Reduction of Finite Element Models for Explicit Car Crash Simulations

K. Flídrová[a,b], D. Lenoir[a], N. Vasseur[b], L. Jézéquel[a]

[a] Laboratory of Tribology and System Dynamics UMR-CNRS 5513,

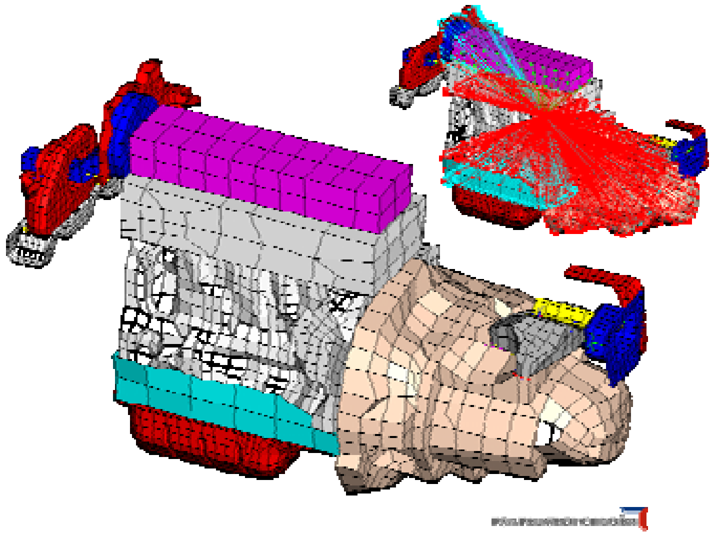
Centrale Lyon – University of Lyon

[b] PSA Peugeot Citroën

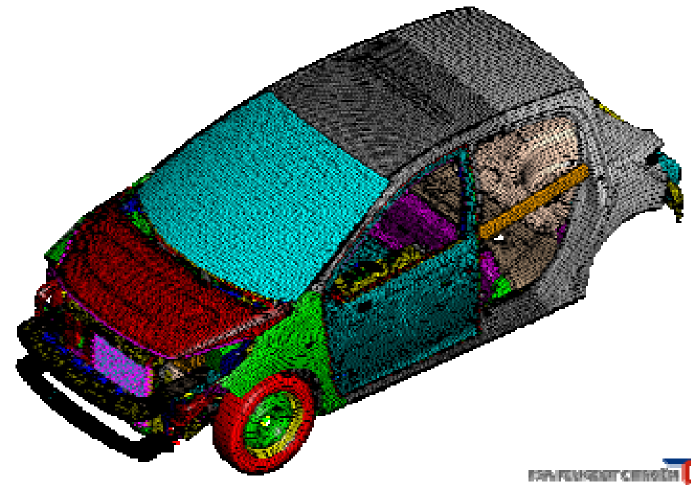
03/11/2009

Context

Because of computational time save, industrial explicit finite element models of complete car crash are relatively coarse.



Power train



Car crash model

In car crash, we define 2 groups of components:

1. Components which **have to break** : engine supports, …

→ 3D non-linear fracture modelization.

2. Components which **have not to break** : transmission case, crank-case, …

→ Rigid body modelization

Objectives

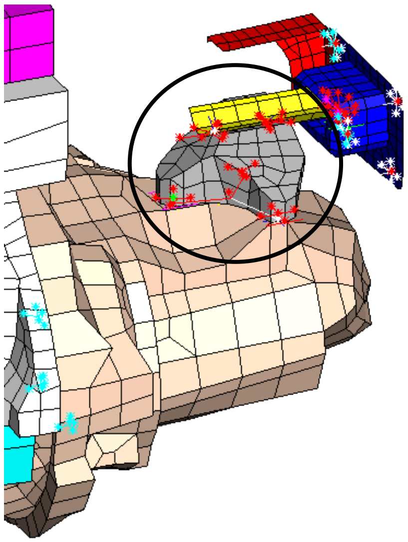
➔The aim of our work is to propose a **better modelization of components which have not to break** in car crash, more precisely:

1. Improve the stiffness modelling of massive cast components in the connection areas with adjacent components.

2. Dispose a representative mass distribution to have a realistic inertia behaviour.

3. Have a good geometry description for contact simulation ➔ satisfactory precision of computed contact forces.

4. Reduce or at least conserve the computational time.



Proposed modelization

➔ Modelization of rigid cast components by linear elastic superelements in explicit analysis.

In explicit analysis, the mass matrix must be strictly diagonal. Generally, the reduced mass matrix is not. It's diagonalization is necessary.

2 reduction methods are proposed:

1. Guyan's (static) reduction with diagonalized mass matrix equivalent to rigid body inertia,
2. 1st order approximation free-mode method who gives directly a diagonal mass matrix.

Abaqus/Standard

- FE model.
- Export of global matrices and vectors.

→

Matlab

- Import of FE matrices.
- Reduction of FE model.
- Export of reduced model in Radioss format.

→

Radioss

- Explicit analysis with FE mesh and superelements.

Guyan's reduction with diagonalized mass matrix

Method description

1. The **Guyan's (static) reduction** of **stiffness matrix** $\boldsymbol{K}$

2. The **diagonal mass matrix of reduced system** is computed consequently:

Hypothesis: The global inertia effects of diagonal reduced mass matrix corresponds to structure inertia considered as rigid body.

$$\sum_i m^i = m_T$$

Mass

$$\sum_i m^i({x_j^i}^2 + {x_k^i}^2) + J_{ll}^i = J_{ll} \qquad \sum_i m^i x_j^i x_k^i = J_{jk}$$

Inertia

$$\sum_i m^i x_j^i = m_T x_{jG}$$

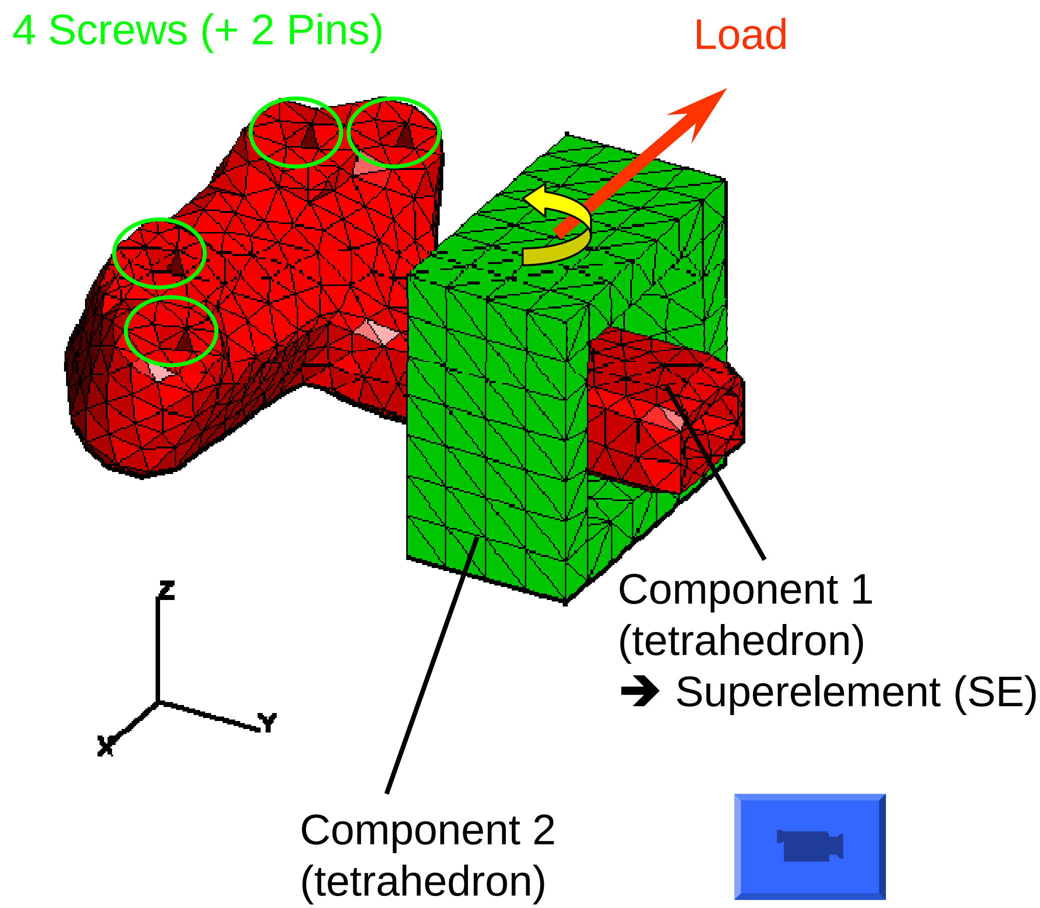
Centre of Gravity

i is the total node number, j = 1, 2, 3, k = 2, 3, 1 and l = 3, 1, 2

➔ System of 10 equations with $4i$ unknowns, where $4i$ > 10 ➔ Use of optimisation methods to distribute the mass and inertia in the new diagonal reduced mass matrix.

Guyan's reduction with diagonalized mass matrix

Presentation of test model



Load: Imposed displacement in x direction.

Component 2: Can rotate about z axis.

Screws and Pins: Rigid body + general spring (zero length).

Boundary conditions: Fixation of screws and pins.

Materials: Behaviour purely elastic.

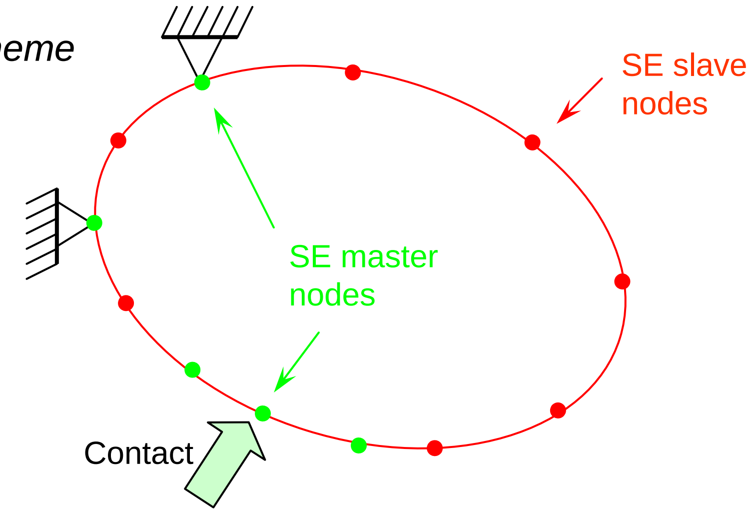
Post-treatment :

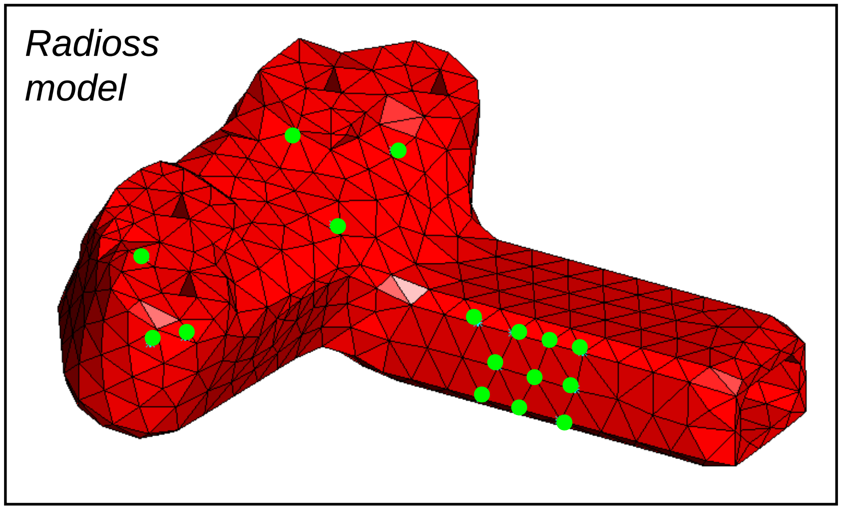
- Contact force between component 1 and 2.
- Forces in screws and pins.

Guyan’s reduction with diagonalized mass matrix

Contact management n°1: Complete Radioss SE model

Scheme





In explicit run with SE, the original complete mesh is used (standard procedure in Radioss). The results are projected on slave nodes (classical data recovery).

Advantages:

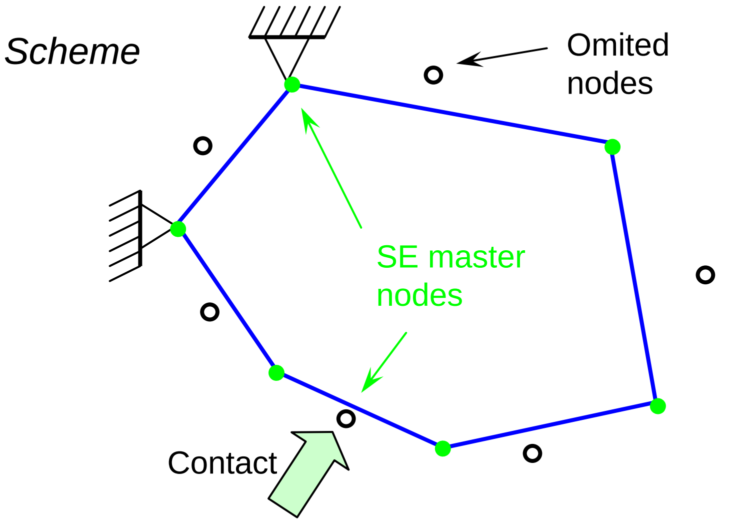
- 3D visualisation of reduced component.
- Good precision of computed forces.

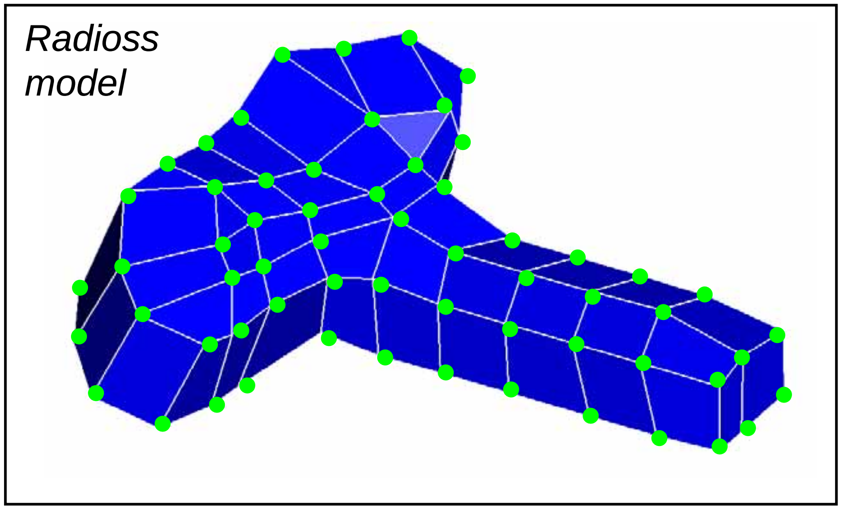
Disadvantages:

- Long computational time due to results projection on superelement (SE) slave nodes.

Guyan’s reduction with diagonalized mass matrix

Contact management n°2: Model with complete deformable shell mesh





Creation of a complete shell mesh on the reduced component surface. The mesh nodes are the SE master nodes.

Advantages:

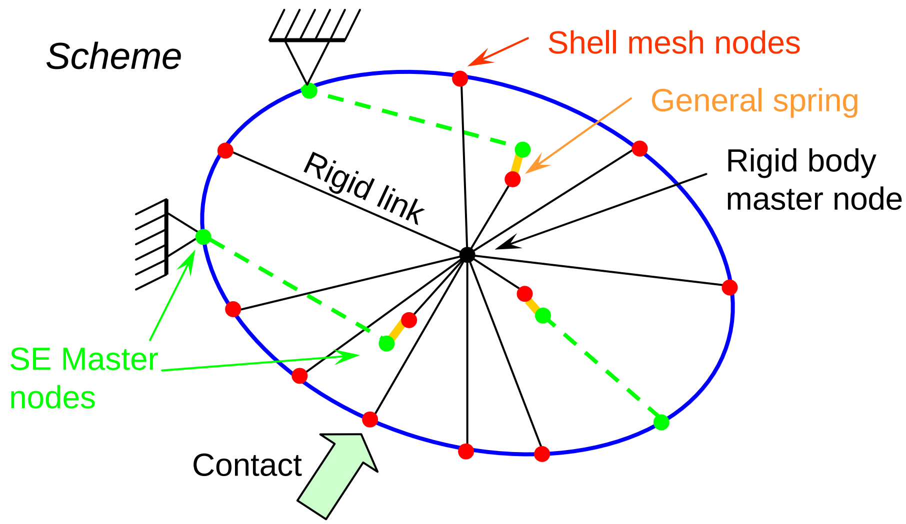
- 3D visualisation of reduced component.
- Good precision of computed forces.

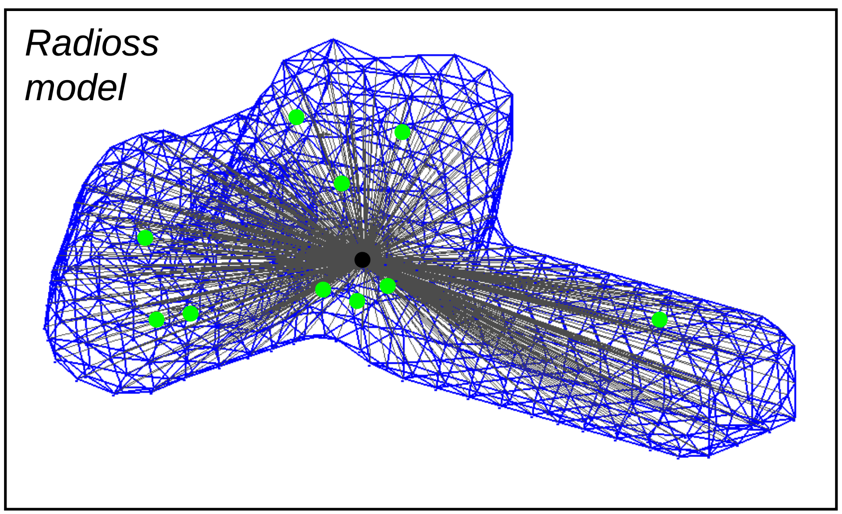
Disadvantages:

- Important computational time.
- Manual shell mesh creation.

Guyan's reduction with diagonalized mass matrix

Contact management n°3: Model with complete rigid shell mesh





Creation of a rigid shell mesh on the reduced component surface connected with SE via a rigid generalized spring (zero length).

Advantages:

- 3D visualisation of reduced component.
- Short computational time.
- Automatic shell mesh creation.

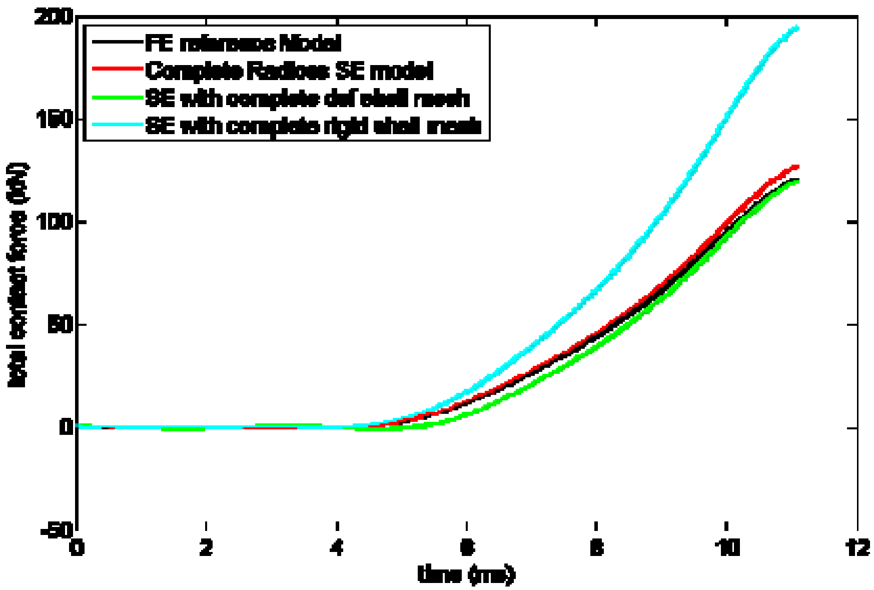
Disadvantages:

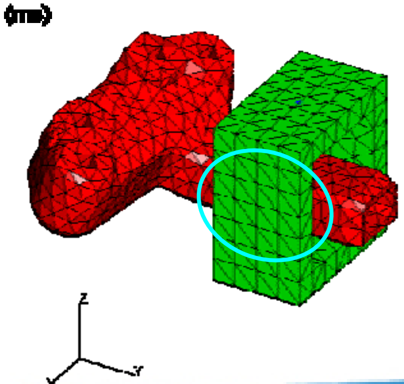
- Worse precision of computed contact forces.

Guyan's reduction with diagonalized mass matrix

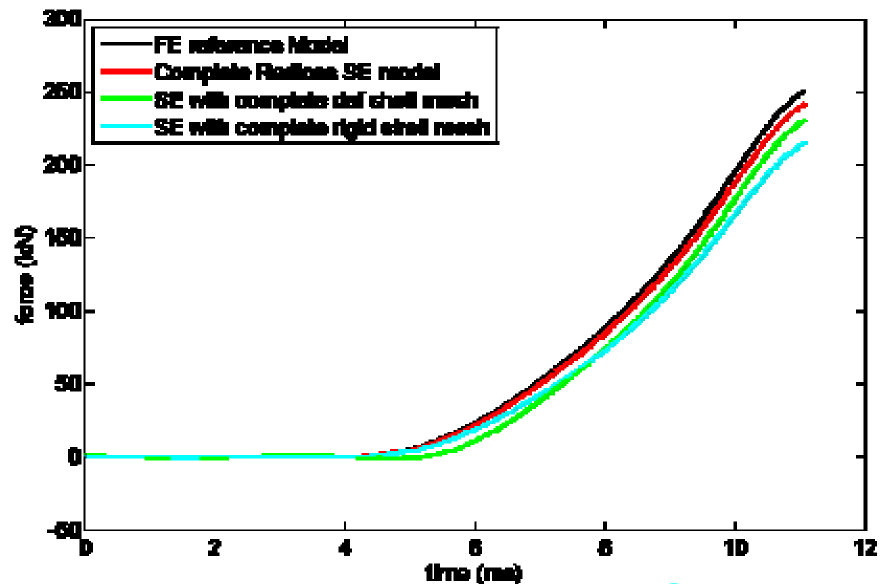
Results

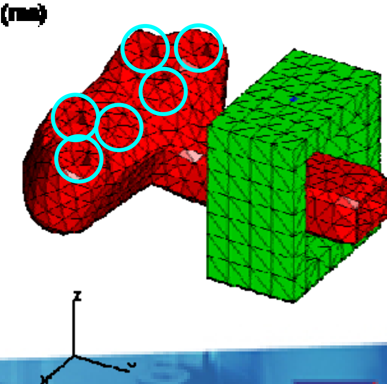
Total contact force





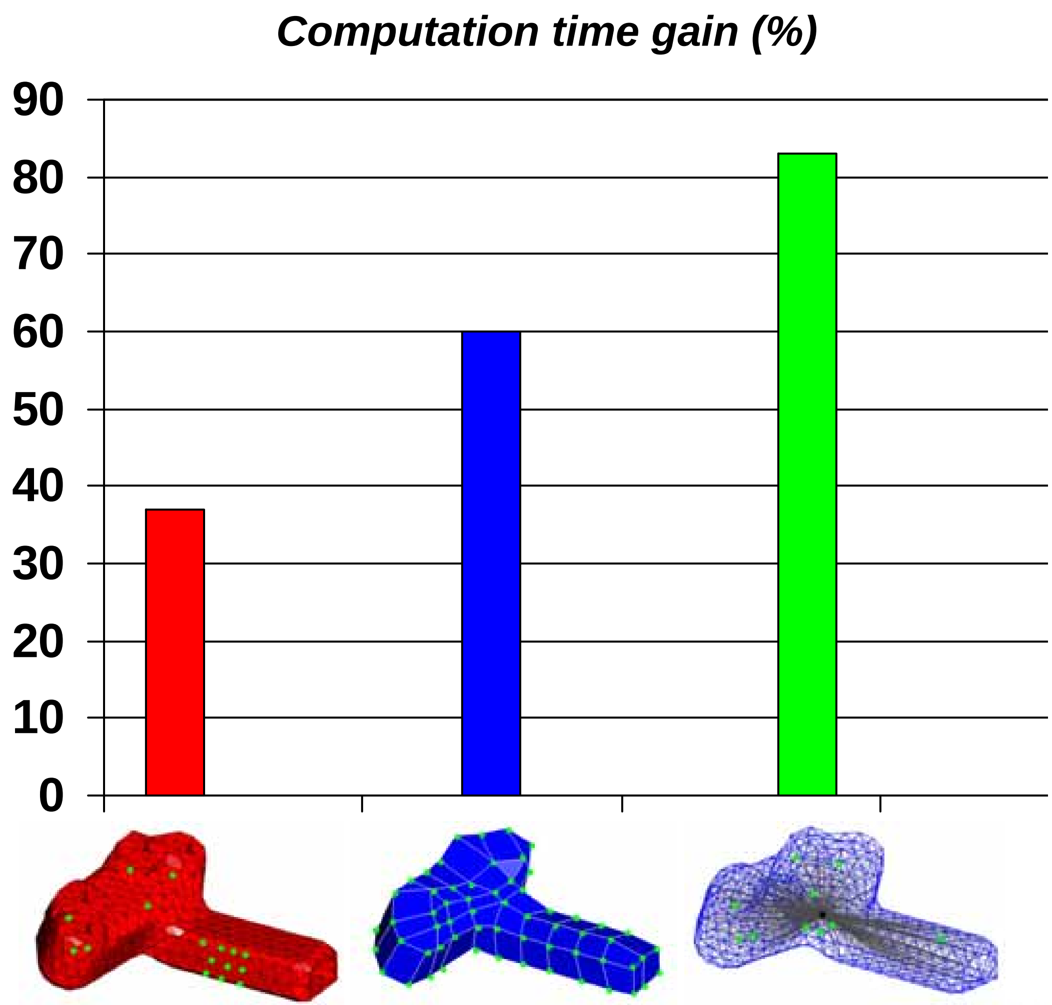
Total force in connexion zone





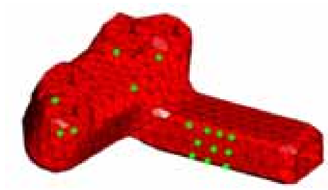
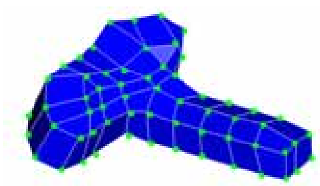
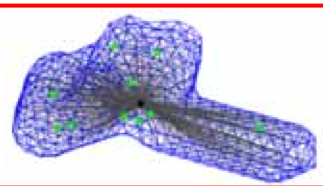
Guyan's reduction with diagonalized mass matrix

Results



Guyan's reduction with diagonalized mass matrix

Model's review

	Precision $F_{contact}$	Precision $F_{connexion}$	CPU time	3D visualisation
	++	++	--	++
	+	+	-	+
	--	++	++	++

- The **most interesting models** for the car crash simulations are:
  1. SE with contact management n°4: SE with rigid complete shell mesh.
  2. SE with contact management n°1: Complete Radioss SE model.

Ductile fracture modelization in Radioss

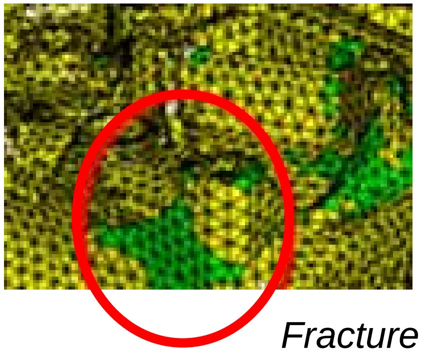
Johnson-Cook fracture criterion

3D volumic fracture modelization of **components which have to break** with Johnson-Cook fracture criterion.

$$\varepsilon_f = (D_1 + D_2 \exp(D_3 \sigma^*))(1 + D_4 \ln \dot{\varepsilon}^*_{eq})(1 + D_5 T^*)$$

ε_f Fracture strain

σ^* Stress triaxiality ratio, $\sigma^* = \frac{\sigma_m}{\sigma_{eq}}$



Fracture

Perspectives

1. Development of free-mode reduction method for explicit analysis

The reduction basis is constituted by **free eigenmodes** which are completed by **attachment modes** representing the **residual flexibilities** on junction nodes.

Advantages :

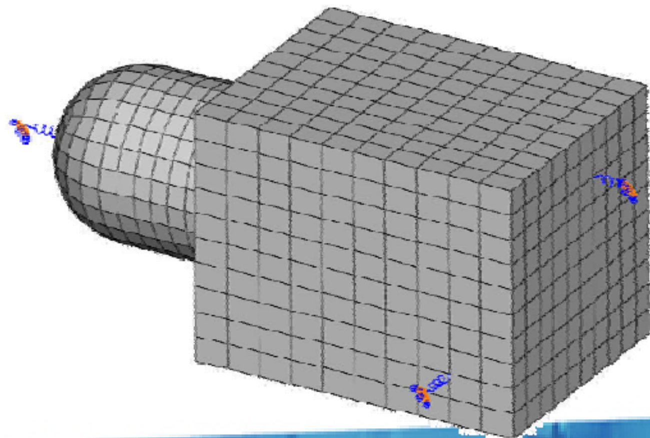
- Diagonal mass matrix.
- Good results precision.

Disadvantages :

- Special treatment of substructures with rigid body modes.
- Special technique of substructures assembly.
- Realisation more difficult than for static reduction.

1st results :

- Method application on a model of *Fixed beam* and *Simplified Power train*. The obtained results are good for the 2 test models.
- November : Method application in Radioss.

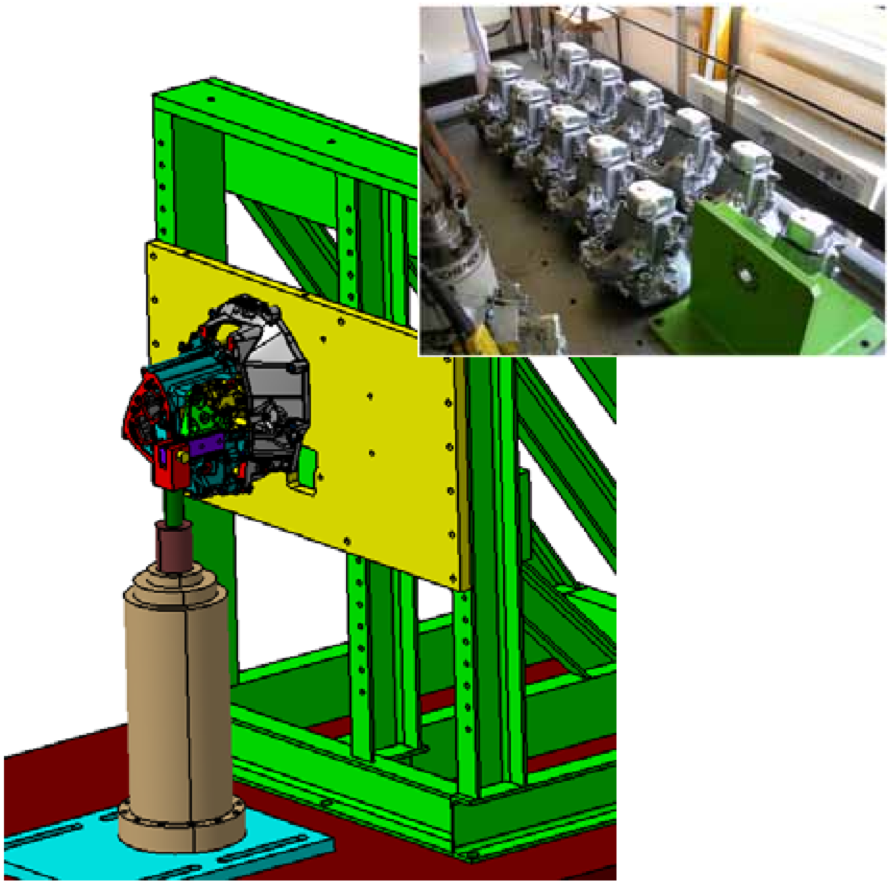


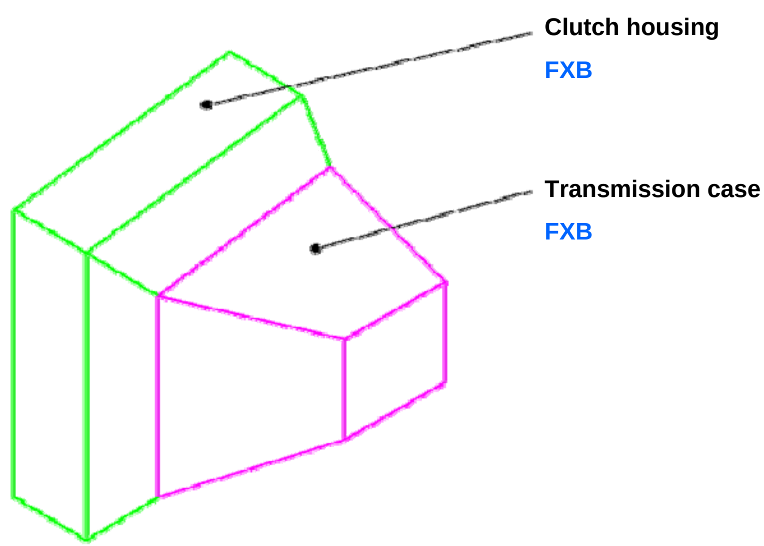
Perspectives

2. Physical tests of transmission case stiffness

➔ November 2009.

➔ Numerical simulation of physical tests: Validation of stiffness modelization by superelements.





Questions