Identification of a Delay-Damaged Mesomodel for the Localization and Rupture of Composites: Feasibility and Identification Strategy

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Outline of the presentation

Damage meso-modelling of laminates :

Basic aspects
Example of application
Extension to dynamics and identification issues

Identification issues and associated strategy

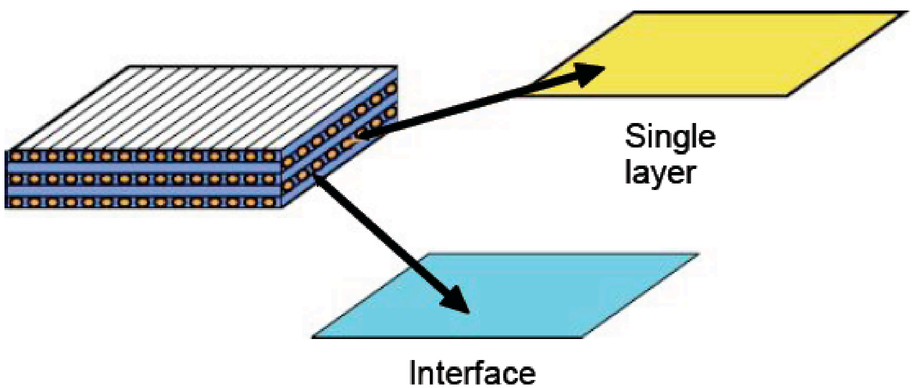
Identification difficulties of a rate damg model for localization
Proposed formulation
First results

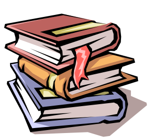
Perspectives

Damage meso-modelling of laminates: basic aspects

Meso-scheme: a laminate = ply + interfaces

Damage mechanims :
internal meso-damage variables
(meso: uniform throughour each ply)

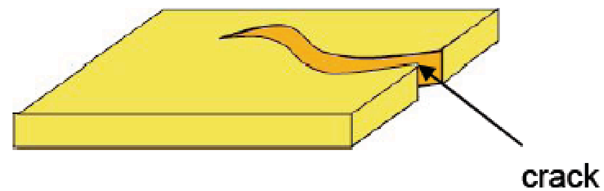




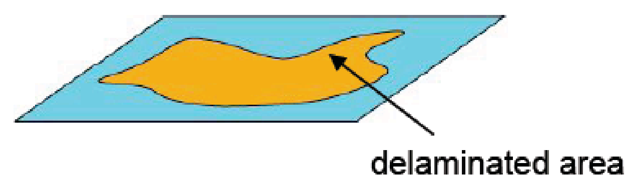
Ladevèze (86-92), De Borst 92

Type of cracks after localization

Concerning the layer



Concerning the interface
(surface mechanical model)



Ladevèze,Ledantec 92, Allix-Ladevèze-Vittecoq 92

Use of Hoenig-Delameter paper on periodic crack oriented array 1974

Elastic energy (plane stresses)

$$e_d = \frac{1-d_f}{2}\left[\frac{\langle\tilde{\sigma}_{11}\rangle_+^2}{E_1^0} + \frac{\phi\left(\langle\tilde{\sigma}_{11}\rangle_-^2\right)}{E_1^0} - \left(\frac{\nu_{12}^0}{E_1^0} + \frac{\nu_{21}^0}{E_2^0}\right)\tilde{\sigma}_{11}\tilde{\sigma}_{22}\right] + \frac{1-d'}{2}\left[\frac{\langle\tilde{\sigma}_{22}\rangle_+^2}{E_2^0}\right] + \frac{1}{2}\left[\frac{\langle\tilde{\sigma}_{22}\rangle_-^2}{E_2^0}\right] + \frac{1-d}{2}\left[\frac{\tilde{\sigma}_{12}{}^2}{G_{12}^0}\right]$$

$$\tilde{\sigma} = K_0\left[\epsilon + \epsilon_0\right]$$

- opening and closure of microcracks
- specific behaviour in compression for the fiber direction

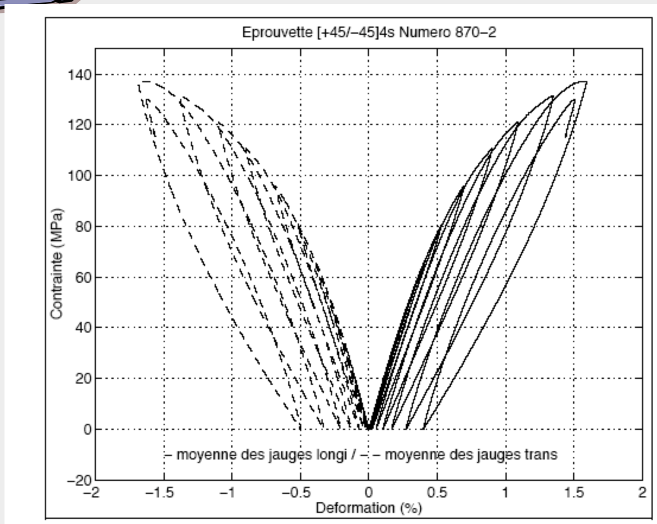
Damage kinematic (stiffness variation)

d_f: fracture of the fiber

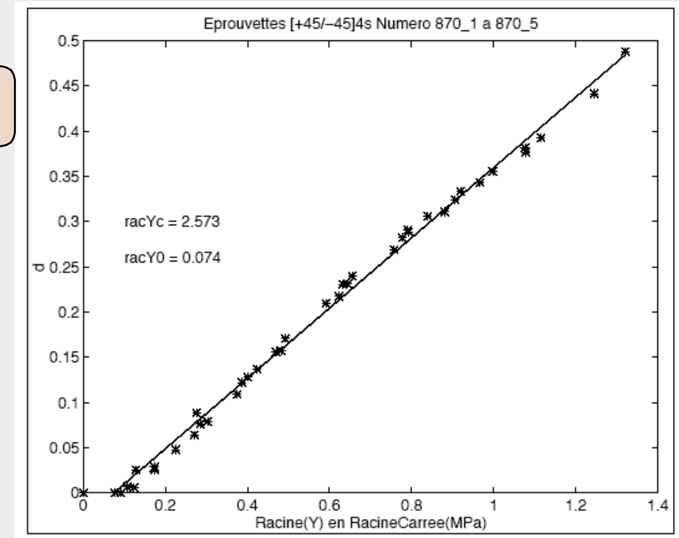
d, d': microcraking of the matrix and matrix/fiber debonding

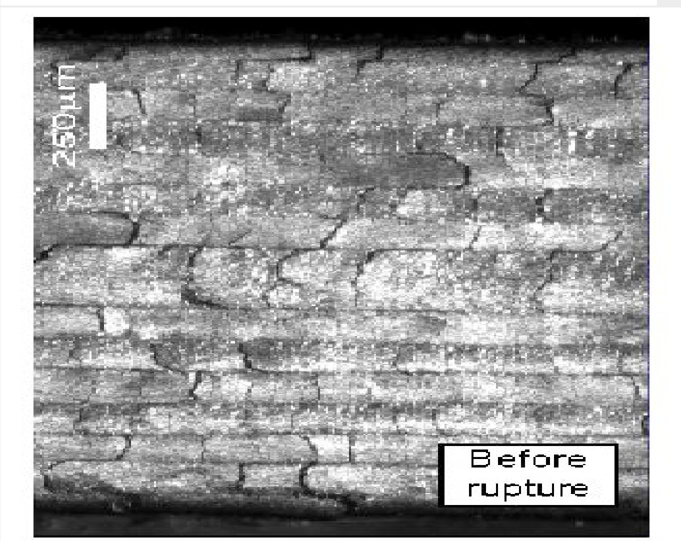
- constant within the thickness of the ply

« Mechanics of Fibrous Composite », Herakovich CT

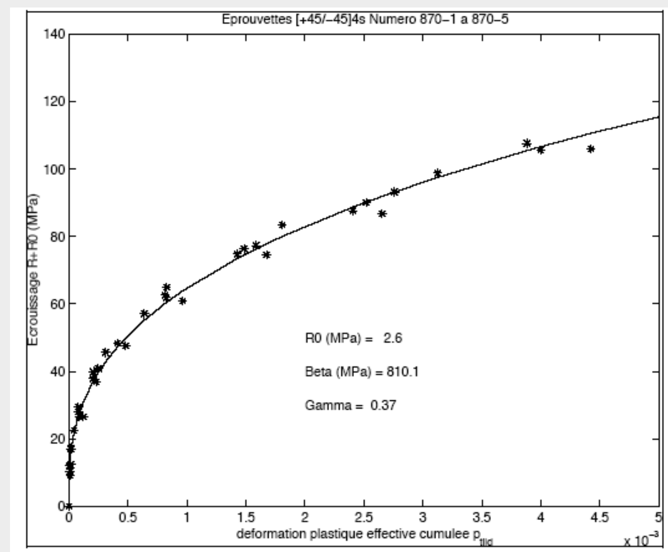


d master curve





Inelasticity
master curve



Material M18/M55J example from Allix-Lévéque 98

A look on the interface model identification

Link between fracture Mechanics and Damage Mechanics of the interface

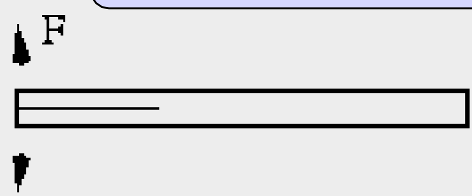
Comparison of the critical energy release rate →

$$G_{cI}^{p} = Y_c;\; G_{cII}^{p} = \frac{Y_c}{\gamma_1}\;;\; G_{cIII}^{p} = \frac{Y_c}{\gamma_2} \quad \text{and} \quad \left(\frac{G_I}{G_{cI}^{p}}\right)^{\alpha} + \left(\frac{G_{II}}{G_{cII}^{p}}\right)^{\alpha} + \left(\frac{G_{III}}{G_{cIII}^{p}}\right)^{\alpha} = 1$$

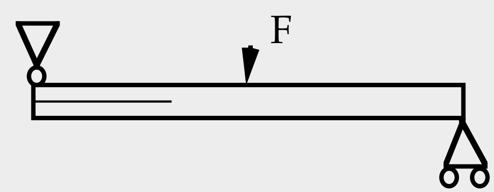
Pure mode

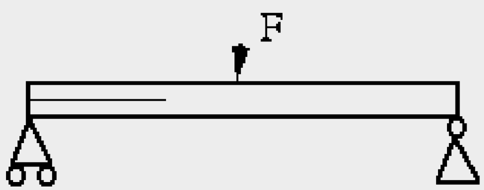
Mixte mode

Utilization of standard Fracture Mechanics test for 0°, 22°.5 45° interfaces



Mode I:DCB





Mode II:ENF

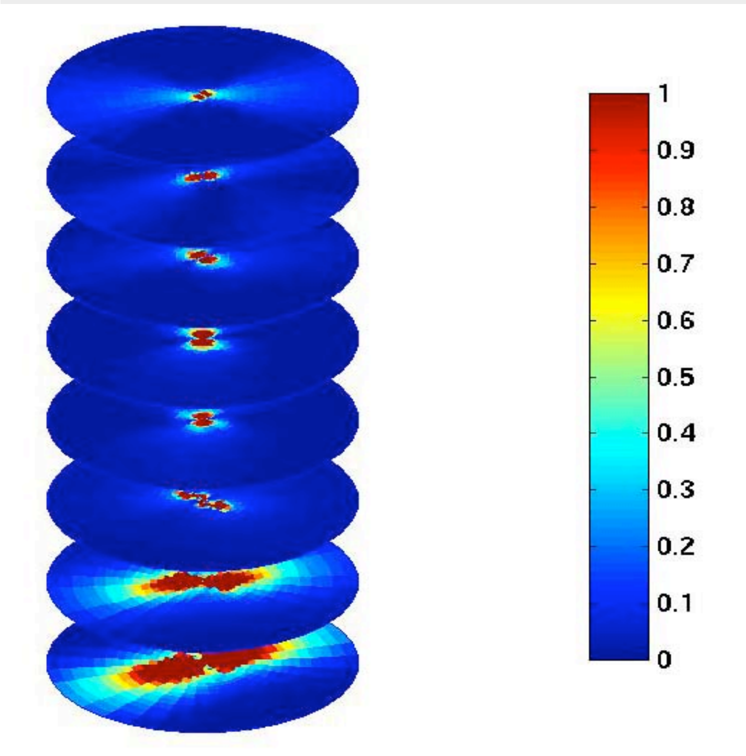
Mixte mode: MMF

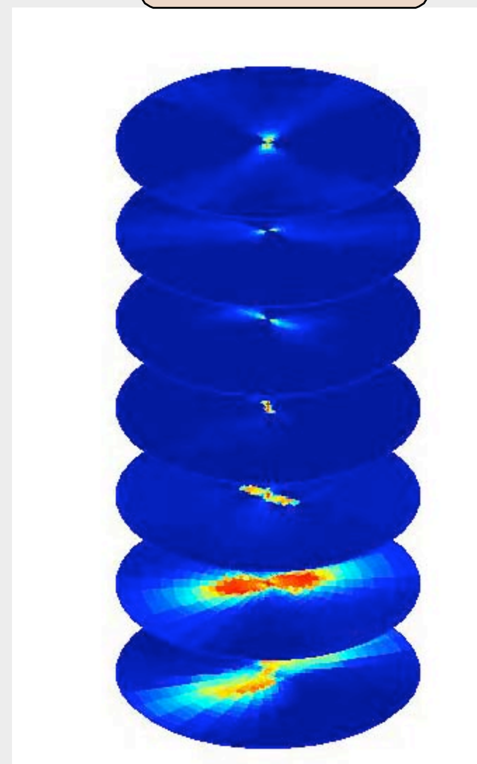
Test conducted at EADS CCR

Allix-Guinard (2000)

Ply

Interface



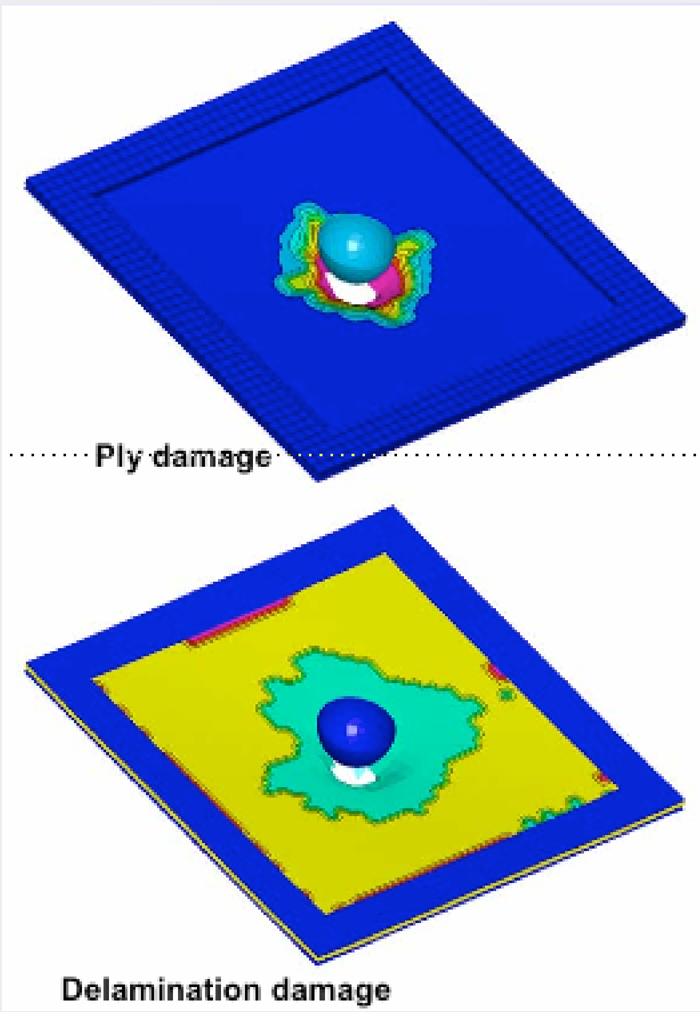


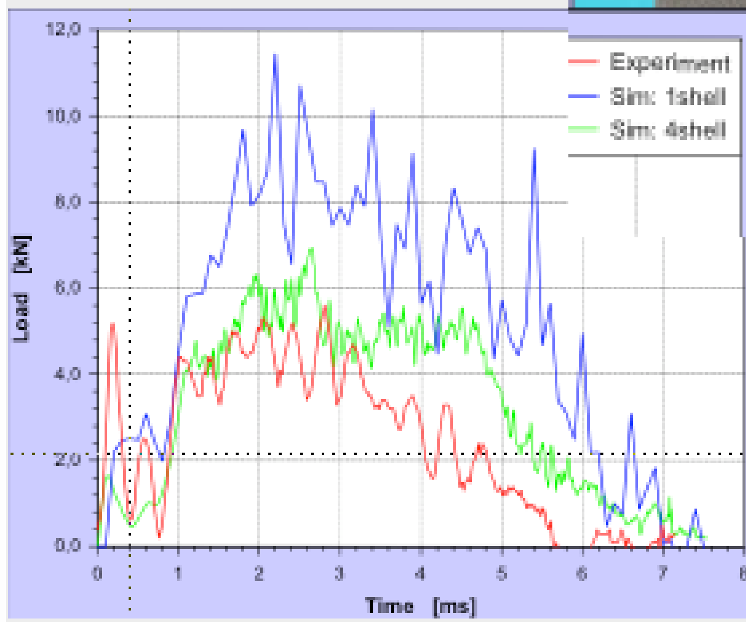
d_{ply} Cumulated ply damage

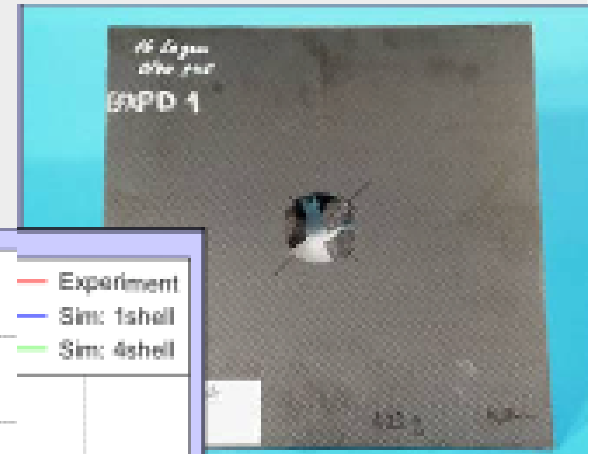
d_{int}

Numerical prediction of double-helix delamination for a T300/914
Quasi-isotropic 8 plies for 15J impact

Example of a low velocity-impact Courtesy of A Johnson DLR







Extension to dynamic loading of the damage meso-model

An objective prediction of the rupture:

Non local damage model (Bazant- Pijaudier 87 ...)
Second gradient approach (Lasry-Belytscko 88, DeBorst-Mülhaus 92 ...)
Rate dependent damage model (Needleman 88, Loret-Prevot 92 …)

Physically suited to carbon/epoxy laminates:

Meso model (Ladevèze 89)
Damage Model with bounded rate (Allix Deü 98)

Damage Model with bounded rate

The damage is not instantaneous :"delayed" compared to the static case

A maximum damage rate exists **$1/\tau_c$**

$$\dot{d} = \frac{1}{\tau_c}[1 - \exp[< f(Y) - d >_+], \;\; d \leq 1$$

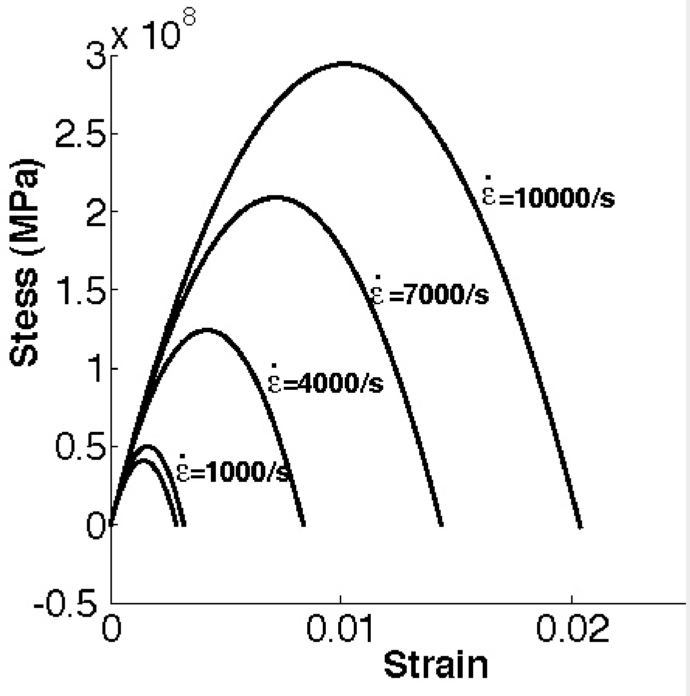
d= f(Y) « static law »

τ_c and a are material constants that govern the rupture process

τ_c is a characteristic time

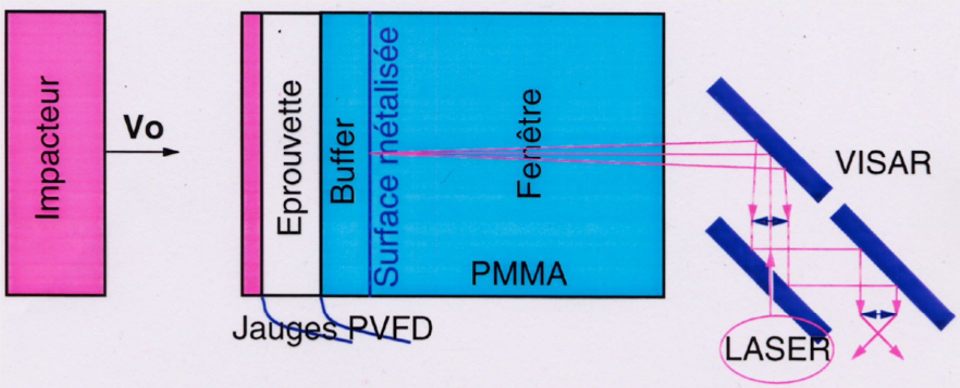
e thickness of the ply

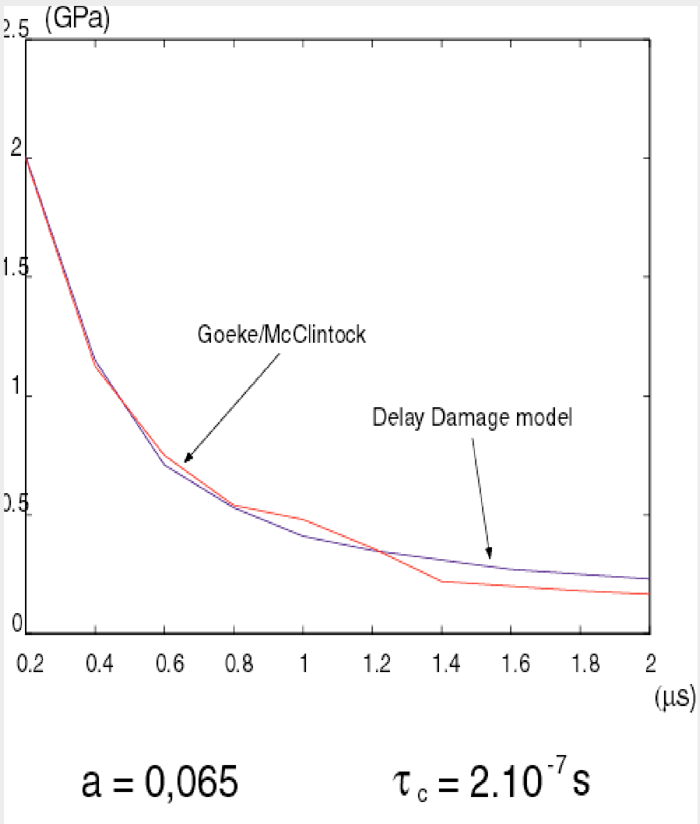
$$\tau_c = 0(\frac{e}{c_r}) \approx 1\mu s$$



c_r Rayleigh wave speed of the matrix

Possible identification for 3D-Composites or Metallic Materials

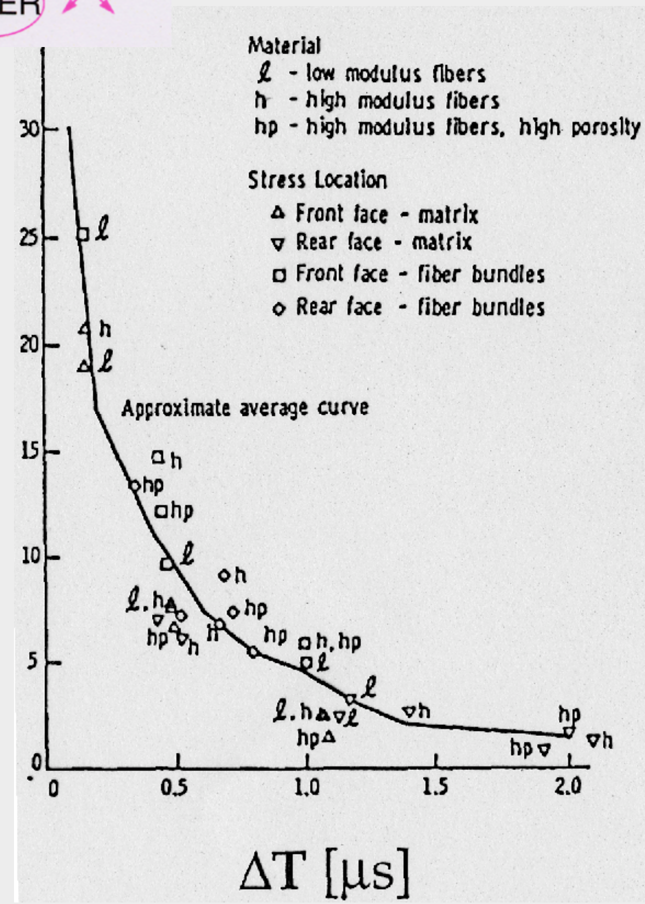




Identification of $1/\tau_c$ Plate-Plate experiments

Carbon/Carbon (Allix-Sen-Gupta 98-2003)

Metallic material Combescure-Suffis 2004



Possible identification for 2D-Composites

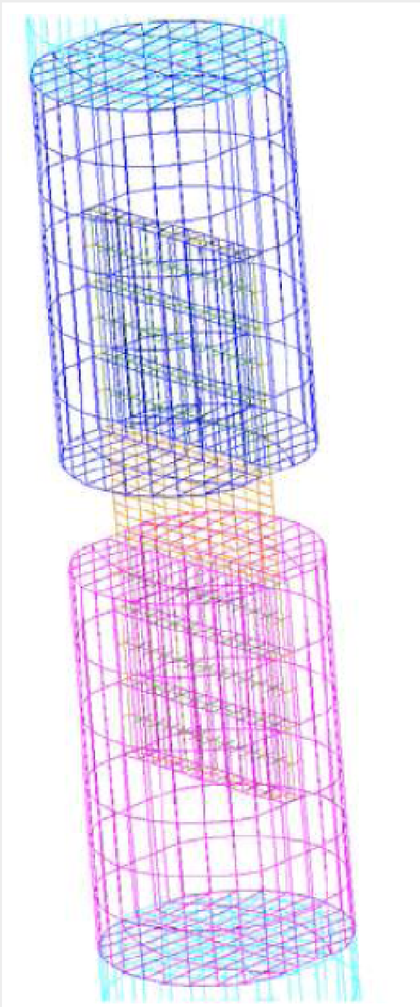
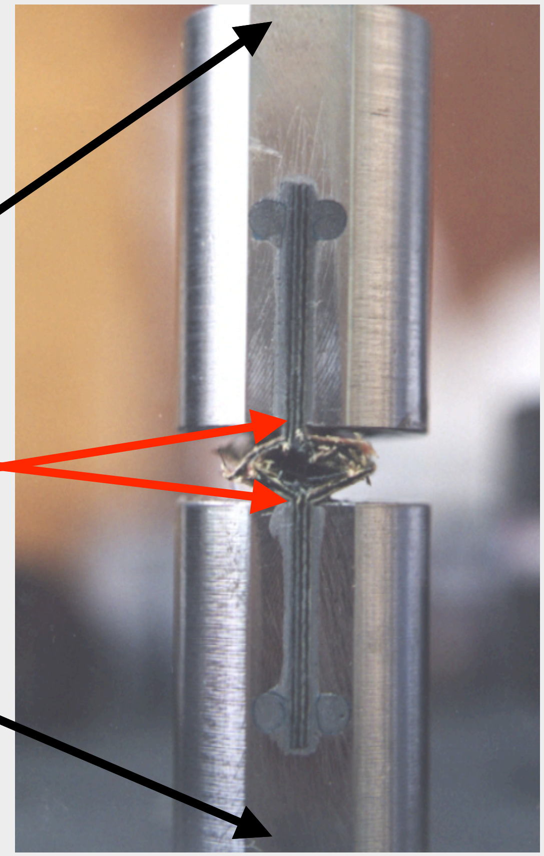


Plate-Plate experiments not adapted to laminates -> Hopkinson bar test

Measurement of F and V deduced by strain gages on the bars



- Test with localization of damage -> strongly heterogeneous
- Rupture in dynamics -> strong corruption of the boundary conditions

Position of identification problem with uncertain boundary conditions

The problem of the influence of the noise on measurements
Is known to be a key question :

Usually a model of the noise is used

Kalman filter Maier, Corgliano …
Tykhonov regularization, Orkicz …
Iterative Tykhonov regularization Cimetiere
Influence of the choice of the norm (Deramaeker-Ladevèze …)

In the test which are considered there is no a priori information about the noise and its level which can be very high

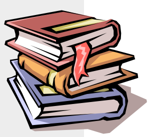
---> corrupted measurements

Behaviour of identification method with uncertain boundary conditions

Method proposed by *Rota*

- **In order to recover a well-posed problem,**

some equations have to be released:



↪ Split into two auxiliary problems [*Rota*]

$\tilde{u}^e_d$, $\tilde{f}^e_d$ | **E ?** | $\tilde{u}^s_d$, $\tilde{f}^s_d$

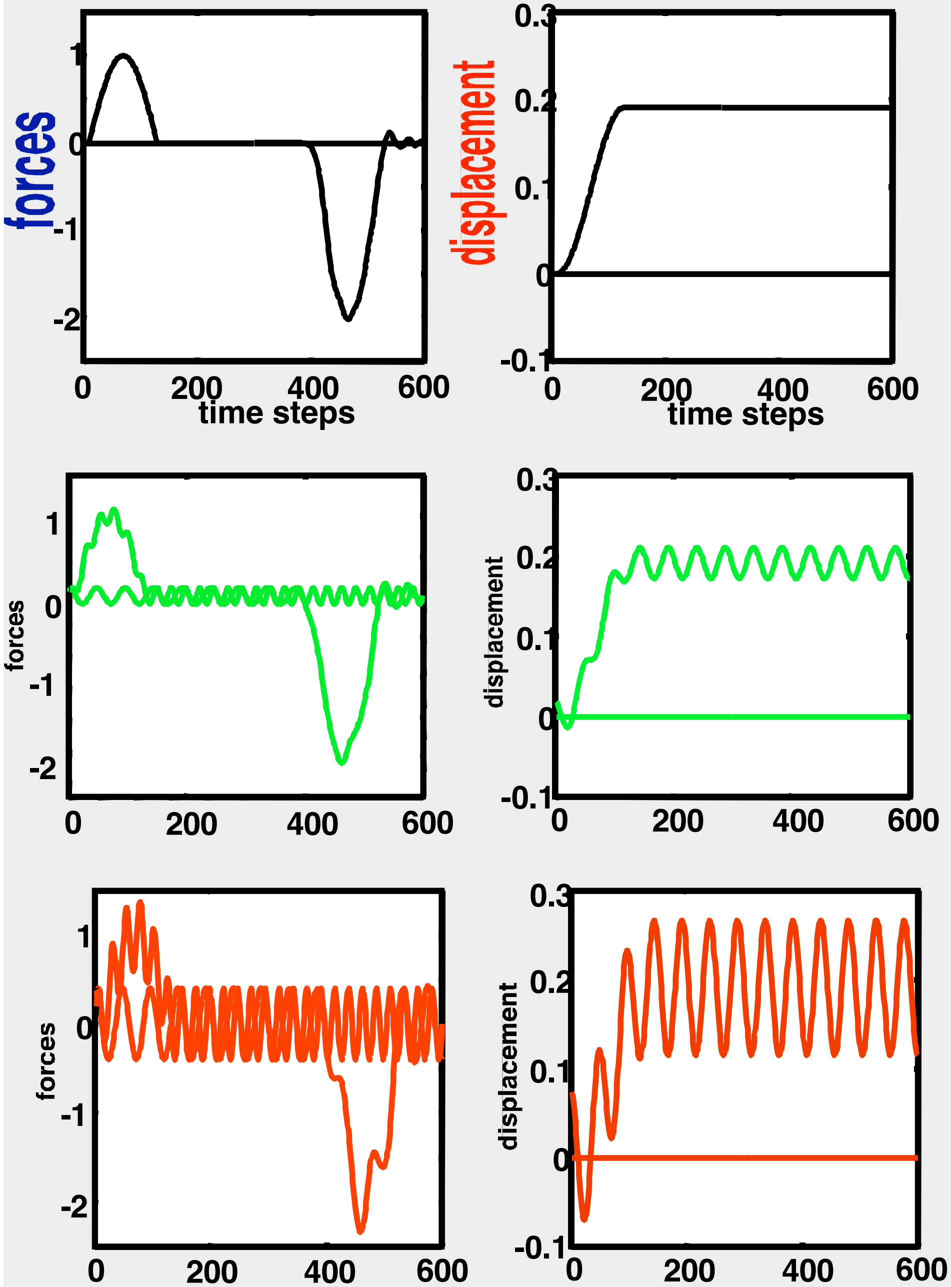
Prescribed displacements	Prescribed forces
$\tilde{u}^e_d$ | E | $\tilde{u}^s_d$	$\tilde{f}^e_d$ | E | $\tilde{f}^s_d$
↪ yields a solution field: $u_{CA}(E)$	↪ yields a solution field: $u_{SA}(E)$

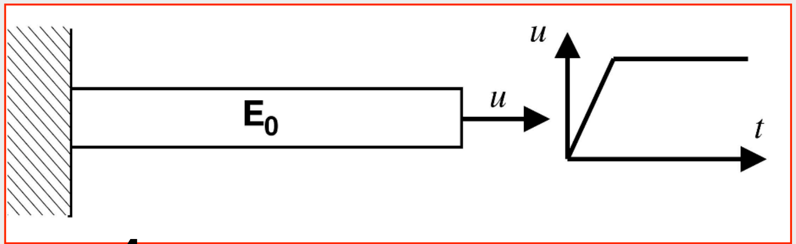
definition of a distance between the two calculations : $e(u_{CA}(E), u_{SA}(E))$

- **The identification becomes :**

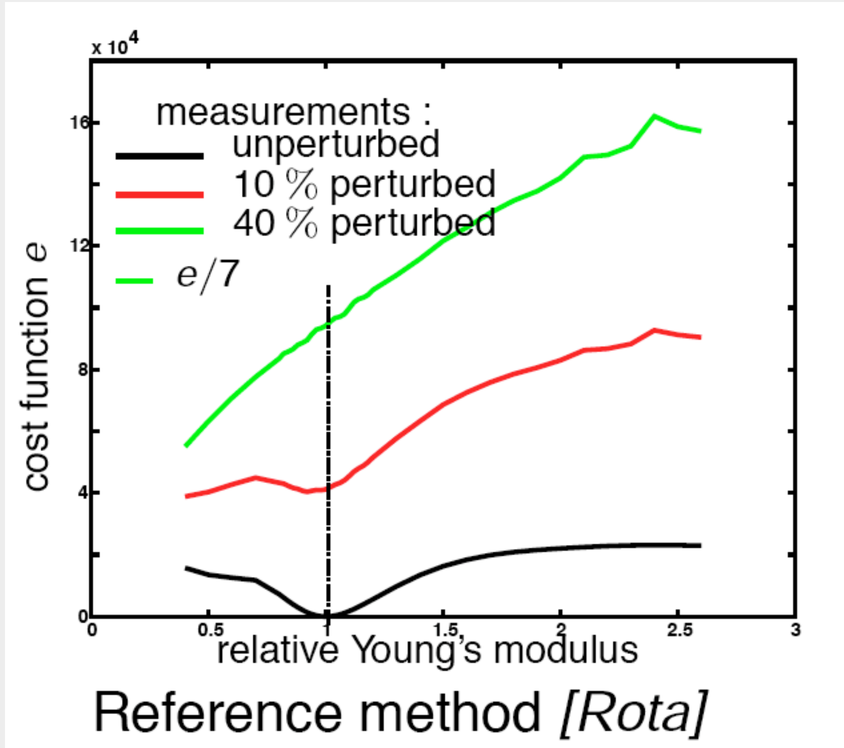
$$\min_E C(E) = \min_E e(u_{CA}(E), u_{SA}(E))$$

Results as a function of the level of corruption

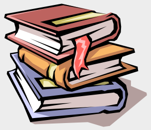




Error x 10^4



Error function of E/E_0



Allix, Feissel (2002)

Remark on the previous method

- There are multiple ways to split the experimental information
- Experimental corrupted measures are strongly prescribed

Main aspects of the proposed method

- To deal with all the information in one analysis
- To avoid prescribing strongly corrupted experimental data

Proposed identification strategy: main lines

Split information into:

Reliable and Non-reliable information

Reliable : Constrains of the problem

Non-reliable : Minimization of an error

Concept of Modified Error in Constitutive Relation
Leads to a true validation method proposed & developed in vibration

(Ladevèze & coll.)

Basic ideas : extension and adaptation of the framework for identification problems in dynamics with corrupted measurements

Proposed identification strategy: example in elasticity

First step : splitting of the information

Deterministic model

Reliable	Uncertain
Equilibrium: $\rho.\ddot{u} - div\sigma = 0$	Constitutive relation: $\sigma = E.\epsilon$ Measurements: $\tilde{u}_d$ and $\tilde{f}_d$

Corrupted values

The constrain $\underline{div}\sigma = \rho\ddot{\underline{u}}$ will be always enforced

Second step: Confrontation of the model and the measurments :

"Decorruption" of the Measurements (E fixed)

$$\boxed{J(\underline{u}_d, \underline{f}_d, \sigma, \varepsilon(u))} = \int_0^T \frac{1}{2} \int_\Omega (\sigma - E.\epsilon) . E^{-1} . (\sigma - E.\epsilon) + \int_{\partial\Omega_f} d_f(f_d, \tilde{f}_d) + \int_{\partial\Omega_u} d_u(u_d, \tilde{u}_d)$$

Error in constitutive relation   Distance to the measure

under the constraints:

$$u \text{ CA à } u_d, \quad \sigma \text{ DA à } f_d, \quad \rho.\ddot{u} + div\, \sigma = 0$$

$\boxed{u_d \, and \; f_d}$ are results of the minimization and appear to be regularized

values of the experimental boundary measurements $\tilde{u}_d$ and $\tilde{f}_d$

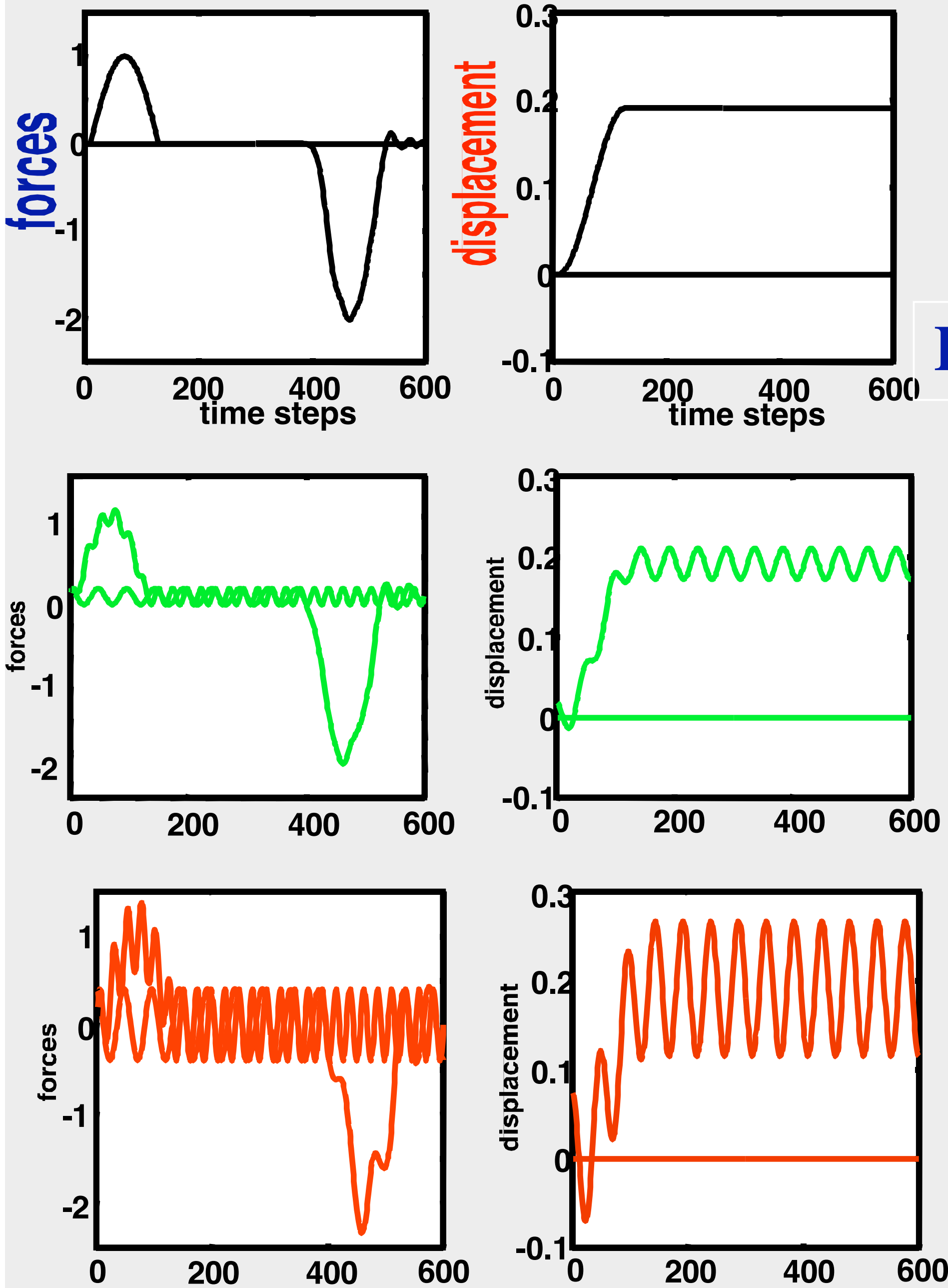
$\boxed{\hookrightarrow}$ yields the solution fields: $\sigma(E), u(E), u_d(E), f_d(E)$

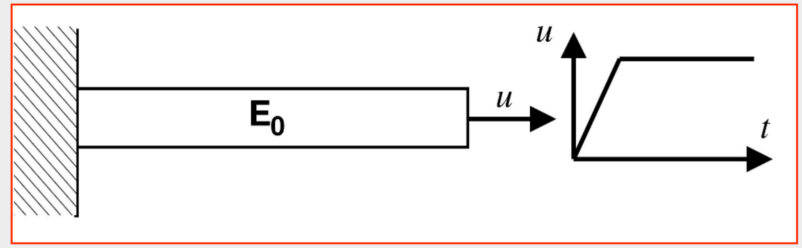
Third step: Determination of the constitutive parameter and model error estimation

$$\widehat{J}_2(E) = \frac{1}{2}\int_0^T dt \int_\Omega (\sigma - E\varepsilon) E^{-1} (\sigma - E\varepsilon)\Big|_{\underline{u}_d(E),\underline{f}_d(E),\sigma(E),\varepsilon(u)(E)} d\Omega$$

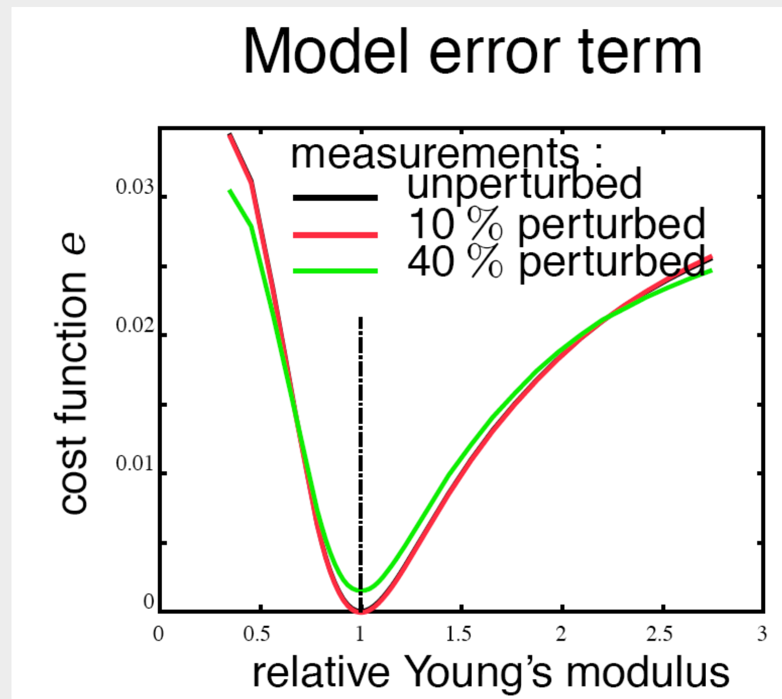
Error in purely Constitutive Relation for the solution of the decorruption problem

Results as a function of the level of corruption



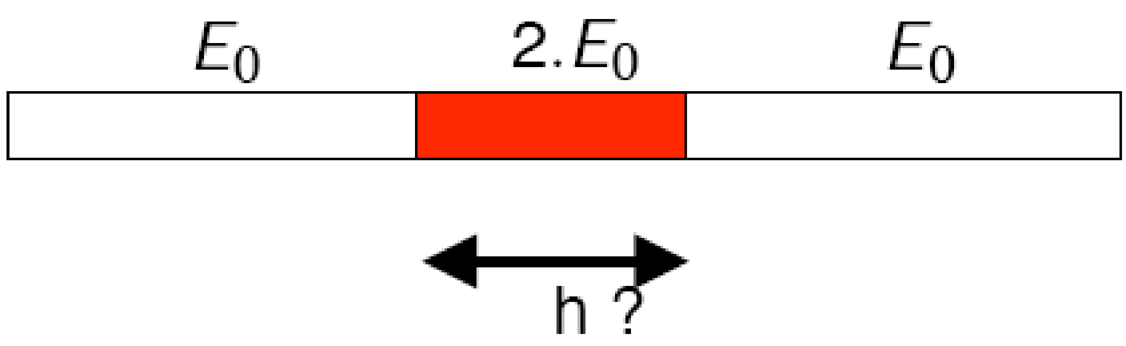


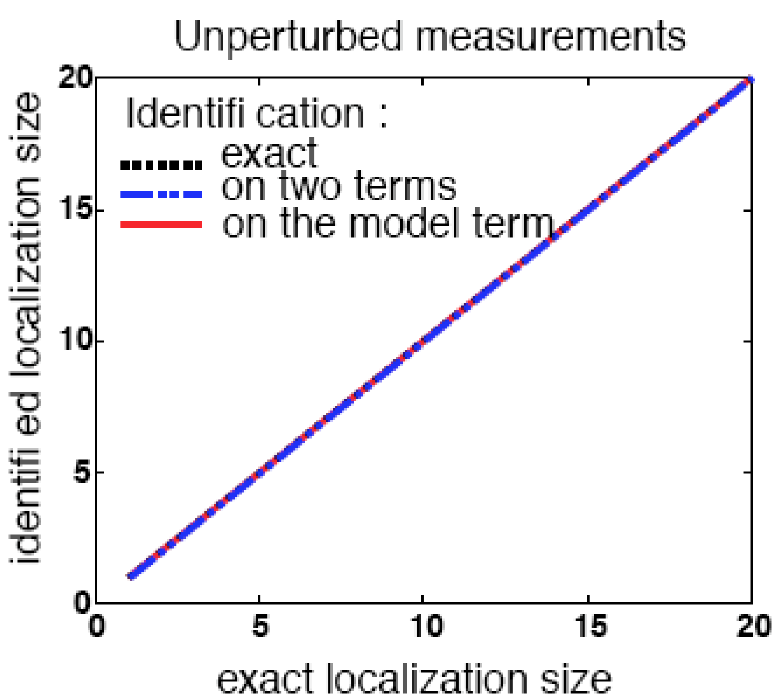
Error for the proposed formulation

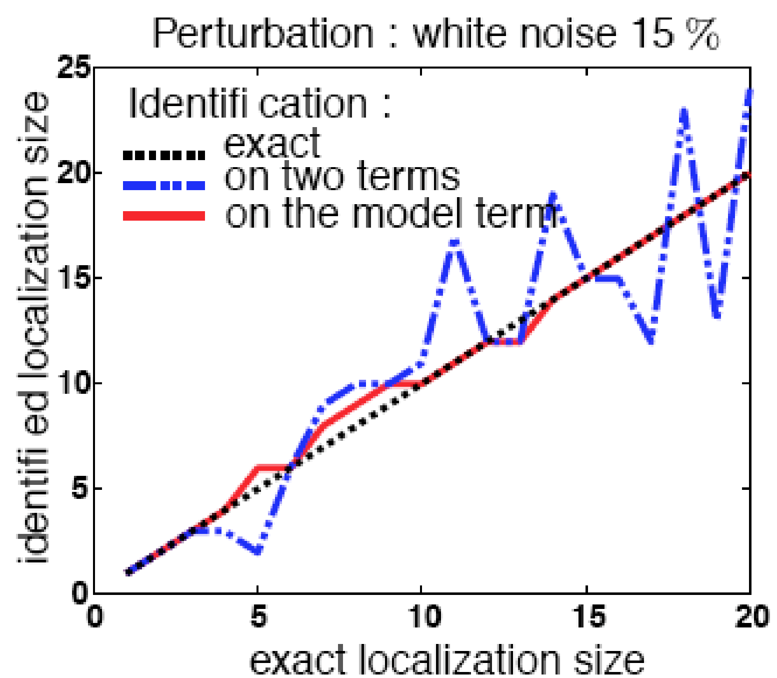


Error function of E/E_0

Example with defects







40% of white noise on the boundary condition in u and F

- **reference Young's modulus**

  $E = E_0$

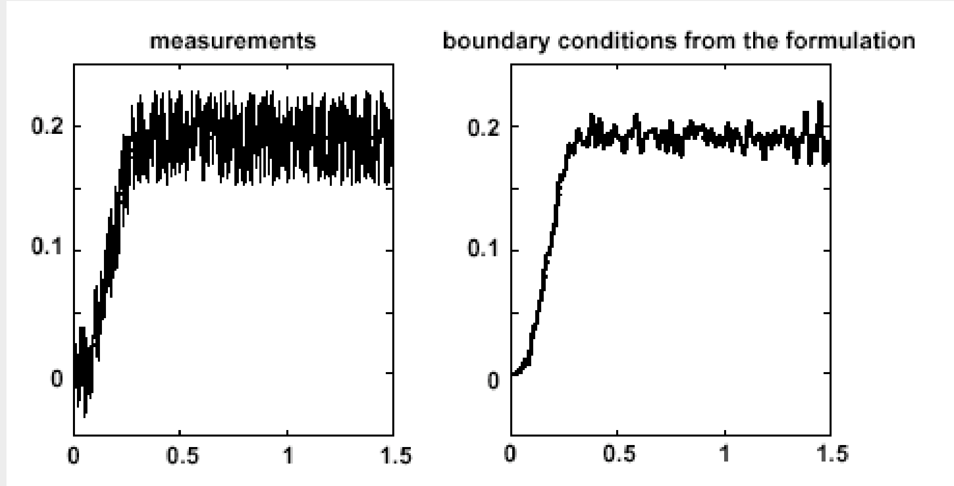
- **perturbed measurements**

  $\tilde{u}_d = u_d^{calc} + \delta u_d$

  and

  $\tilde{f}_d = f_d^{calc} + \delta f_d$

  $\langle \delta f_d \rangle_t = 0$ and $\langle \delta u_d \rangle_t = 0$



- **reference Young's modulus**

  $E = E_0$

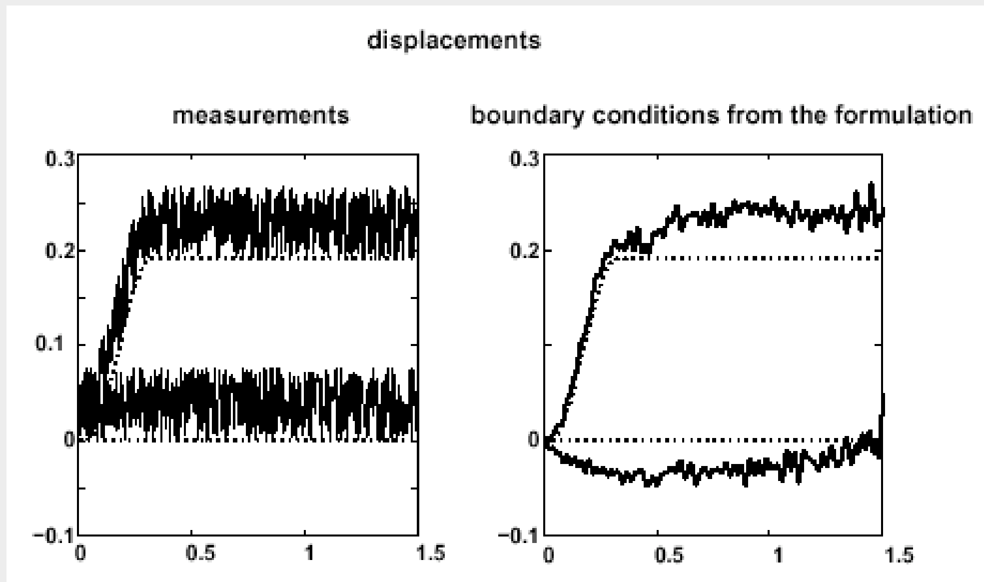
- **perturbed measurements**

  $\tilde{u}_d = u_d^{calc} + \delta u_d$

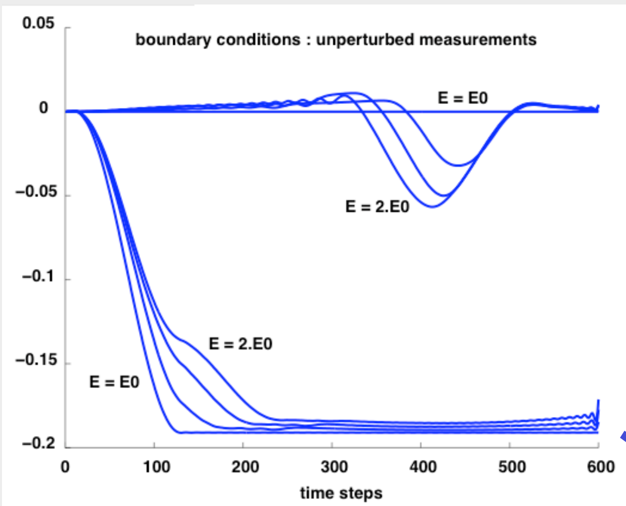
  and

  $\tilde{f}_d = f_d^{calc} + \delta f_d$

  $\langle \delta f_d \rangle_t \neq 0$ and $\langle \delta u_d \rangle_t \neq 0$



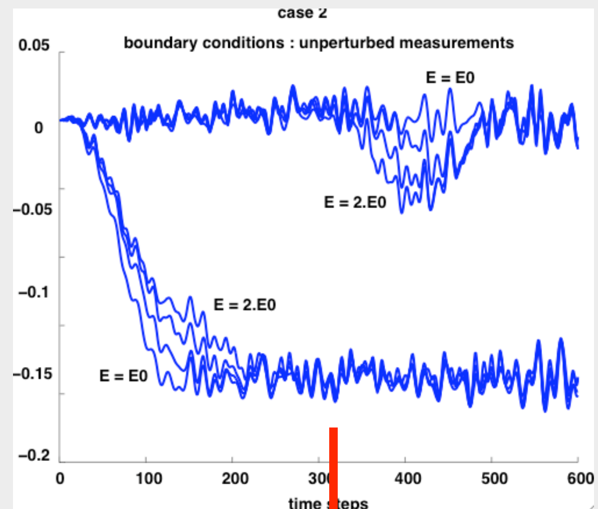
Filtering property of the method-2



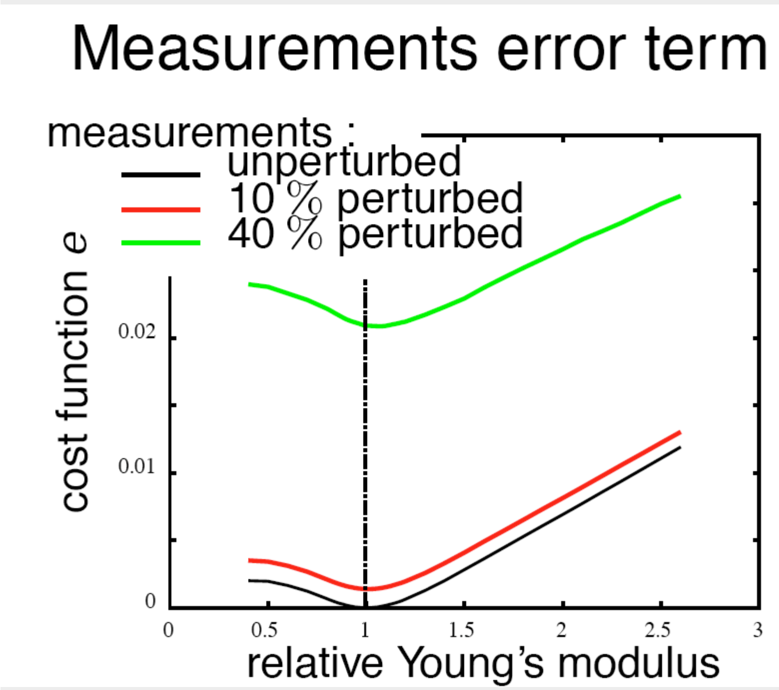
Computed boundary conditions

<-----without noise

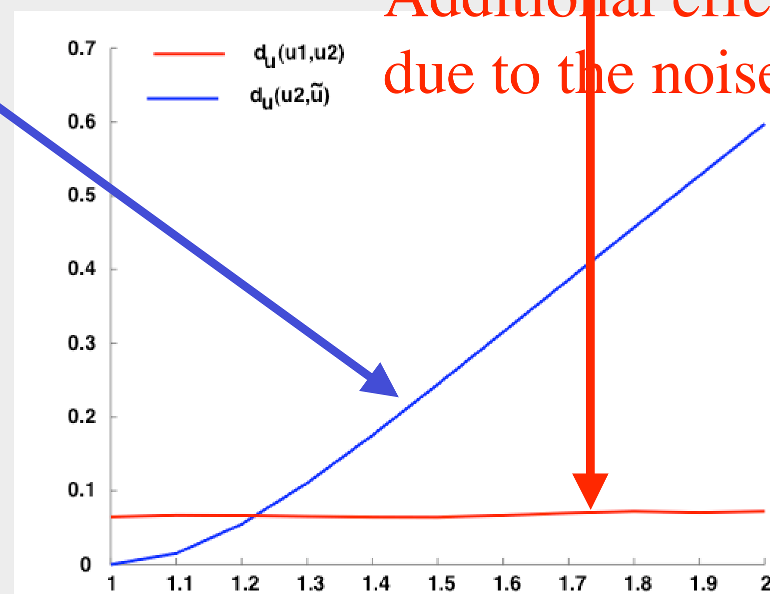
with noise ------->



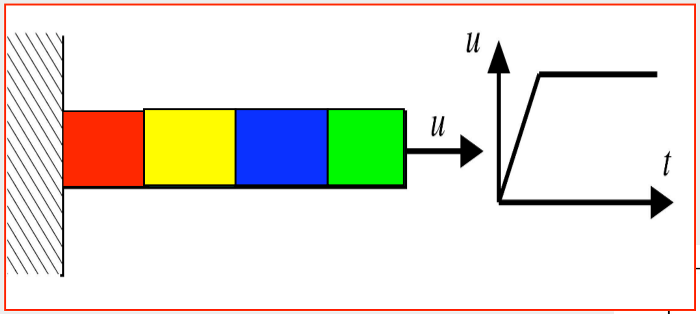
Effect of the error in the model

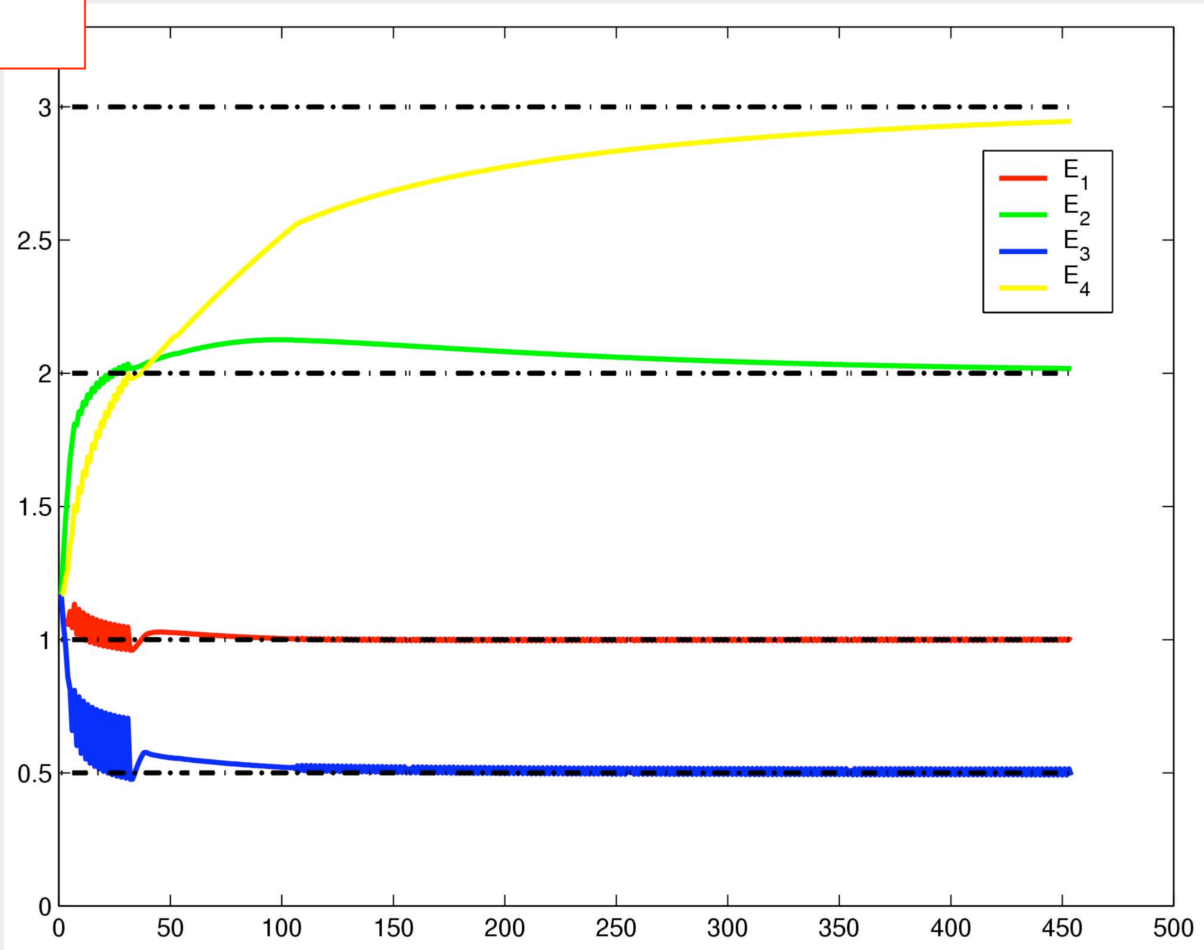


Additional effect due to the noise



Example of an heterogeneous media





Conclusion & Perspectives

A first step in order to build a robust identification method for imprecise boundary conditions

Courtesy of
A Jonhson
DLR

Present work concerns the development of numerical strategy in case of damage with localization