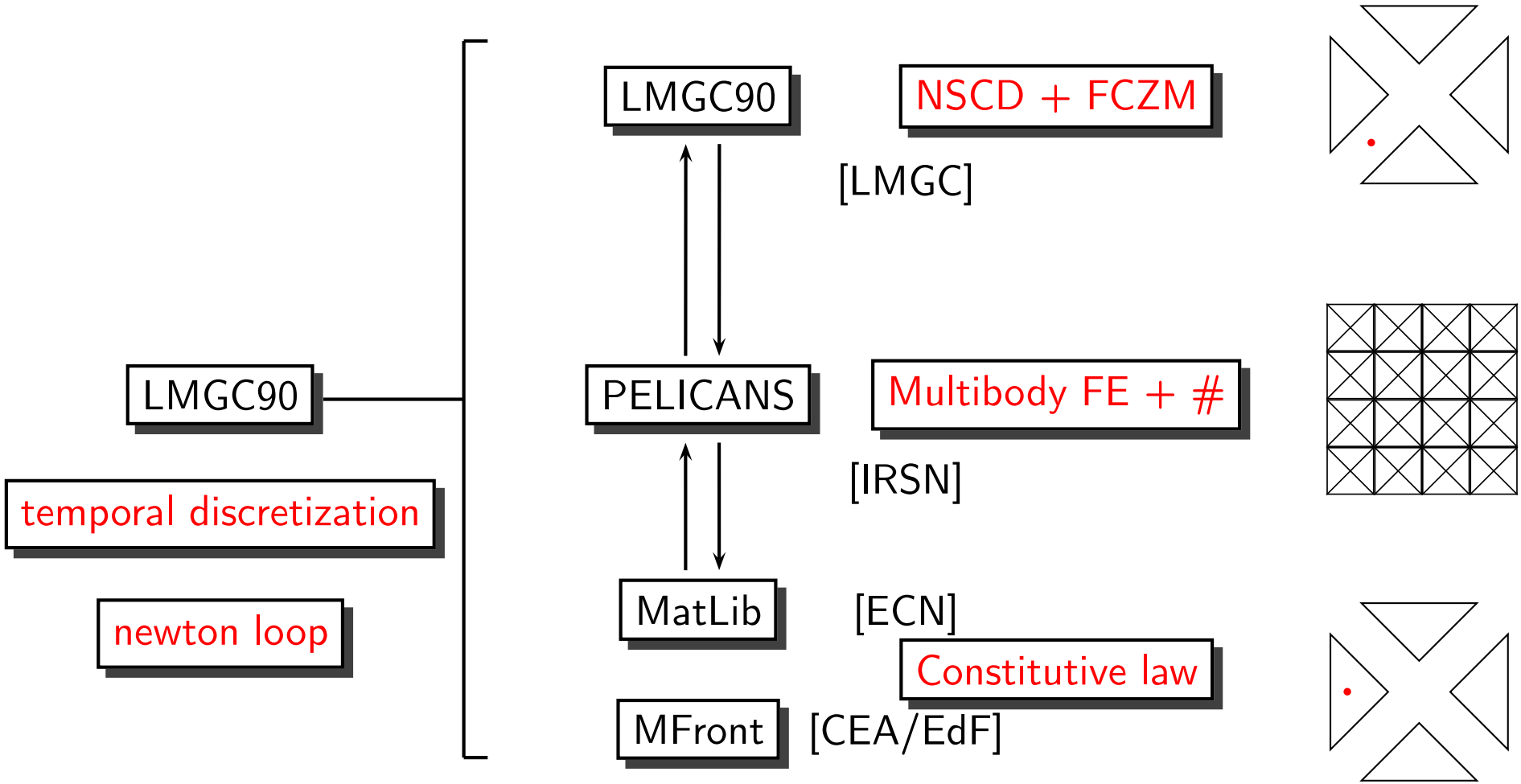
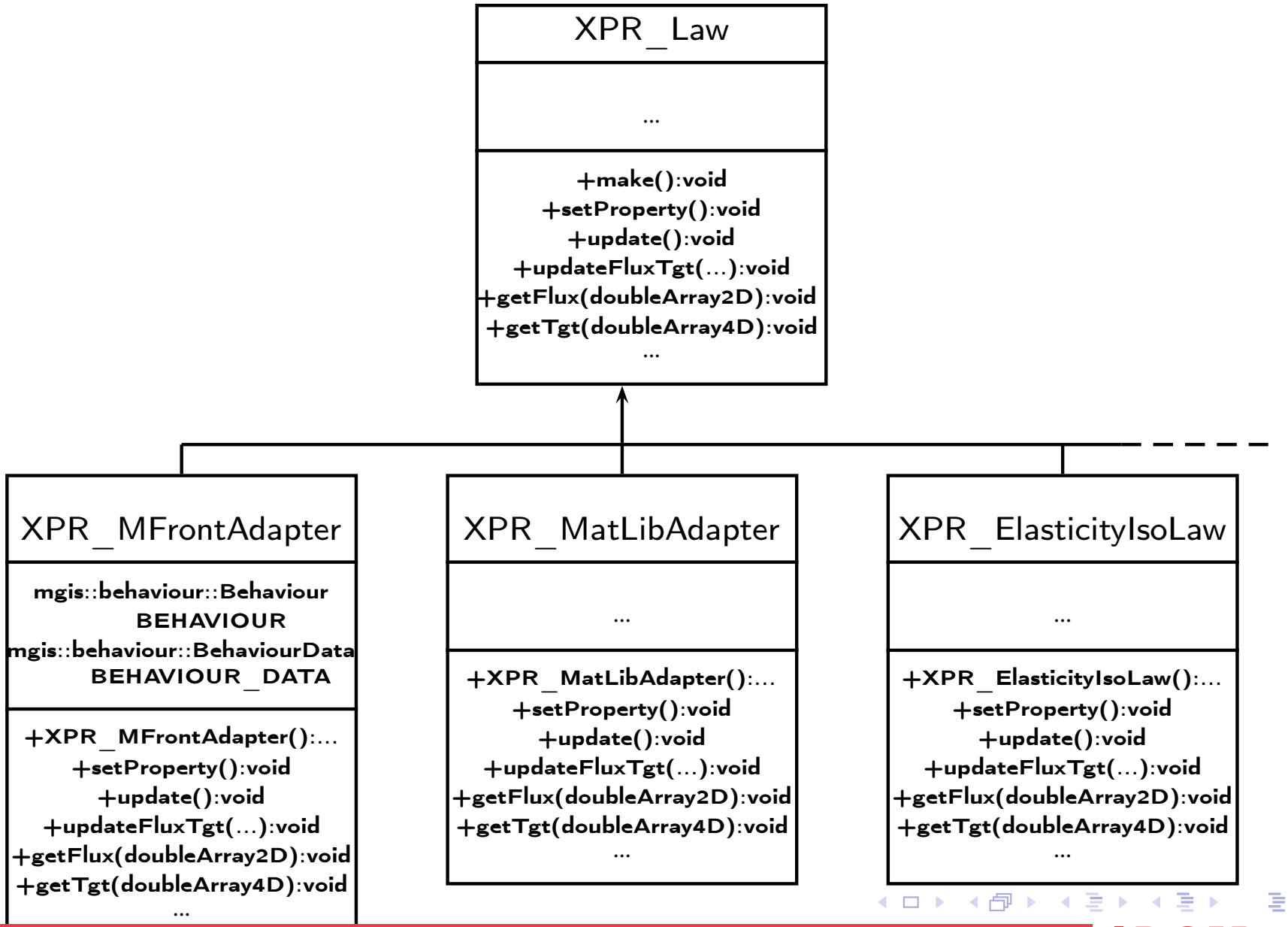


# Numerical Platform : Xper



# Abstract class for constitutive law



# Implementation (1)

## Include

```
#include <MGIS/Behaviour/Behaviour.hxx>
#include <MGIS/Behaviour/BehaviourData.hxx>
#include <MGIS/Behaviour/Integrate.hxx>
```

## Private data members

```
mgis::behaviour::Behaviour BEHAVIOUR
mgis::behaviour::BehaviourData BEHAVIOUR_DATA
```

## Constructor: XPR_MFrontAdapter::XPR_MFrontAdapter

```
// Hypothesis
// 2D Plane strain
mgis::behaviour::Hypothesis hypothesis = mgis::behaviour::Hypothesis::PLANESTRAIN ;
// 3D
if( NB_DIMS == 3 ) hypothesis = mgis::behaviour::Hypothesis::TRIDIMENSIONAL ;

// Load Behaviour
// small strain
BEHAVIOUR = mgis::behaviour::load( lname, bname, hypothesis ) ;
// Finite deformation: PK1 and DPK1/DF
if( FD ){
auto o = mgis::behaviour::FiniteStrainBehaviourOptions;
o.stress_measure = mgis::behaviour::FiniteStrainBehaviourOptions::PK1 ;
o.tangent_operator = mgis::behaviour::FiniteStrainBehaviourOptions::DPK1_DF ; }

// BehaviourData
BEHAVIOUR_DATA = mgis::behaviour::BehaviourData( BEHAVIOUR ) ;
```

# Implementation (2)

- void setProperty()

```
mgis::behaviour::setMaterialProperty( BEHAVIOUR_DATA.s0, name, value ) ;
```

- void update()

```
mgis::behaviour::update( BEHAVIOUR_DATA ) ;
```

- void updateFluxTgt( doubleArray2D const strain, double dt )

```
// Compute the consistent tangent operator
BEHAVIOUR_DATA.K[0] = 4 ;

// Update gradients: BEHAVIOUR_DATA.s1.gradients from strain          [WARNING: indexes]

BEHAVIOUR_DATA.dt = dt ;
mgis::behaviour::BehaviourDataView bdv = mgis::behaviour::make_view( BEHAVIOUR_DATA ) ;
int r = mgis::behaviour::integrate( bdv, BEHAVIOUR ) ;
if( r==-1 ) PEL_Error:: object()->raise_plain( "MFront integration failed" ) ;
else if( r==0 ) PEL_Error:: object()->raise_plain( "MFront integration succeeded but results are unreliable" ) ;
```

- void getFlux( doubleArray2D stress ) const

```
// Update stress: stress from BEHAVIOUR_DATA.s1.thermodynamic_forces          [WARNING: indexes]
```

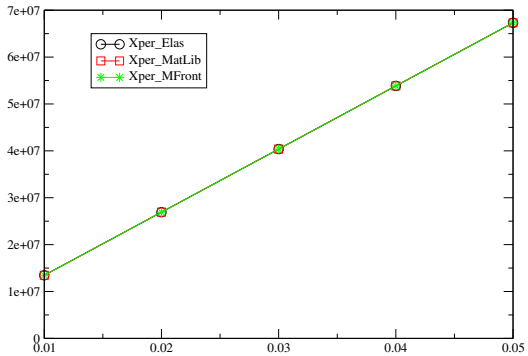
- void getTgt( doubleArray4D tgt ) const

```
// Update tangent: tgt from BEHAVIOUR_DATA.K          [WARNING: indexes]
```

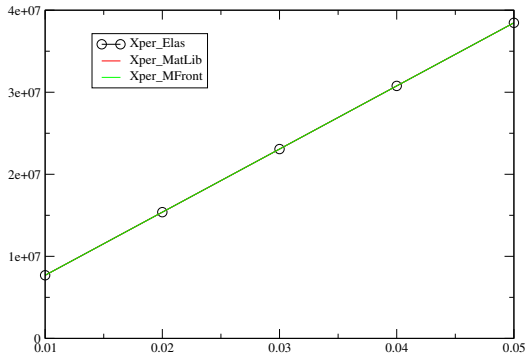
# Unit validation (Small strain)

## Isotropic Elasticity [*IsotropicStandardElasticity.mfront*]

Traction - $\Sigma_{11}$vs$E_{11}$

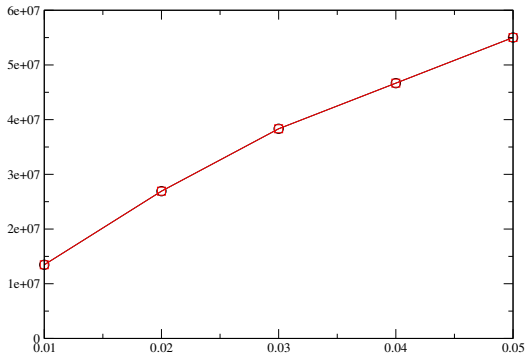



Shear - $\Sigma_{12}$vs$E_{12}$

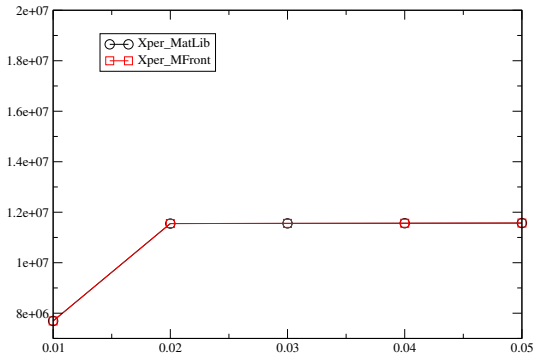



## Isotropic J2 Plasticity [*StandardElastoViscoPlasticity.mfront*]

Traction - $\Sigma_{11}$vs$E_{11}$



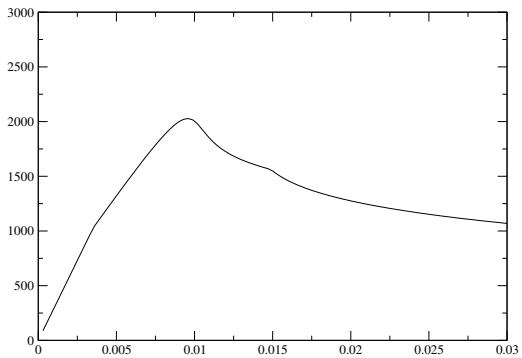

Shear - $\Sigma_{12}$vs$E_{12}$



# Unit validation (Small strain)

- GTN [*GursonTvergaardNeedlemanPlasticFlow_NumericalJacobian.mfront*]

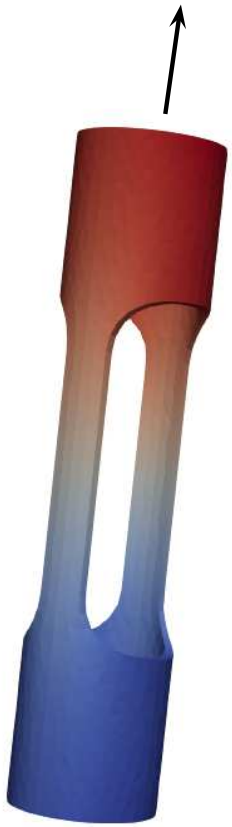
  Traction - $\Sigma_{44}$ vs $E_{44}$




| | Ref | Xper |
|---|---|---|
| $\Sigma_{xx}$ | 910,12 | 910,12 |
| $\Sigma_{yy}$ | 1069,37 | 1069,37 |
| $\Sigma_{zz}$ | 870,308 | 870,308 |

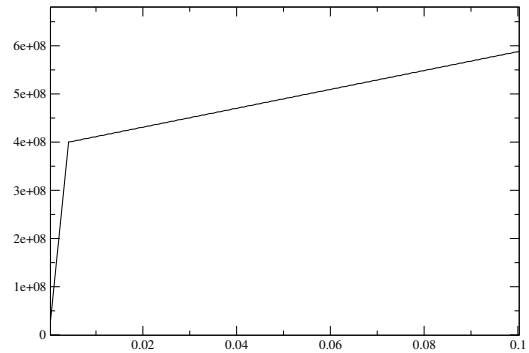
# Zircaloy clad traction test

- Zircaloy4 (Rosinger79) [*StandardElastoViscoPlasticity.mfront*]



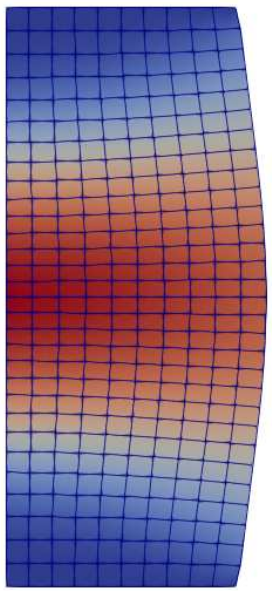
$U_z$

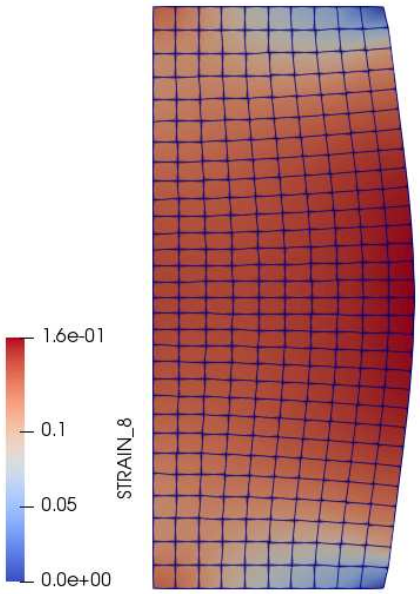
$S_{VM}$



# UO2 compression test

- $UO_2$ (Salvo,14) [*Creep_L3F.mfront*]

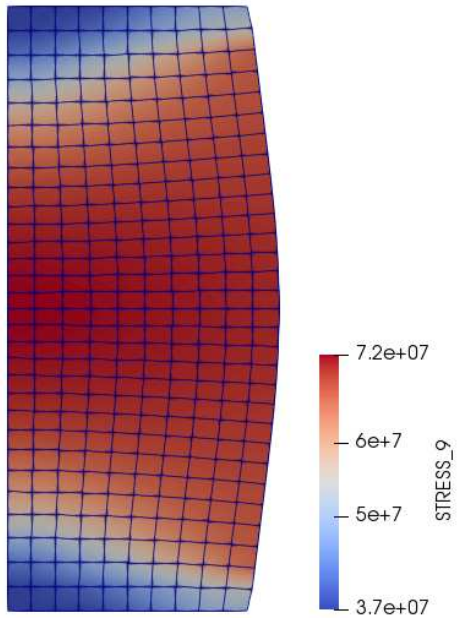




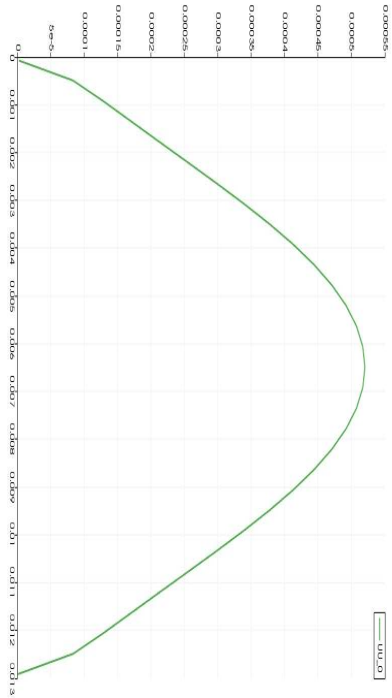

$E_{zz}$




$S_{zz}$




$S_{VM}$



$U_r$ vs z

# Outlook

- Finite deformation: PK1 and DPK1/DF

```
if( FD ){
auto o = mgis::behaviour::FiniteStrainBehaviourOptions;
o.stress_measure = mgis::behaviour::FiniteStrainBehaviourOptions::PK1 ;
o.tangent_operator = mgis::behaviour::FiniteStrainBehaviourOptions::DPK1_DF ; }
```

[Warning: indexes]

[*saintvenantkirchhoff.mtest*] ... Work in progress...

- Thx Thomas !