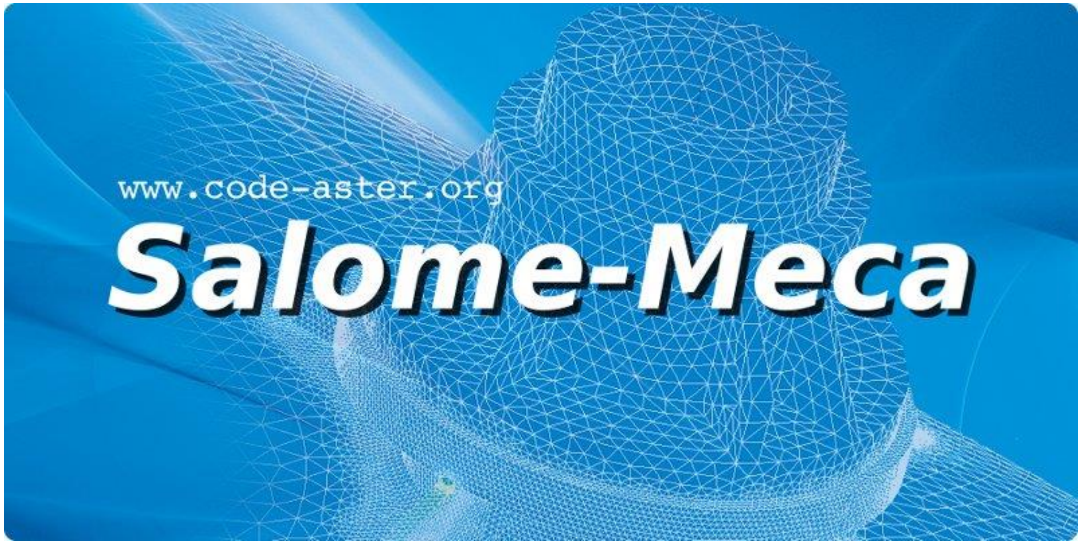
Local resolution of constitutive laws



Code_Aster, Salome-Meca course material

GENERAL CONCEPTS

General concepts

- Defining solid Ω which is in equilibrium with external forces

$$\int_{\Omega} \underline{\underline{\sigma}}(\vec{u}) : \underline{\underline{\varepsilon}}(\delta\vec{u}).d\Omega = \int_{\Omega} \vec{f}(\vec{u}) : \delta\vec{u}.d\Omega + \int_{\Gamma_g} g(\vec{u}) : \delta\vec{u}.d\Gamma$$

Unknowns (3D):
- Displacement field (3 components)
- Stress field (6 components)

Equations (3D):
- (weak) equilibrium (3 equations)

Six equations missing !
=> behaviour law required to close the system

General concepts

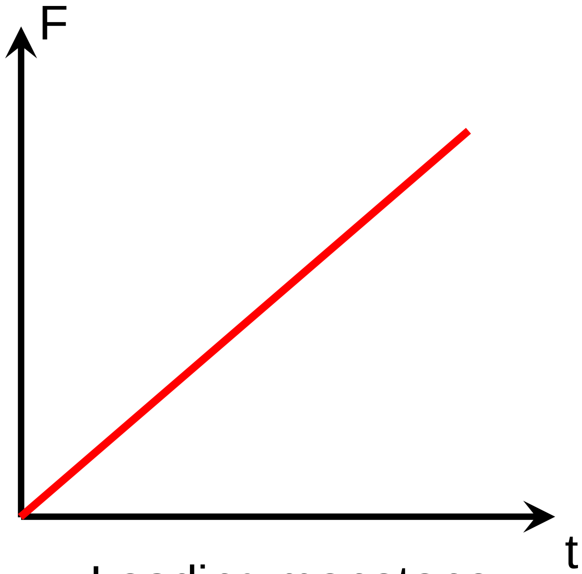
- The behaviour law:
  - Identify from experimental: from try to complete structure (representativity)
  - Using formalism (general prooves for convergence)
  - Develop in non-linear framework
  - Test (verification and validation)

General concepts

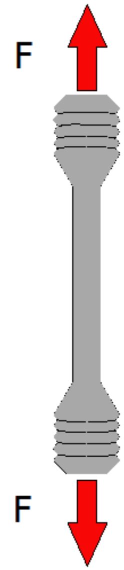
- Example:
  - Behaviour law for metal from 1D tensile-test (plasticity)

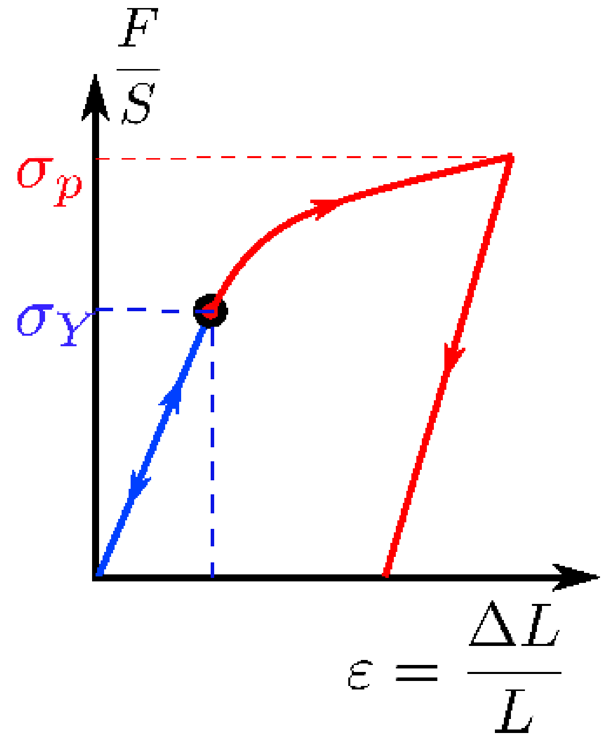
General concepts: example

1/ Elaborate a representative *try*



Loading monotone



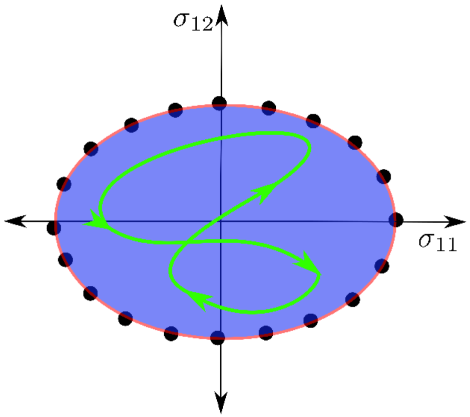


- **We can observe :**
  - An elasticity domain with a Yield Stress σ^Y
  - An irreversible strain ε^P
  - A hardening caracterized by $\sigma^P > \sigma^Y$
  - Plasticity, a phenomenon that is independent of velocity

General concepts : example

2/ Identify to extend to the REV (Representative Elementary Volume)

First part: the elastic domain until σ^Y



The elasticity domain is defined by :

$$f(\underline{\underline{\sigma}}) < 0$$

Experimentaly :

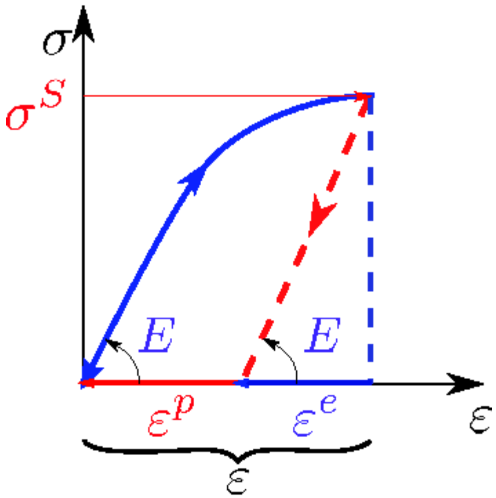
- f is a function of $\underline{\underline{\sigma}}^D = dev(\underline{\underline{\sigma}})$
- more particulary $f(\underline{\underline{\sigma}}^D) = f(J_1, J_2)$

with
$$\begin{cases} J_1 = \frac{1}{2} dev(\underline{\underline{\sigma}}).dev(\underline{\underline{\sigma}}) \\ J_2 = \frac{1}{3} trac\left(dev(\underline{\underline{\sigma}}).dev(\underline{\underline{\sigma}}).dev(\underline{\underline{\sigma}})\right) \end{cases}$$

General concepts : example

2/ Identify to extend to the REV (Representative Elementary Volume)

Second part: the plastic domain from σ^Y



The partition of strains:

$$\underline{\underline{\varepsilon}} = \underline{\underline{\varepsilon}}^e + \underline{\underline{\varepsilon}}^p$$

For elastic case :

$$\underline{\underline{\sigma}} = \underline{\underline{\underline{\underline{E}}}} : \underline{\underline{\varepsilon}}^e \Leftrightarrow \underline{\underline{\sigma}} = \lambda . tr(\underline{\underline{\varepsilon}}^e) + 2\mu . \underline{\underline{\varepsilon}}^e$$

General concepts : example

A general theoretical framework: mechanics and thermodynamics

First law of thermodynamics:

$$\frac{\partial E_{\text{int}}}{\partial t} + \frac{\partial E_{cin}}{\partial t} = P_{ext} + Q_{ext}$$

With PPV, we can formulate a variational internal energy:

$$\rho \frac{\partial e}{\partial t} = \underline{\underline{\sigma}} : \underline{\underline{\dot{\varepsilon}}} + r - div(\underline{q})$$

The second law of thermodynamics: the Inegality of Clausius-Duhem

$$D = \underline{\underline{\sigma}} : \underline{\underline{\dot{\varepsilon}}} - \rho\left(\frac{d\Psi}{dt} - s\dot{T}\right) - \frac{q}{T}.\nabla T \geq 0$$

With Ψ the Helmholtz's free energy

General concepts : example

The method of local state

The thermodynamic state, at the point and the instant considered, is entirely defined at this instant by the state variables (observable (T, ε) and internal $(V_1 = \varepsilon^p, V_k)$).

$$\frac{d\Psi}{dt} = \frac{\partial \Psi}{\partial \underline{\underline{\varepsilon}}^e} \dot{\underline{\underline{\varepsilon}}}^e + \frac{\partial \Psi}{\partial T} \dot{T} + \frac{\partial \Psi}{\partial V_k} \dot{V}_k$$

$$D_{\text{int}} = \left(\underline{\underline{\sigma}} - \rho \frac{d\Psi}{d\underline{\underline{\varepsilon}}^e} \right) : \dot{\underline{\underline{\varepsilon}}}^e + \underline{\underline{\sigma}} : \dot{\underline{\underline{\varepsilon}}}^p - \rho \left(s + \frac{d\Psi}{dt} \right) - \frac{d\Psi}{dV_k} . \dot{V}_k$$

if $\quad \dot{\underline{\underline{\varepsilon}}}^p = \dot{V}^k = \dot{T} = 0$

The first state law :

$$\underline{\underline{\sigma}} = \rho \frac{\partial \Psi}{\partial \underline{\underline{\varepsilon}}^e}$$

and if $\quad \dot{\underline{\underline{\varepsilon}}}^p = \dot{V}^k = 0, \quad \forall \dot{T}$

The second state law :

$$s = -\frac{\partial \Psi}{\partial T}$$

General concepts : example

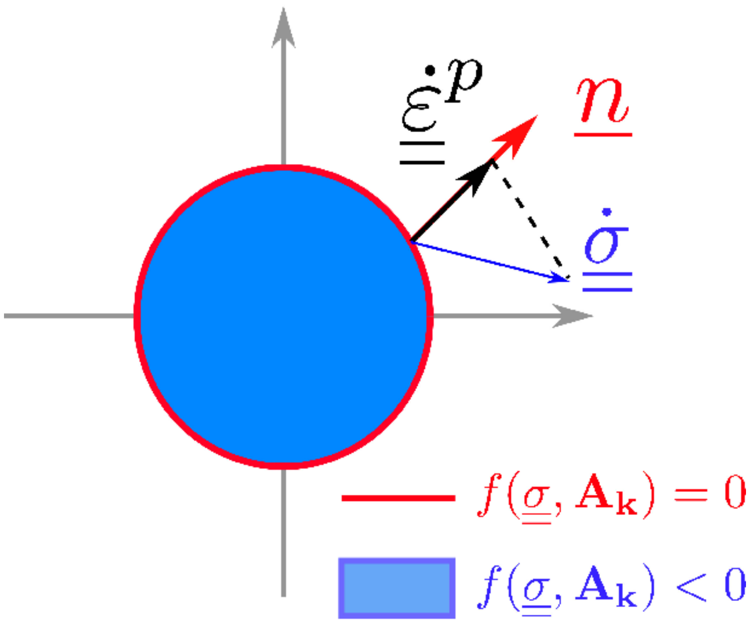
State Variables		Associated thermodynamic forces	State laws
observable	internal		
T		s	$s = -\frac{\partial \Psi}{\partial T}$
$\underline{\underline{\varepsilon}}^{e}$		$\underline{\underline{\sigma}}$	$\underline{\underline{\sigma}} = \rho \frac{\partial \Psi}{\partial \underline{\underline{\varepsilon}}^{e}}$
	$\underline{\underline{\varepsilon}}^{p}$	$-\underline{\underline{\sigma}}$	$\underline{\underline{\sigma}} = -\rho \frac{\partial \Psi}{\partial \underline{\underline{\varepsilon}}^{p}}$
	V_k	A_k	$A_k = \rho \frac{\partial \Psi}{\partial V_k}$

Evolution of internal state variables => irreversible dissipation formalism

General concepts : example

A formalism for plasticity: the maximum plastic work (Hill 1951)

In short, the principle postulate two important ideas :
- the yield surface must be convex function,
- the plastic strain rate is normal to the yield surface



Evolution law (or law of normality)

$$\dot{\varepsilon}^p = \dot{\lambda}\frac{\partial f}{\partial \sigma}$$

Outward normal to the boundary of the domain

$$\underline{n} = \frac{\partial f}{\partial \sigma}$$

General concepts : example

A formalism for plasticity: Intensity of the flow

The plasticity multiplier is determined by the consistency relation

$$df = 0 \Leftrightarrow \frac{\partial f}{\partial \mathrm{A}_\mathrm{k}} dA_k = 0$$

Consistency relation

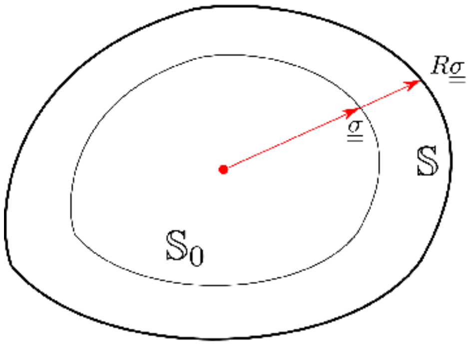
$$\dot{f} \equiv 0$$

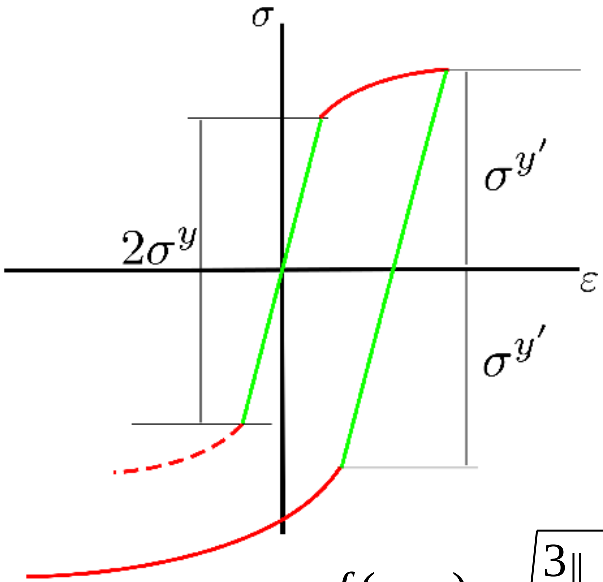
General concepts : example

Summary, a plasticity theory:

- Defining hardening
- Defining yield surface
- Defining flow direction (normal = associative law)
- Défining flow intensity (plastic multiplicator)

General concepts : isotropic hardening



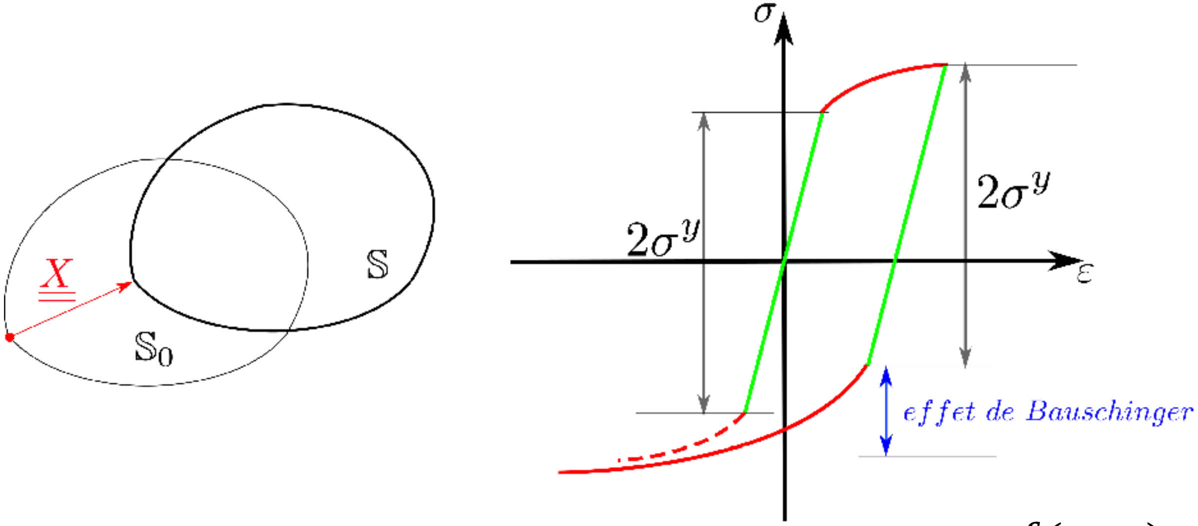


$$f(\underline{\underline{\sigma}}, p) = \sqrt{\frac{3}{2}} \left\| \underline{\underline{\sigma}}^D \right\| - R(p) - \sigma^y$$

An isotropic extension of the elasticity domain is taking into account:

- **Dilatation of the elasticity domain**
- **Evolution of criterion is governed by a single scalar (internal state variable: cumulated plastic strain)**

General concepts : kinematic hardening



$$f(\sigma, p) = \left\| \underline{\underline{\sigma}}^D - \underline{\underline{X}} \right\| - \sigma_y$$

An translation of the elasticity domain is taking into account:

- **Translation of the elasticity domain**
- **Evolution of criterion is governed by a tensor (internal state variable: centre of the elasticity domain)**

General concepts : final system to solve

Partition of strains	$\underline{\underline{\varepsilon}}=\underline{\underline{\varepsilon}}^{e}+\underline{\underline{\varepsilon}}^{p}$	
Elastic strains	$\underline{\underline{\sigma}}=\lambda.tr(\underline{\underline{\varepsilon}}^{e})+2\mu.\underline{\underline{\varepsilon}}^{e}$	
Plasticity criterion	$f(\underline{\underline{\sigma}},p)=\sqrt{\frac{3}{2}}\left\Vert\underline{\underline{\sigma}}^{D}\right\Vert-R(p)-\sigma^{y}$	$f(\underline{\underline{\sigma}},p)=\left\Vert\underline{\underline{\sigma}}^{D}-\underline{\underline{X}}\right\Vert-\sigma_{y}$
Flow law (normality)	$\dot{\underline{\underline{\varepsilon}}}^{p}=\sqrt{\frac{3}{2}}\dot{p}\frac{\underline{\underline{\sigma}}^{D}}{\left\Vert\underline{\underline{\sigma}}^{D}\right\Vert}$ $\begin{cases}\dot{p}>0 \text{ if } f(\underline{\underline{\sigma}},p)=0\\ \dot{p}=0 \text{ if } f(\underline{\underline{\sigma}},p)<0\end{cases}$	$\dot{\underline{\underline{\varepsilon}}}^{p}=\sqrt{\frac{3}{2}}\dot{p}\frac{\underline{\underline{\sigma}}^{D}-\underline{\underline{X}}}{\left\Vert\underline{\underline{\sigma}}^{D}-\underline{\underline{X}}\right\Vert}$
Material parameters	$R(p)$	C $\underline{\underline{X}}=C\dot{\underline{\underline{\varepsilon}}}^{p}$

SOLVING BEHAVIOUR LAWS

Solving behaviour law

Algorithm:

1. **Define functional**
2. **Solve functional**

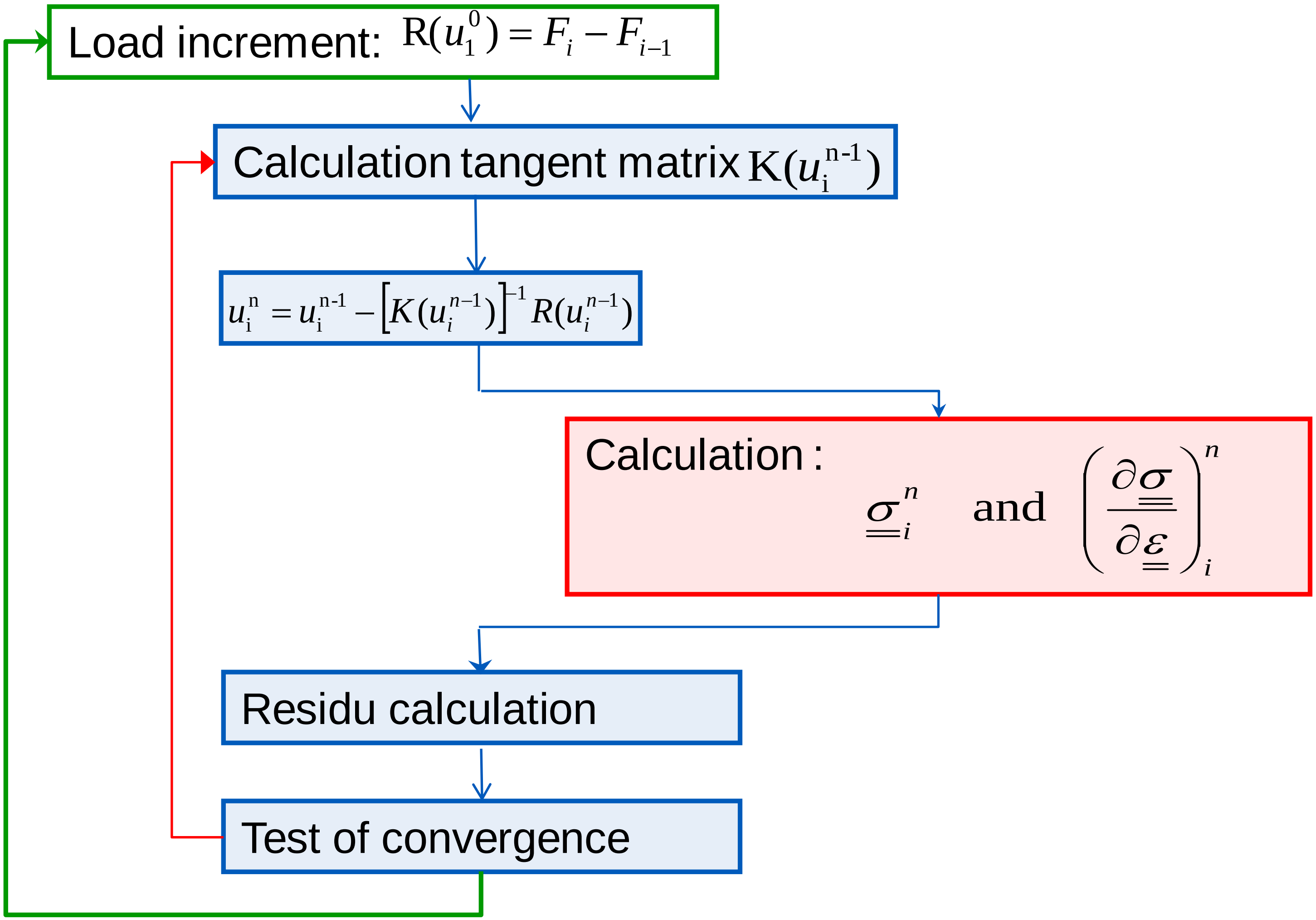
Behaviour law is a functional for stress from strains, external state variables (temperature…) and internal state variables

$$\underline{\underline{\sigma}} = F\left(\underline{\underline{\varepsilon}}, T, V_k\right)$$

Newton's method: need jacobian too !

$$\left(\frac{\partial \underline{\underline{\sigma}}}{\partial \underline{\underline{\varepsilon}}}\right)$$

Solving behaviour law



Solving behaviour law

- From ODE equations => time discretization
  - Implicit choice: stability
  - The choice of the time step depends on the radial nature of the problem
  - Unknown variables at time step: incremental scheme for stress

$$\left(\Delta \underline{\underline{\varepsilon}}, V_k^-\right) \underset{F_\sigma}{\Rightarrow} \Delta \underline{\underline{\sigma}} \Rightarrow \underline{\underline{\sigma}}^+ = \underline{\underline{\sigma}}^- + \Delta \underline{\underline{\sigma}}$$

  - Scheme for internal state variables

$$\left(\Delta \underline{\underline{\varepsilon}}, V_k^-\right) \underset{F_V}{\Rightarrow} V_k^+$$

Incremental choice for stress update: only for small strains!

F_V and F_σ are non-linear functionals to solve

Solving behaviour law: example of algorithm

Test : $\sqrt{\frac{3}{2}}\left\| \underline{\underline{\sigma}}^{D^-} + \Delta\underline{\underline{\sigma}}^{D} \right\| < R(p^-) + \sigma^y$

$$\Delta\underline{\underline{\sigma}}^{D} = 2\mu\Delta\underline{\underline{\varepsilon}}^{D} + 3Ktr\left(\Delta\underline{\underline{\varepsilon}}\right)$$

Oui

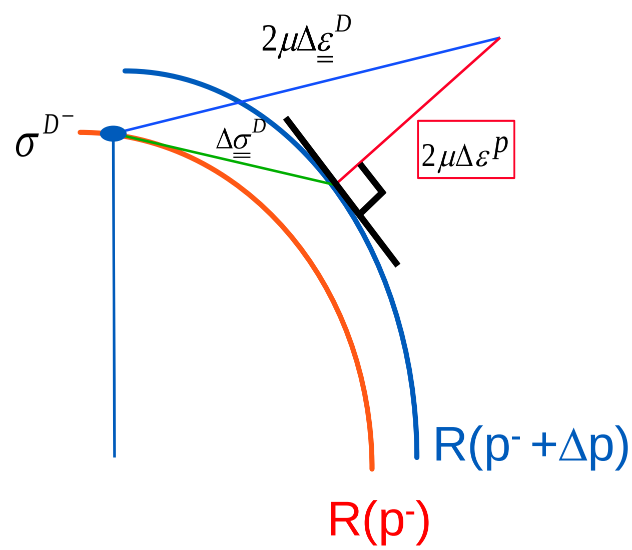
$$\Delta p = 0$$

$$\Delta\underline{\underline{\varepsilon}}^{p} = 0$$

Non

$$\Delta p = \sqrt{\frac{3}{2}}\,\frac{2\mu}{3\mu + R'(p)}\,\frac{\underline{\underline{\sigma}}^{D^-}}{\left\|\underline{\underline{\sigma}}^{D^-}\right\|} : \Delta\underline{\underline{\varepsilon}}$$

$$\Delta\underline{\underline{\varepsilon}}^{p} = \sqrt{\frac{3}{2}}\,\underline{\underline{n}}\,\Delta p$$



$$\underline{\underline{\varepsilon}}^{p^+} = \underline{\underline{\varepsilon}}^{p^-} + \Delta\underline{\underline{\varepsilon}}^{p}$$

$$p^+ = p^- + \Delta p$$

$$\underline{\underline{\sigma}}^{+} = 2\mu\left(\underline{\underline{\varepsilon}}^{D} - \underline{\underline{\varepsilon}}^{p^+}\right) + 3Ktr\left(\underline{\underline{\varepsilon}}\right)$$

Solving behaviour law

- Depending of F_V and F_σ
  - (pseudo)-time integration: implicit or explicit (code_aster: mainly implicit)
  - Non-linear solving: Newton's method, line-search, …
  - Warning ! Hypothesis to solve non-linear equation !
    - Implicit algorithm => unconditional stability BUT when solve ODE using RADIAL hypothesis of loads
  - Parameters for non-linear solving of behaviours laws:
    - In the `COMPORTEMENT` keyword
    - Sometimes, you can choose local non-linear algorithm to solve

Integration of constitutive laws: sum up

- General non-linear algorithm:
  - In practice, only a few laws in *code_aster*
  - Solving the NL local system of *n* equations
  - Explicit method (Runge-Kutta) or implicit method (Newton)
- Specific non-linear algorithms:
  - For some laws (in fact, most of the laws in *code_aster*!)
  - The system is reduced to one single scalar equation
  - Solved by various methods (secant, Newton, Dekker, Brent)
  - Analytical solution for some laws (ex: Von Mises isotropic hardening and / or linear kinematic)

BEHAVIOUR LAWS IN CODE_ASTER

Constitutive laws available

- More than 160 laws in the 13 stable version

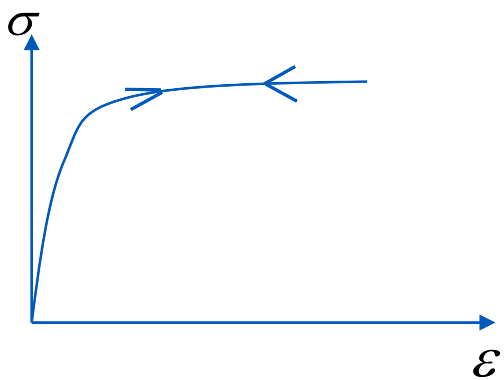
- Various fields of applications
  - Metals, polycrystalline metals
  - Concrete
  - Soils

- Various phenomena
  - Irradiation
  - Damage or cracking
  - Metallurgical phases

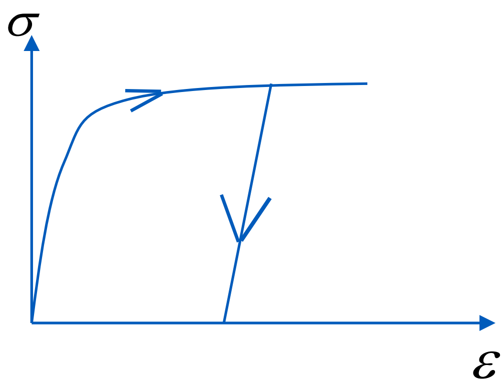
- Documentation
  - Synthesis of non-linear constitutive laws: U4.51.11
  - **DEFI_MATERIAU** syntax: U4.43.01

Constitutive laws available

- 2D and 3D continuum media
  - Non linear elasticity
    - Von Mises isotropic Pseudo-hardening
      - **ELAS_VMIS_LINE**
      - **ELAS_VMIS_TRAC**
      - **ELAS_HYPER**



  - Incremental elasto-plasticity
    - Von Mises isotropic hardening, kinematic linear, mixed
      - **VMIS_ISOT_TRAC**
      - **VMIS_ISOT_PUIS**
      - **VMIS_ISOT_LINE**
      - **VMIS_CINE_LINE**
      - **VMIS_ECMI_TRAC**
      - **VMIS_ECMI_LINE**



Constitutive laws available

- 2D and 3D continuum media (cont.)
  - Other elastoplastic models (metals)
    - **VMIS_CIN1_CHAB**
    - **VMIS_CIN2_CHAB**
    - **VMIS_CIN2_MEMO**
  - Polycrystalline metals
    - **POLY_CFC**
    - **MONOCRISTAL**
    - **POLYCRISTAL**
  - Elasto-visco-plasticity (metals)
    - **LEMAITRE, LEMA_SEUIL**
    - **VISC_CIN1_CHAB**
    - **VISC_CIN2_CHAB**
    - **VISC_ISOT_LINE**
    - **VISC_ISOT_TRAC**
    - **VISC_TAHERI**
    - **VISCOCHAB**
  - Limit loads
    - **NORTON_HOFF**
  - Elasto-visco-plasticity under irradiation
    - **LMARC**
    - **LEMAITRE_IRRA**
    - **GATT_MONNERIE**
    - **VISC_IRRA_LOG**
    - **GRAN_IRRA_LOG**
    - **IRRAD3M**

Constitutive laws available

- 2D and 3D continuum media (cont.)
  - Damage or cracking of metals
    - **ENDO_FRAGILE**
    - **VENDOCHAB**
    - **ROUSSELIER**
    - **ROUSS_PR**
    - **ROUSS_VISC**
    - **RUPT_FRAG**
    - **BARENBLATT**
  - Metallurgical phases (elasto-visco-plastic) for steel or zirconium
    - **META_X_Y_Z**
    - **X = P** (plasticity) or **V** (viscosity)
    - **Y = IL** (linear isotropic) or **INL** (nonlinear isotropic) or **CL** (linear kinematic)
    - **Z = RE** (restoration) and/or **PT** (transformation plasticity)
  - Concrete
    - **BETON_DOUBLE_DP**
    - **GRANGER_FP**
    - **GRANGER_FP_V**
    - **GRANGER_FP_INDT**
    - **BAZANT_FP**
    - **ENDO_ISOT_BETON**
    - **ENDO_ORTH_BETON**
    - **MAZARS**
    - **JOINT_BA**
    - **CORR_ACIER**
    - **KIT_DDI**
    - **BETON_REGLE_PR**
    - **BETON_UMLV_FP**
    - **BETON_BURGER_FP**
    - **BETON_RAG**

Constitutive laws available

- 2D and 3D continuum media (cont.)
  - Soils and geomaterials
    - **DRUCK_PRAGER(N_A)**
    - **CAM_CLAY, BARCELONE**
    - **CJS, HUJEUX**
    - **LAIGLE, LETK**
    - **HOEK_BROWN**
    - **KIT_HM, KIT_HHM, KIT_THH, KIT_THM, KIT_THHM**
- Plates, shells and pipes (local behaviour = plane stress)
  - All 3D constitutive laws (thanks to the method if **C_PLAN** is not supported: **ALGO_C_PLAN = 'DEBORST'**)
- Bars, multi-fiber beams, grids
  - All the laws of 1D behaviour (thanks to the DeBorst method if **1D** is not supported: **ALGO_1D = 'DEBORST'**)
- Discrete elements, shear connections, reinforcements

SYNTAX IN CODE_ASTER

Syntax for the constitutive laws integration

- Choice of parameters for the integration:
  - under the factor key word **COMPORTEMENT**
- General algorithm:
  - Resolution of the local NL system of n equations
  - **ALGO_INTE =**

<table>
<tr><td>Explicit resolution</td><td colspan="2">Implicit resolution by a local Newton, with the possibility of LInear REsearch for certain laws</td></tr>
<tr><td>RUNGE_KUTTA</td><td>NEWTON</td><td>NEWTON_RELI</td></tr>
<tr><td>VISCOCHAB, VENDOCHAB, POLYCRISTAL, MONOCRISTAL VMIS_POU_FLEJOU, VMIS_POU_LINE</td><td>VISCOCHAB, LMARC, MONOCRISTAL, IRRAD3M, CJS, HUJEUX…</td><td>VISCOCHAB, LMARC, MONOCRISTAL, IRRAD3M</td></tr>
</table>

Syntax for the constitutive laws integration

- General algorithm:
  - Convergence
    - Residue to achieve: **RESI_INTE_RELA (10^{-6})**
    - Maximum number of iterations: **ITER_INTE_MAXI (20)**
  - Tips
    - For behaviour which are "difficult" to integrate, increase **ITER_INTE_MAXI**
      - ssnd105b where **ITER_INTE_MAXI = 250** for **VISCOCHAB**
      - ssnv172a where **ITER_INTE_MAXI = 100** for **MONOCRISTAL**
      - ssnl106i where **ITER_INTE_MAXI = 500** for **VMIS_POU_LINE**
    - For certain behaviours, it is better to integrate finely the behaviour (ex: Hujeux) **RESI_INTE_RELA =10^{-8}**

Syntax for the constitutive laws integration

- Specific algorithms:
  - For some laws (in fact, most of the laws in *code_aster* !)
  - The system is reduced to one single scalar equation $\Delta\lambda : \gamma(\Delta\lambda) = 0$
  - Solved by various methods:
    - **ALGO_INTE = 'SECANTE', 'DEKKER', 'NEWTON_1D', 'BRENT'**
    - Convergence: **RESI_INTE_RELA (10^{-6}), ITER_INTE_MAXI (20)**
  - Analytical resolution
    - **VMIS_ISOT_LINE, VMIS_ISOT_TRAC, VMIS_ISOT_PUIS,**…
    - **CZM_*, ENDO_SCALAIRE,**…
    - No additional keyword is required ! (except for plane stresses)
    - Ex: hsnv125a: **VMIS_ISOT_LINE** in 3D and ~~**ITER_INTE_MAXI**~~ **= 100**

INCOMPRESSIBILITY

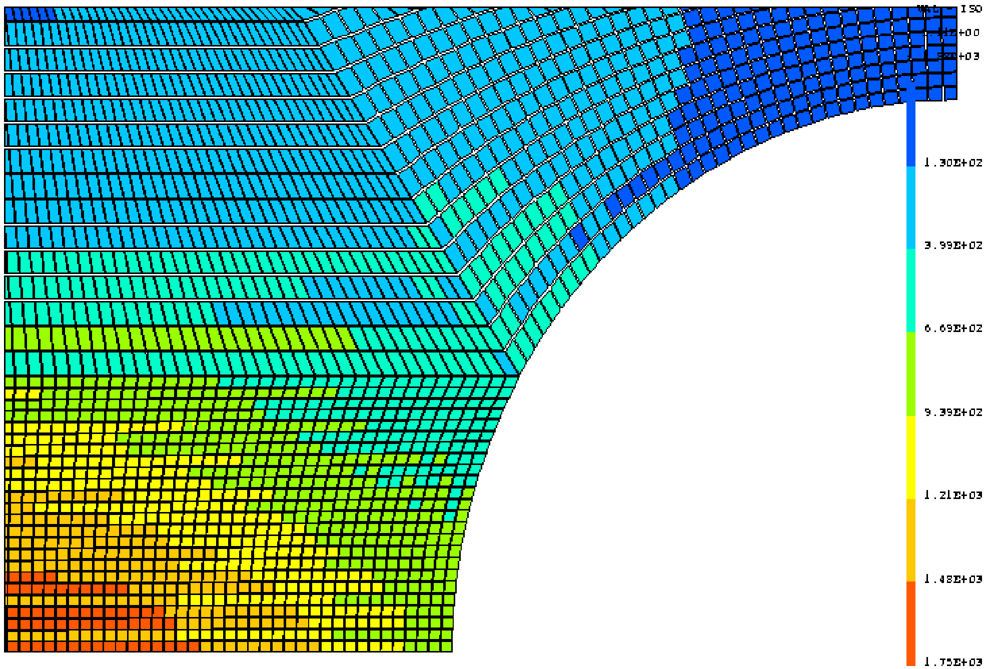
Quasi-incompressibility

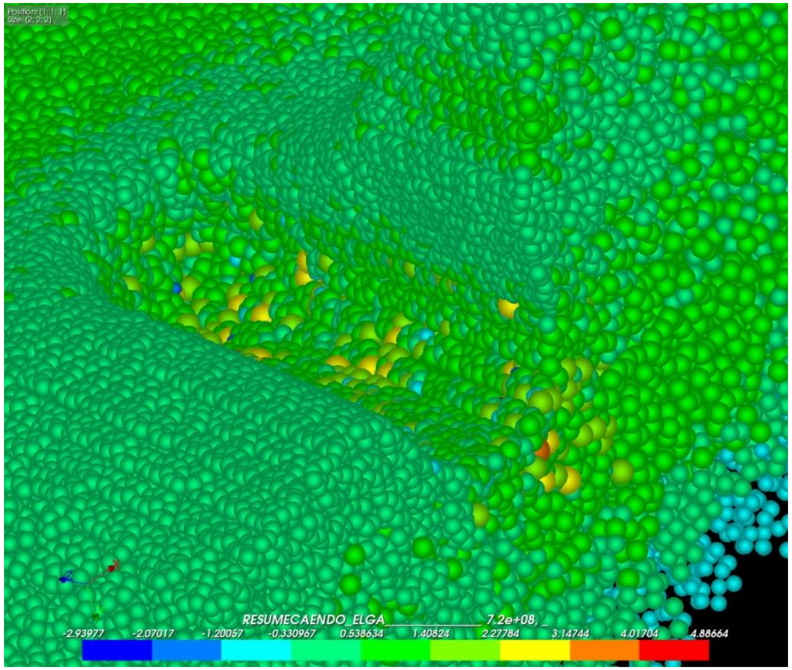
- For special choice of Poisson ratio
  - Example: hyperelasticity (for elastomer)

$$\upsilon \approx 0.5$$

- In case of high level of plasticity (generalized plasticity)
  - Plastic flow at constant volume implies incompressibility condition
  - Numerical consequences
    - Too rigid behaviour
    - Possibility of oscillations of the stress (fluctuation on the tensor trace)

Quasi-incompressibility





Notched specimen: σ_{yy}

Scour at the rib foot of a valve: $Tr(\sigma)/\sigma_{eq}$

Quasi-incompressibility

- Two solutions:
  - Sub-integration
  - Quasi-incompressible model
- Sub-integration
  - Integrals evaluated numerically (Gauss): $$\int_{\Omega_e} f(x)\,d\Omega = \sum_{i=1}^{npg} f(\xi_i)\,\omega_i$$
  - Choice of sub-integrated finite elements in **AFFE_MODELE**: **3D_SI**, **AXIS_SI**, **D_PLAN_SI**, **C_PLAN_SI**

In 2D:	**QUAD4**	1 Gauss point instead of 4
In 2D:	**QUAD8**	4 Gauss points instead of 9
In 3D:	**HEXA20**	8 Gauss points instead of 27

Linear cell with sub-integration: hourglass control required

Quasi-incompressibility

Quasi-incompressible formulations

- Mixed formulation with 2 or 3 fields:
  - Fields: displacement, volumetric strain and the associated Lagrange multiplier (which would correspond to the pressure in the incompressible case).
- Two fields for quadratic cells: `3D_INCO_UP`, `D_PLAN_INCO_UP`, `AXIS_INCO_UP`
- Two fields for linear cells (OSGS stabilization or “bubble” function): `3D_INCO_UPO`, `D_PLAN_INCO_UPO`, `AXIS_INCO_UPO`
- Three fields only for quadratic cells: `3D_INCO_UPG`, `D_PLAN_INCO_UPG`, `AXIS_INCO_UPG`

R3.06.08: Finite elements dealing with the quasi-incompressibility

- Remarks:
  - Formulation very effective, but a little more "expensive"
  - Led to non-positive matrices solver: MUMPS has to be preferred

KINEMATIC HYPOTHESIS

Models of small deformations

- **DEFORMATION = 'PETIT'**
  - HPP (assumption of small perturbations, french abbreviation)
  - everything is small! Lagrangian description = Eulerian description
- **DEFORMATION = 'GROT_GDEP'**
  - Large displacement & rotation
  - Green-Lagrange strains ⬄ Piola-Kirchhoff stresses in initial configuration
  - pure hyper-elastic media (linear or nonlinear elasticity? rubber!)
  - hpp: all other behaviours + large displacements and rotations
- **DEFORMATION = 'PETIT_REAC'**
  - Approximation of large strains
  - Small strains with geometry update at each iteration: order 2 terms are neglected
  - Total deformation = sum of linearized strain increments based on different configurations. Physical sense?
  - Stresses: simple time derivation => not objective i.e. not rigid rotation invariance of the structure => **PETIT_REAC** is not suitable for large rotations
  - Approximation valid only for very small time increments, quasi-radial loading, elastic deformation small compared to plastic deformation
  - Absence of geometric contribution to the tangent matrix

Models of small deformations

- **DEFORMATION = 'SIMO_MIEHE'**
  - Comprehensive approach of large deformations
  - Elastic deformations are measured in the current configuration (deformed)
  - Plastic deformations are measured in the initial configuration
  - Model incrementally objective: exact solution in the presence of large rotations. Very robust, quadratic convergence.
  - Requires specially adapted behaviour laws: elasto-(visco)-plasticity isotropic hardening von Mises, Rousselier.
- **DEFORMATION = `GDEF_LOG'**
  - Another approach of large deformations: Logarithmic deformations (Miehe & Apel)
  - Used with all HPP laws (kinematic, anisotropy, **C_PLAN** ...)
  - Costs more CPU time than **SIMO_MIEHE**

Conclusion

Documentation

- Utilisation
  - U4.51.11: synthesis of non-linear behaviour
  - U4.43.01: syntax of the command **DEFI_MATERIAU**
- Reference
  - R5.03.02: integration of isotropic hardening or kinematic linear laws
  - R5.03.03: taking into account the plane stresses
  - R5.03.XX: integration of other behaviours
  - R5.03.14: implicit and explicit integration of nonlinear laws
  - R5.03.03: Hypothesis of plane stresses in non-linear behaviours
  - R3.06.08: Finite elements dealing with the quasi-incompressibility
  - R5.03.21: Elasto(visco)plastic modelling with isotropic hardening in large strains (**SIMO_MIEHE**)
  - R5.03.22: Behaviour law in large rotations and small deformations (**GROT_GDEP**)
  - R5.03.24: Models for large deformations **GDEF_LOG**

End of presentation

Is something missing or unclear in this document?
Or feeling happy to have read such a clear tutorial?

Please, we welcome any feedbacks about *Code_Aster* training materials.
Do not hesitate to share with us your comments on the *Code_Aster* forum dedicated thread.