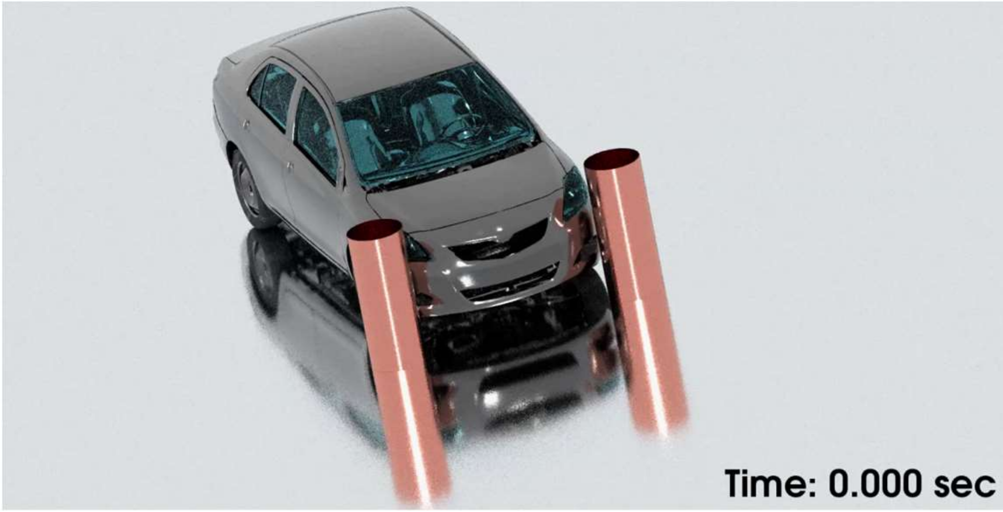
Vehicle **impact analyses** on security barriers

EPX Users Meeting

JRC, Bruxelles, 6th June

Vehicle security barriers - certification

- Performance of barriers assessed generally through **physical tests**
- Expensive and not always repetitive
- Only one scenario is tested
- **Numerical simulations** could allow design and pretesting of barriers
- Development of **generic models** to foster standardization



Vehicle security barriers – objectives with EPX

- Create (publicly available) generic vehicle models in the LS-Dyna format
- Convert the models to EPX (as automatically as possible)
- Perform "virtual tests" with EPX of security barriers for specific applications
- Use best-estimate simulations for parametric analyses and reduced models (e.g. using machine learning)

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Generic vehicle model (N1 category)

- Day cab vehicle – flat bed
- Rear wheel drive
- Vehicle mass: 3 500 (±100) kg
- Overall vehicle length: 6 200 (± 380) mm
- Wheel base length: 3 805 (± 710) mm

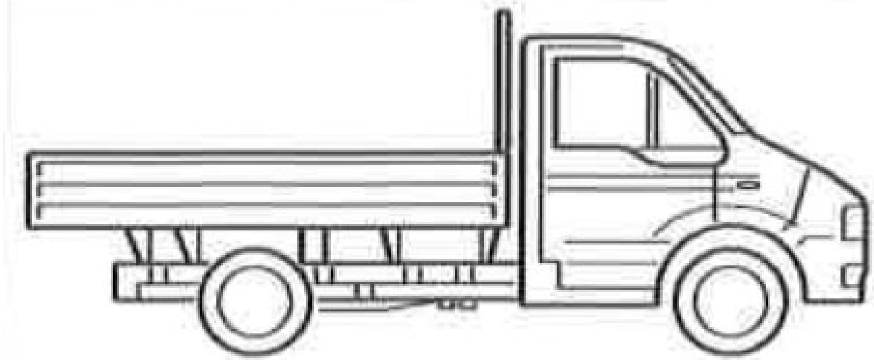
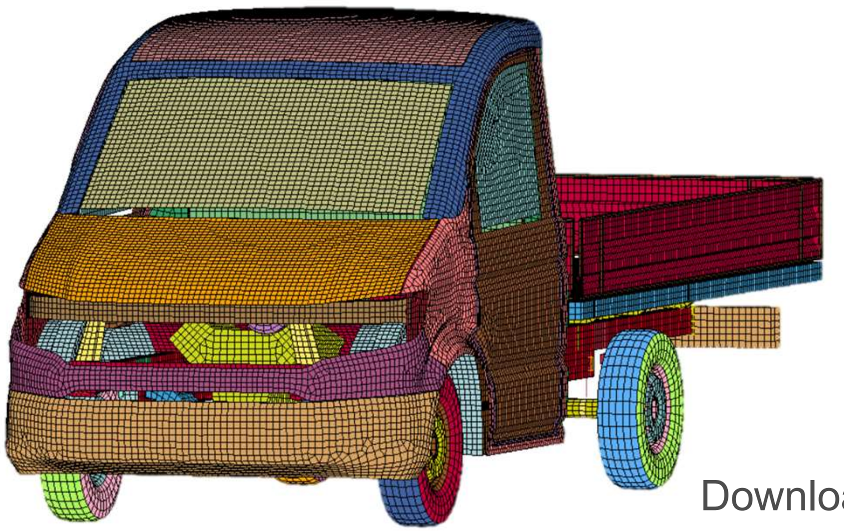


Table 2 — Vehicle impact method: Test vehicle specification

UN ECE international vehicle classification	M1	N1G	N1	N2	N3	N3
Type of test vehicle [A] (1)	Car	4×4 single cab pick-up	Day cab vehicles			
			3 500 kg flat bed (RWD) [B]	7 500 kg 2-axle rigid	18 000 kg 2-axle rigid	32 000 kg 4-axle rigid (Tipper)
Nominal test vehicle mass (kg)	**1 500**	**2 500**	**3 500**	**7 500**		**30 000**
Minimum unladen mass (kg)	1 234	1 620	1 675	3 575	6 100	10 500
Maximum ballast (kg)	266	880	1 825	3 925	1 400	19 500
Inertial test vehicle mass (kg)	**1 500**	**2 500**	**3 500**	**7 500**	**7 500**	**30 000**
Tolerance (kg)	± 50	± 50	± 100	± 100	± 140	± 590
Overall vehicle length (mm)	4 500	4 900	6 200	7 612	9 557	10 240
Tolerance (mm)	± 360	± 320	± 380	± 1 522	± 1 911	± 500
Wheel base length (between extreme axles) (mm)	2 700	2 900	3 805	4 310	5 907	6 500
Tolerance (mm)	± 540	± 580	± 710	± 830	± 1 250	± 200

[A] The types of vehicle are illustrated in Figure 1.

[B] RWD = rear wheel drive.



Download at https://counterterrorism.ec.europa.eu/

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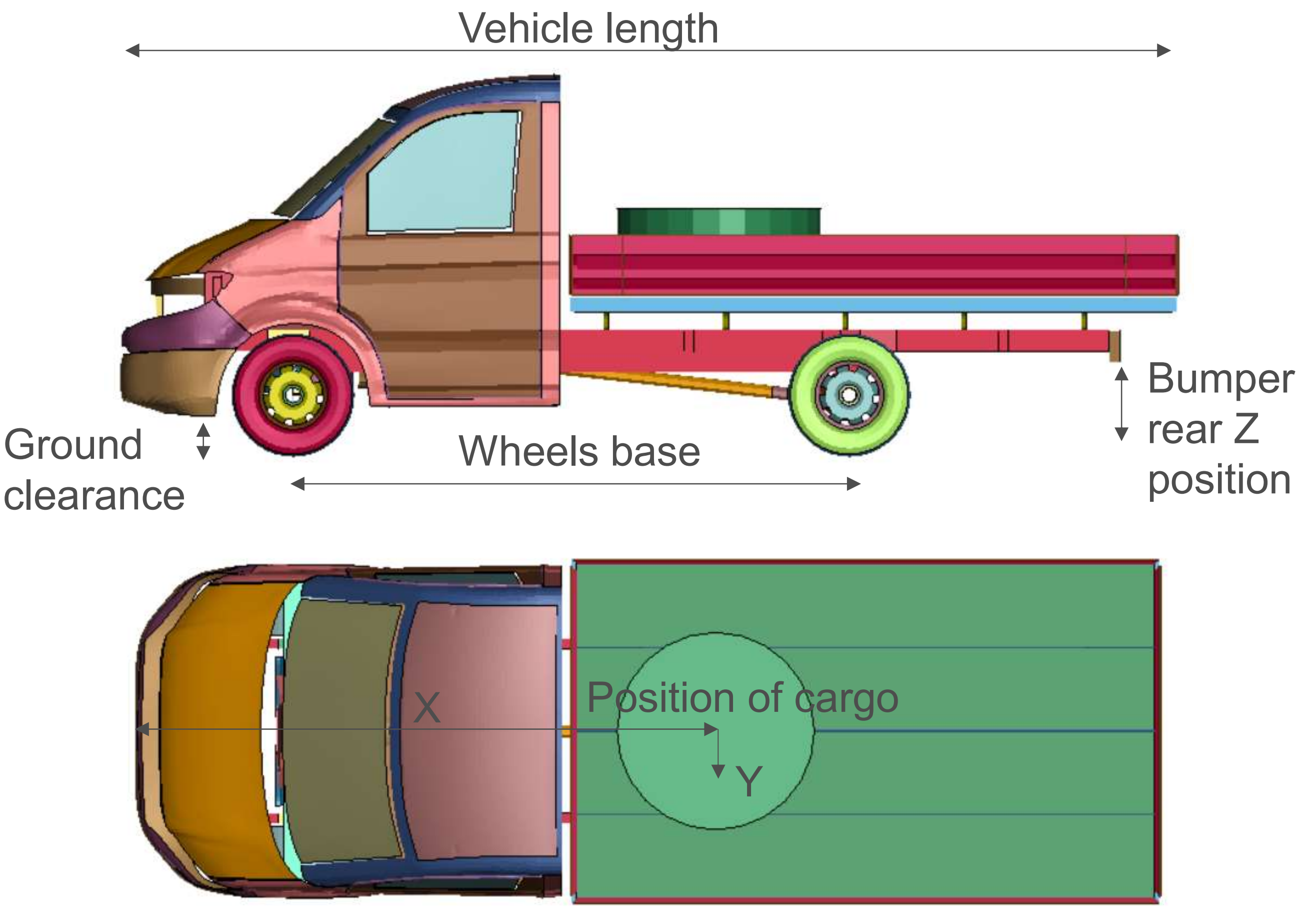
Parameters - DIMENSIONS

- Mass from parameter equally distributed on key parts
- Crashrelated stiffness
- Suspension



Model details

- Nodes: 73 037
- Beam elements: 1516
- Shell elements: **62488**
- Solid elements: **16694**
- Discrete elements: 20
- Parts: **104**

Validation

- Vehicle in idle
- Linear track
- **Curb test EN16303**
- **Crash test**

LS-Dyna

Computational Speed

- time step = **3 10^{-3} ms** (= 3 µs)
- Bollard crash test case – 300 ms simulation time - 4 CPU – **1h 8min**

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Crash test – rigid bollard

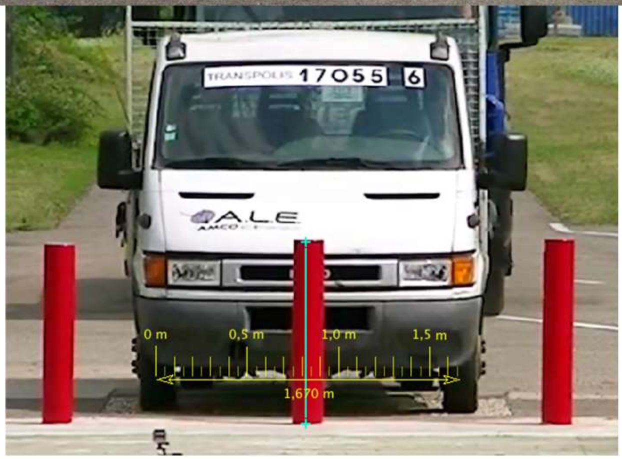
LS-Dyna

- Initial velocity 48 km/h
- Total mass = 3500 kg

- Agreement with experiment
- Accelerometer data not available

Model setup

- Dimensions of the vehicle are taken extracting two frames from the experimental test video on Tracker
- In this case, it is set on the height of the bollard, which is known to be 1000 mm (from the video data)



Bollard used in the experimental test

Bollard: rigid material

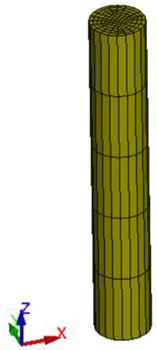
Density: 7830 kg/m^3

Young’s modulus: 207 GPa

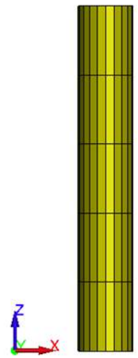
Poisson’s ratio: 0.28

The bollard is fully constrained

Overview



Modeled bollard



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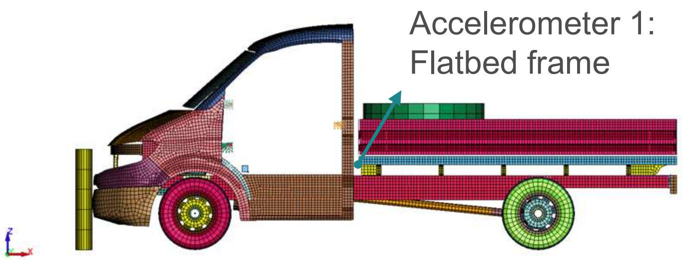
Experiment vs FEM model - Deceleration

Position of the marker

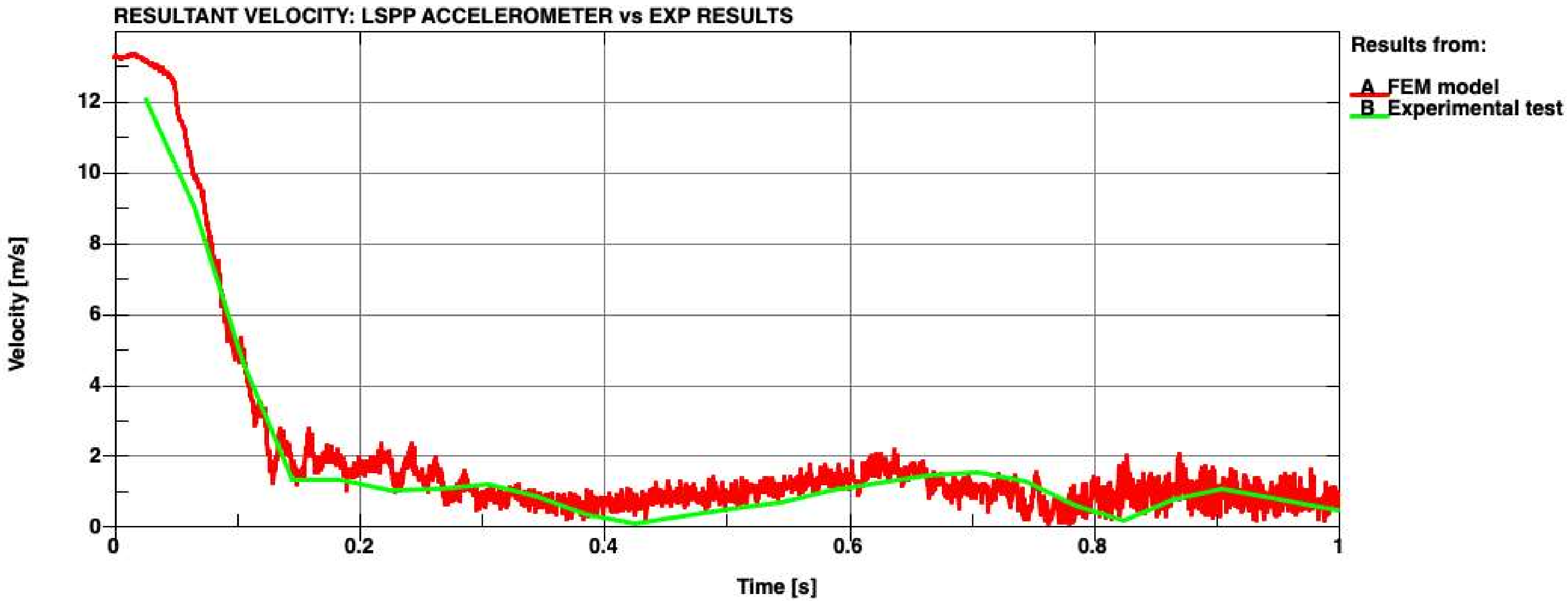


Tracker results

Experiment vs FEM model - Deceleration

LS-Dyna

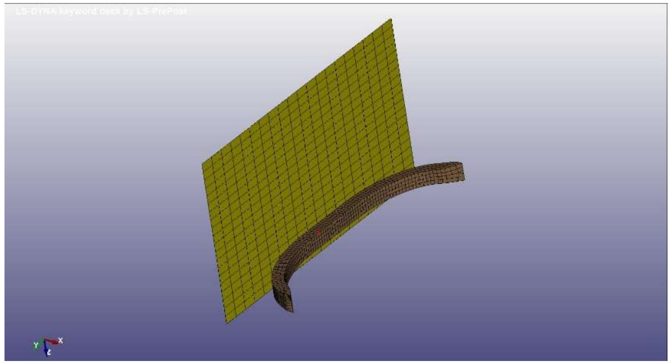
- Results of the experimental test analyzed on Tracker (green curve) follow the trend of the accelerometer 1 placed in the FEM model on LSPP (red curve)

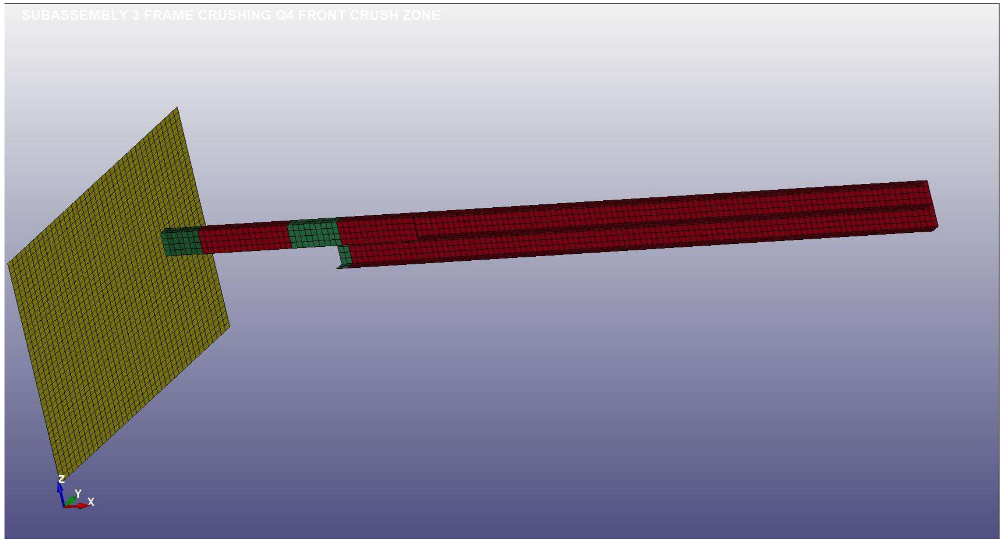


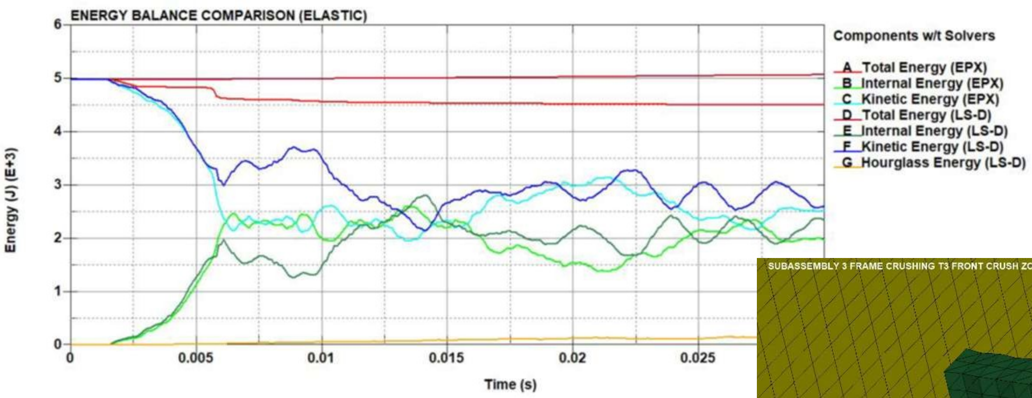
Conversion LS-Dyna → EPX

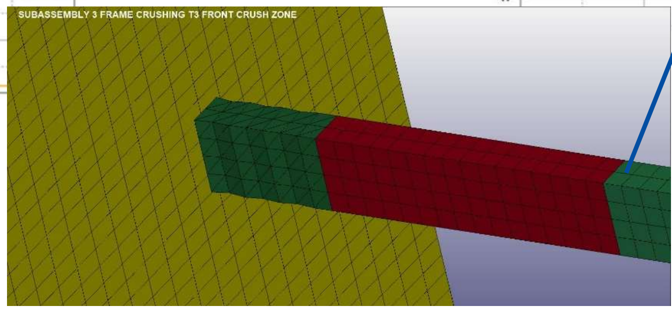
- Reading LS-PrePost keyword files
  - globally achieved
- Contact-impact algorithm
  - penalty (DECO) vs. Lagrange multipliers (COUP)
  - master-slave (GLIS) vs. pinballs (PINB)
- Rigid body constraints
- Mechanisms (suspension systems, directions, etc.)

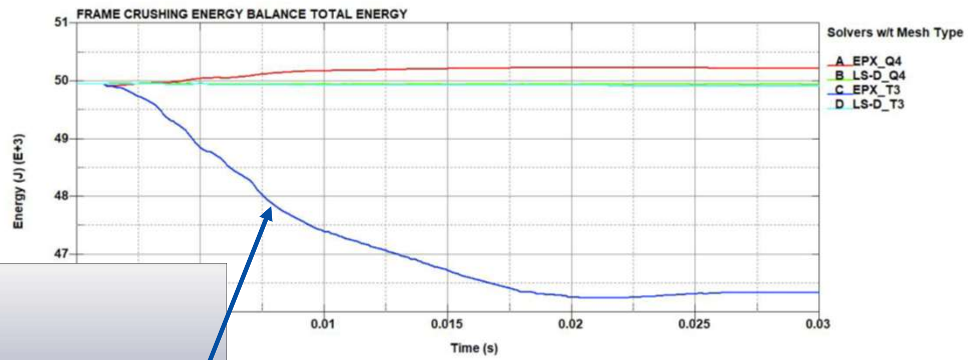
Contact-impact algorithm
energy dissipation











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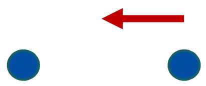
EPX contact algorithm – energy dissipation

before impact



$V_1 = 0$ $V_2 = V_{init}$

contact condition

$$C \cdot v^{n+\frac{3}{2}} = 0$$

after impact

$V_1 = V_2$

→ inelastic impact

(some of the initial kinetic energy is lost)

Literature inspiration

R.C. Fetecau, J.E. Marsden, M. Ortiz and M. West. *Non-smooth Lagrangian Mechanics and Variational Collision Integrators*. SIAM J. Applied Dynamical Systems, vol. 2, No. 3, pp. 381-416 (2003).

Key idea

→ impose the total energy conservation by adding the α parameter

→ the exact contact instant (between t_n and t_{n+1}) is selected such that the corresponding contact force satisfies the energy conservation condition at t_{n+1}

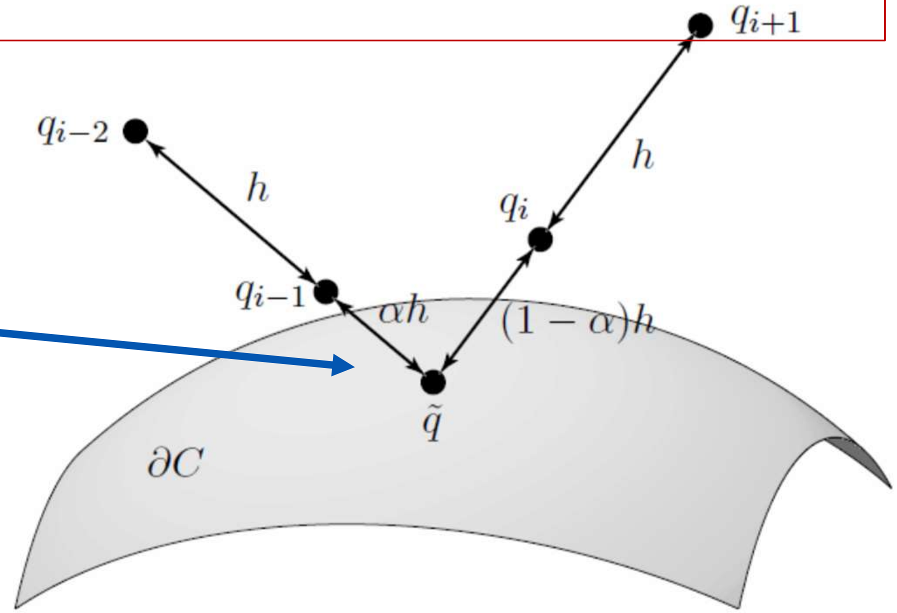
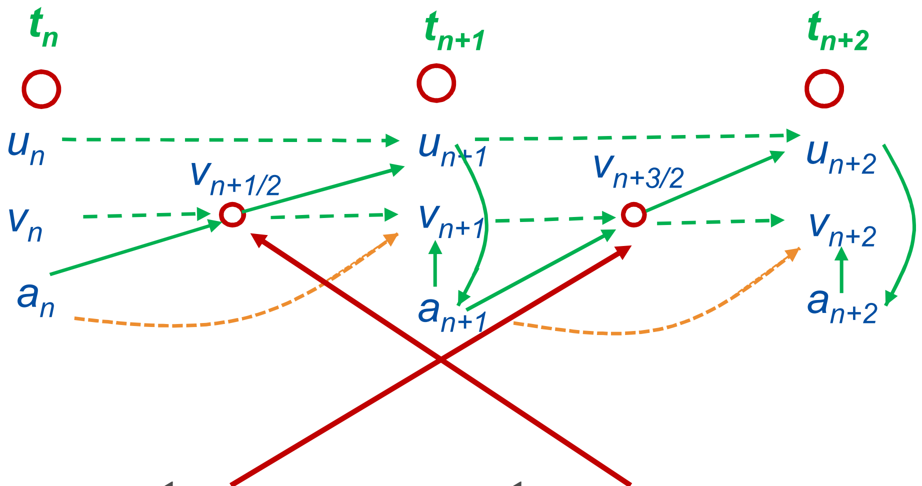


Figure 1. *The discrete variational principle for collisions.*

NEW contact algorithm – kinetic energy

Kinetic energy jump



$$\Delta E = \frac{1}{2} v^T_{n+\frac{3}{2}} \cdot M \cdot v_{n+\frac{3}{2}} - \frac{1}{2} v^T_{n+\frac{1}{2}} \cdot M \cdot v_{n+\frac{1}{2}}$$

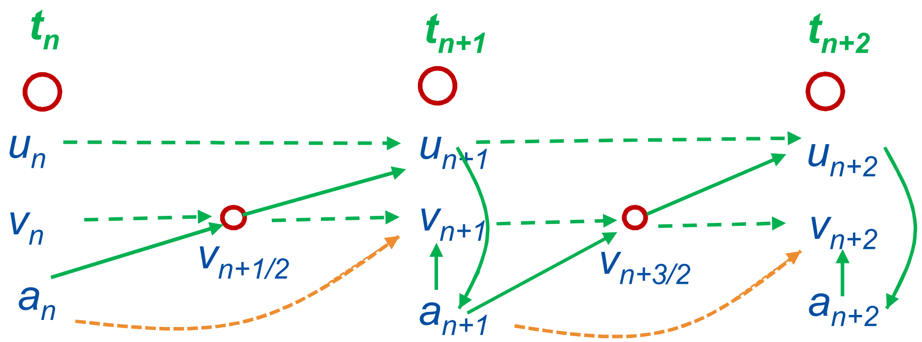
$$f_{cont} = C^T \cdot \lambda$$

$$\Delta E = \Delta t v^T_{n+\frac{1}{2}} \cdot C^T \cdot \lambda + \frac{1}{2} \Delta t^2 \lambda^T \cdot B \cdot \lambda$$

$$B = C \cdot M^{-1} \cdot C^T$$

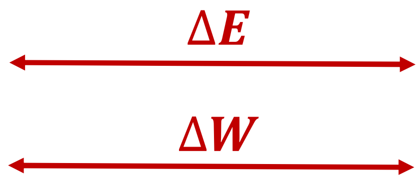
NEW contact algorithm – energy balance

- without contact



Kinetic energy evolution

$$\Delta E = \Delta t \cdot v^T_{n+\frac{1}{2}} \cdot f + \frac{1}{2}\Delta t^2 f^T \cdot M^{-1} \cdot f$$



Work of external and internal forces

$$\Delta W = \tilde{u}^T \cdot f$$

$$\tilde{u} = \Delta t \cdot \boldsymbol{v_{n+1}}$$

$$\tilde{u} = \Delta t \cdot \left(v_{n+\frac{1}{2}} + \frac{\mathbf{1}}{\mathbf{2}} \Delta t \cdot a_{n+1} \right)$$

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NEW contact algorithm – energy balance

- with contact

Kinetic energy evolution

$$\Delta E = \Delta t \cdot v^T_{n+\frac{1}{2}} \cdot f + \frac{1}{2}\Delta t^2 f^T \cdot M^{-1} \cdot f$$

$$f \rightarrow f_{ei} + f_{cont}$$

$$\alpha = \frac{1}{2}$$

Work of external and internal forces

$$\Delta W = \tilde{u}^T \cdot f$$

$$f \rightarrow f_{ei} \cancel{+ f_{cont}}$$

contact forces produce no work

$$\tilde{u} = \Delta t \cdot \left(v_{n+\frac{1}{2}} + \frac{1}{2}\Delta t \cdot a_{n+1} \right)$$

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NEW contact algorithm – energy balance
- with contact

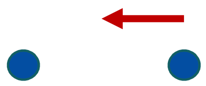
The choice $\boldsymbol{\alpha} = \frac{\mathbf{1}}{\mathbf{2}}$ leads to

$$C \cdot \left(v^{n+\frac{1}{2}} + \boldsymbol{\alpha} \cdot \Delta t \cdot a^{n+1}\right) = 0 \quad \Longrightarrow \quad C \cdot \boldsymbol{v}^{\boldsymbol{n+1}} = 0$$

→ corresponds to an obsolete version (LIAJ option) of the EPX contact conditions (replaced because of the higher contact force oscillations)

NEW contact algorithm – rigid points

before impact



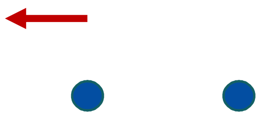
$V_1 = 0$ $V_2 = V_{init}$

contact condition

$$C \cdot v^{n+\alpha} = 0$$

$$\boxed{\alpha = \frac{1}{2}}$$

after impact

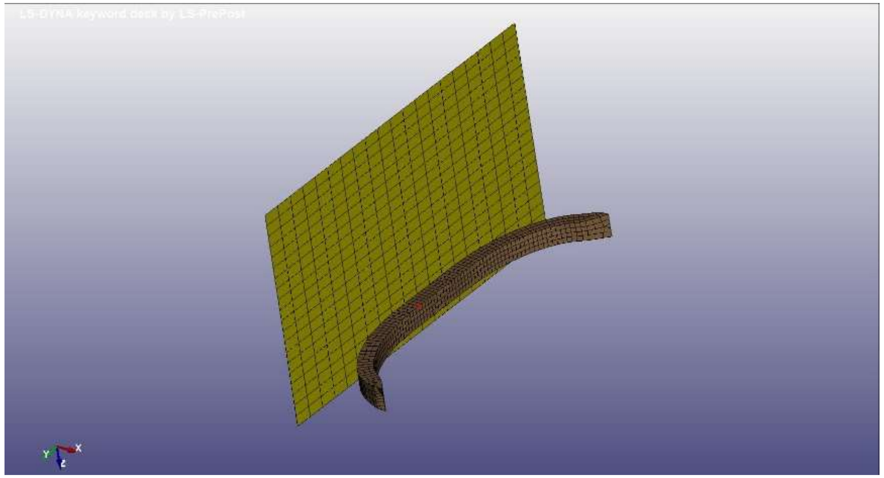


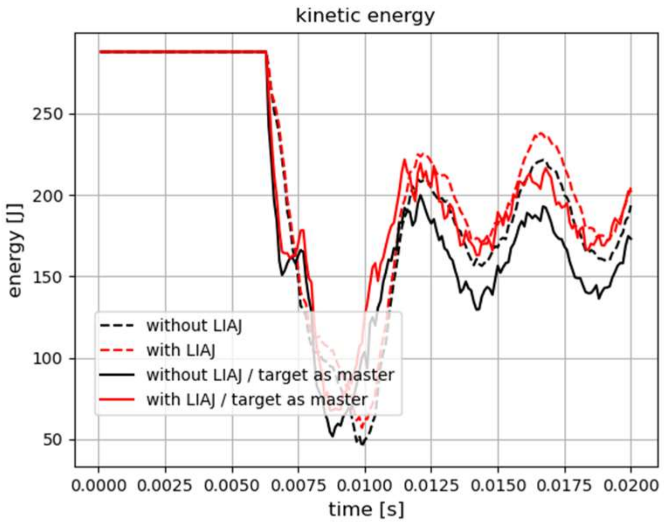
$V_1 = -V_{init}$ $V_2 = 0$

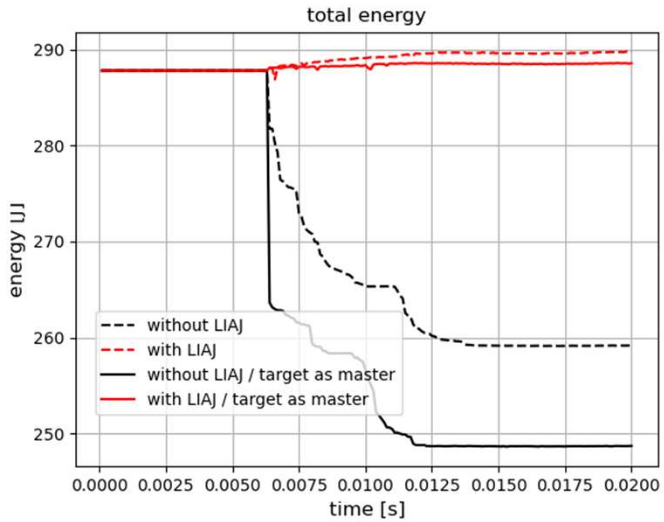
→ elastic impact

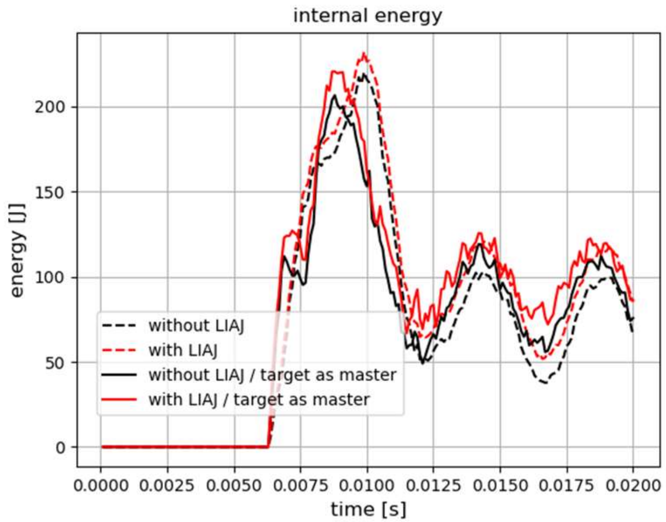
(kinetic energy is conserved)

Case study









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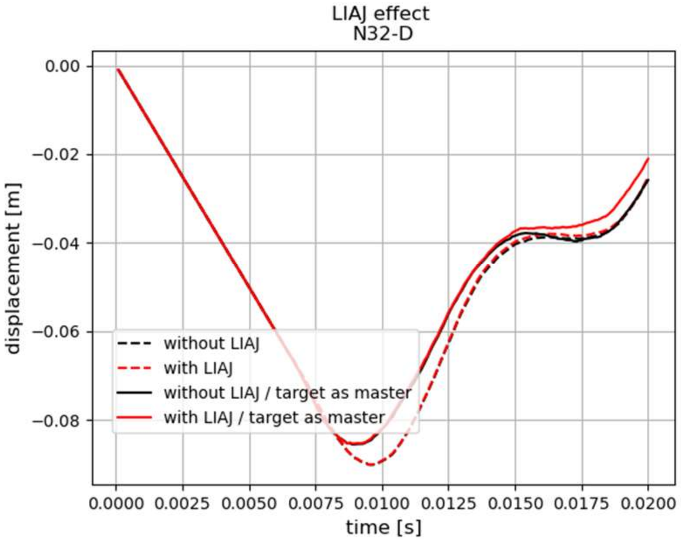
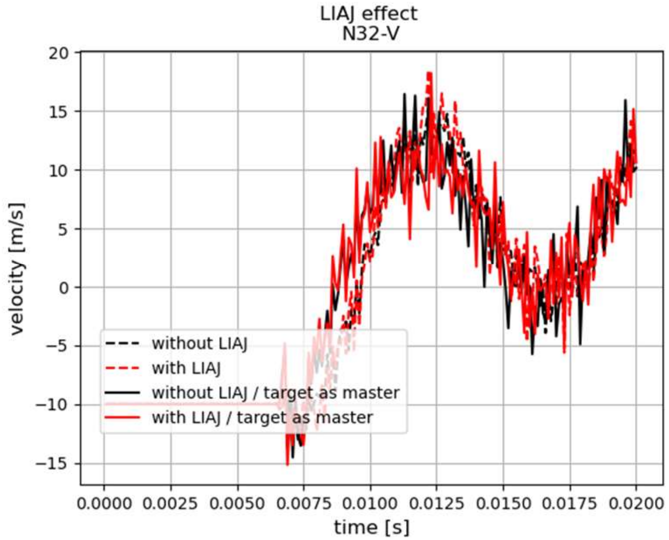
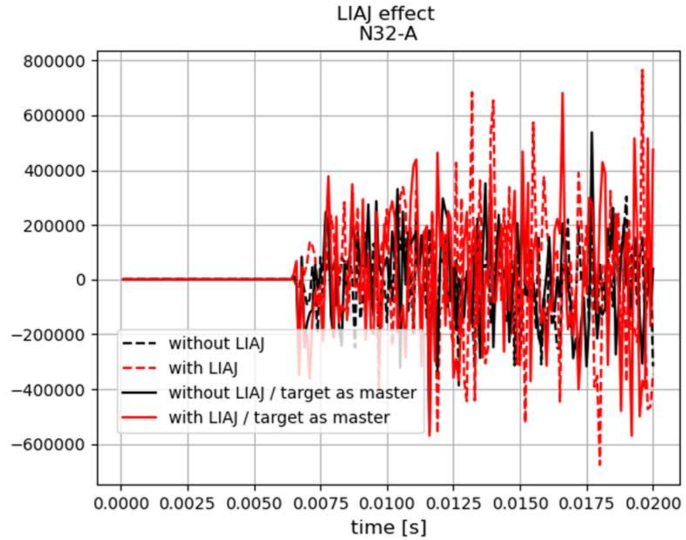
Case study – cross beam





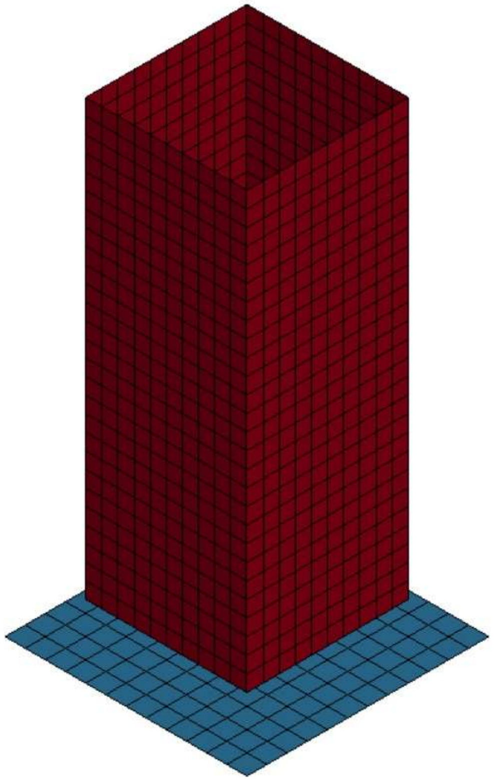


computation time step: 1,3 10^{-6} s

output time step: 10^{-4} s

Bouncing tube - introduction

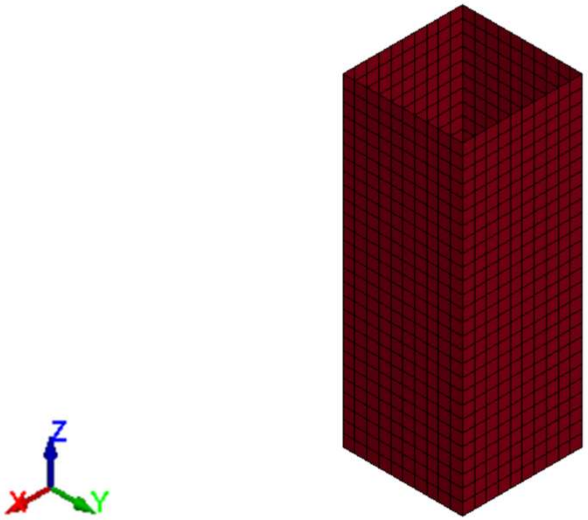
- **GOAL:** compare the results of a tube shock with a rigid surface between EPX and LS-Dyna
- **PROCEDURE**: the models provided by JRC are run on LS-Dyna with the necessary adjustment, and then results are compared

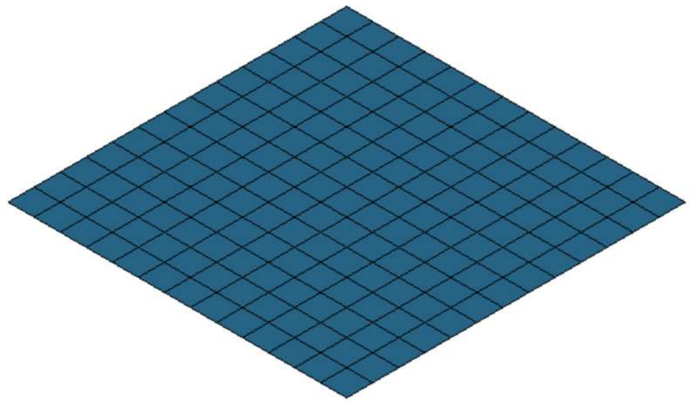


Tube model

Bouncing tube - model setup

- **One model is analyzed:** the model includes a squared section tube that impacts against a rigid flat barrier
- **Initial velocity toward Z direction:** -10 m/s
- The velocity is applied to every node of the **bouncing tube**





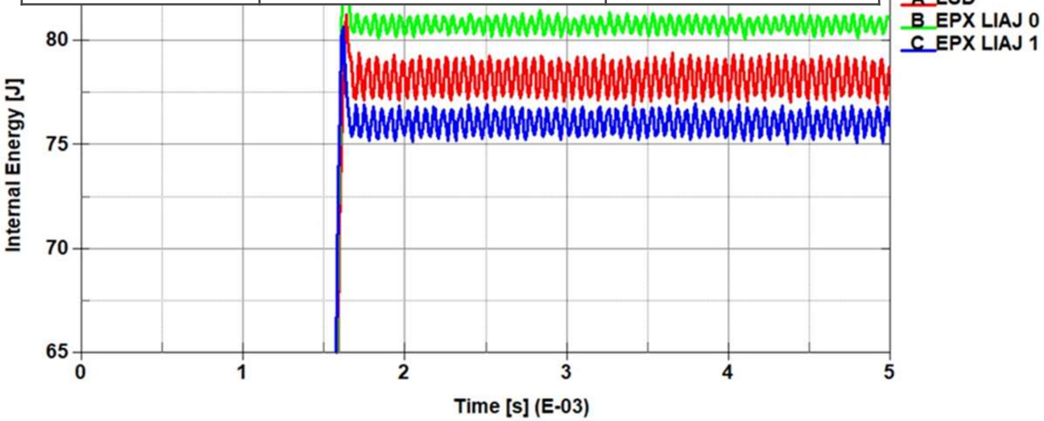
Tube mesh size: 10 mm

Barrier mesh size: 11.5 mm

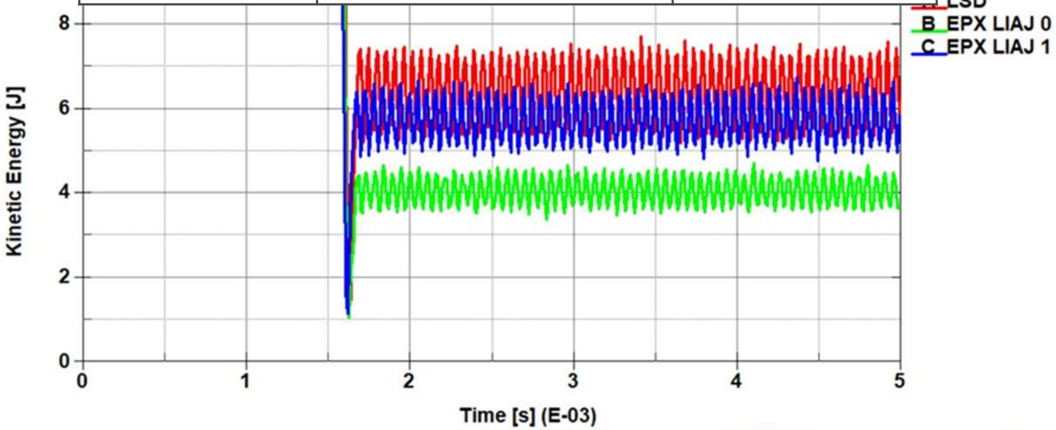
Termination time: 5 ms

Results - Plastic material case 1

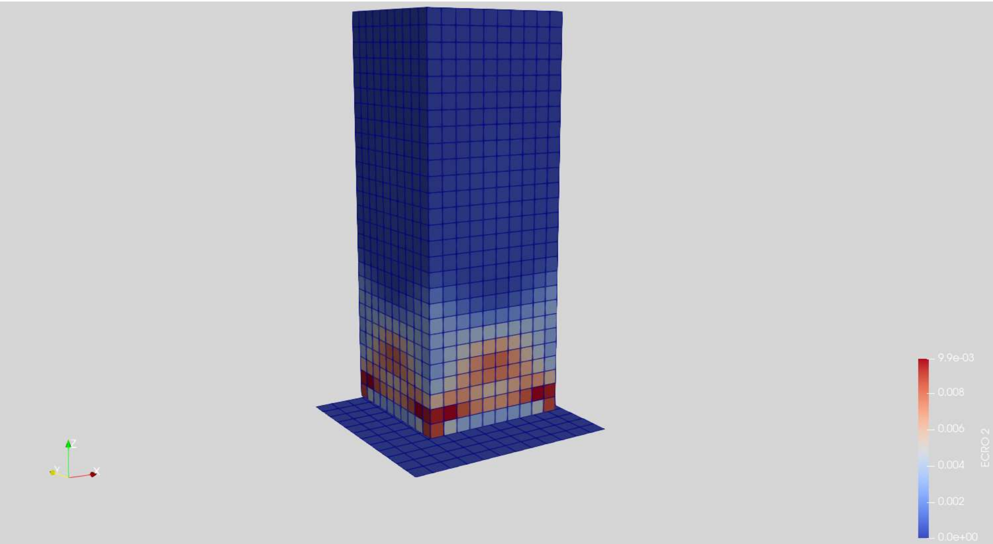
INTERNAL ENERGY	Mean value between 2 ms and 5 ms	%Error
LSD	78.2 J	
EPX LIAJ 0	80.8 J	3.2%
EPX LIAJ 1	76.1 J	2.7%

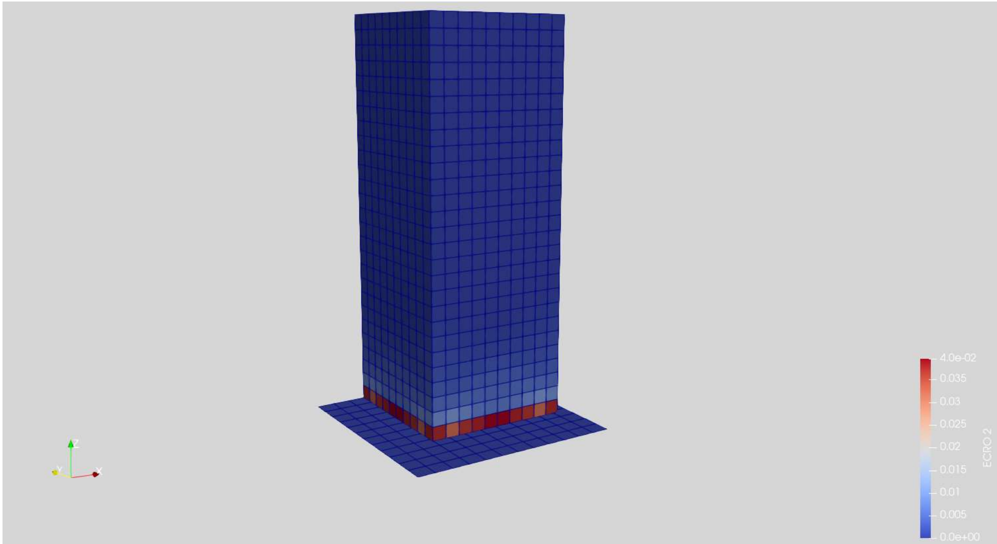


KINETIC ENERGY	Mean value between 2 ms and 5 ms	%Error
LSD	6.37 J	
EPX LIAJ 0	4.04 J	57%
EPX LIAJ 1	5.74 J	11%



Bouncing tube - plasticity





LIAJ ALPH 1.0

(default)

LIAJ ALPH 0.0

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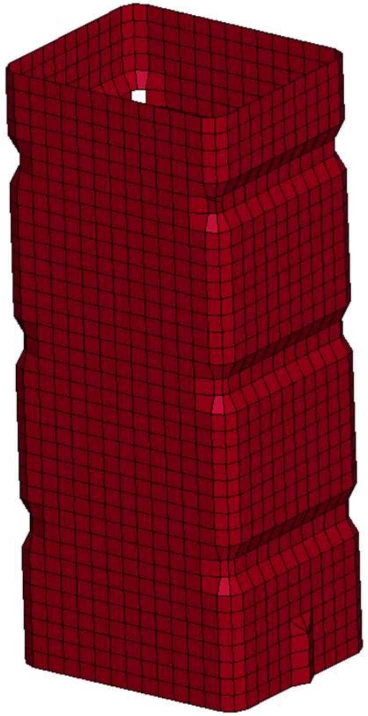
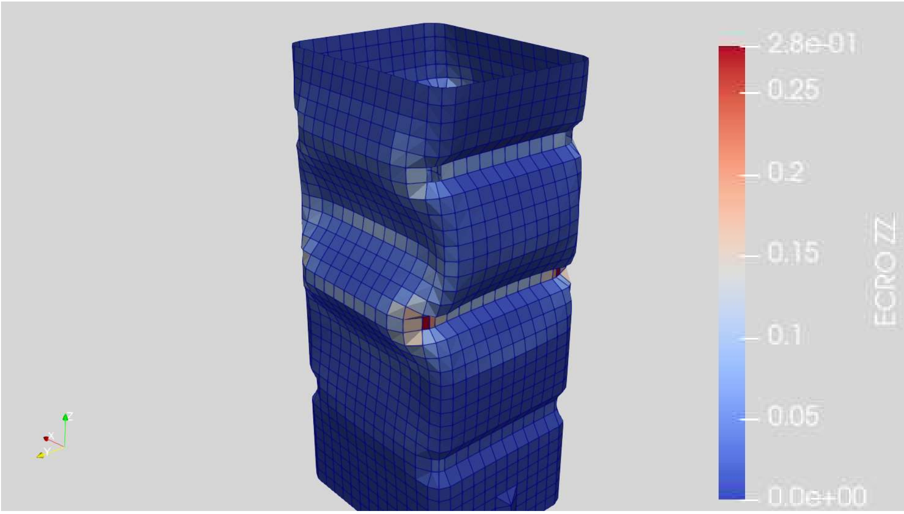
Crushing tube - introduction

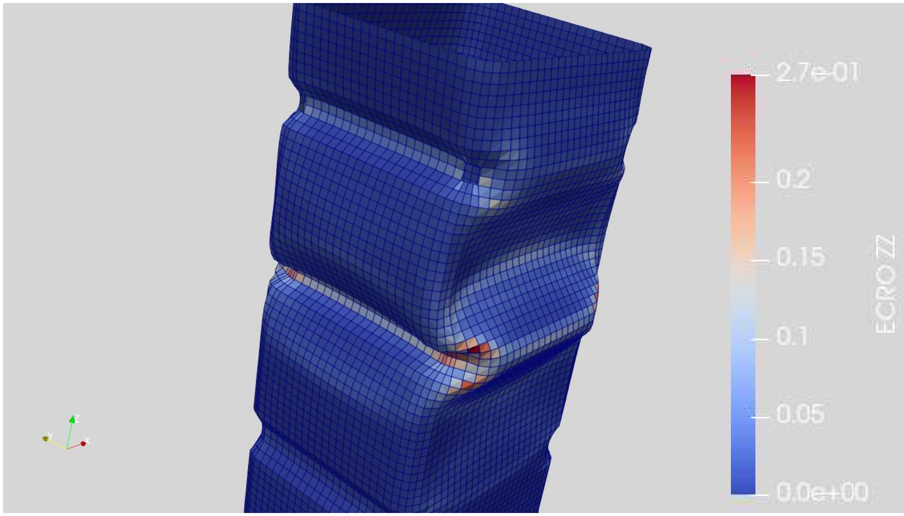
- **GOAL:** compare results of a tube crushing case study between EPX and LS-Dyna
- **PROCEDURE**: the models provided by JRC are run on LS-Dyna with the necessary adjustment, and then results are compared

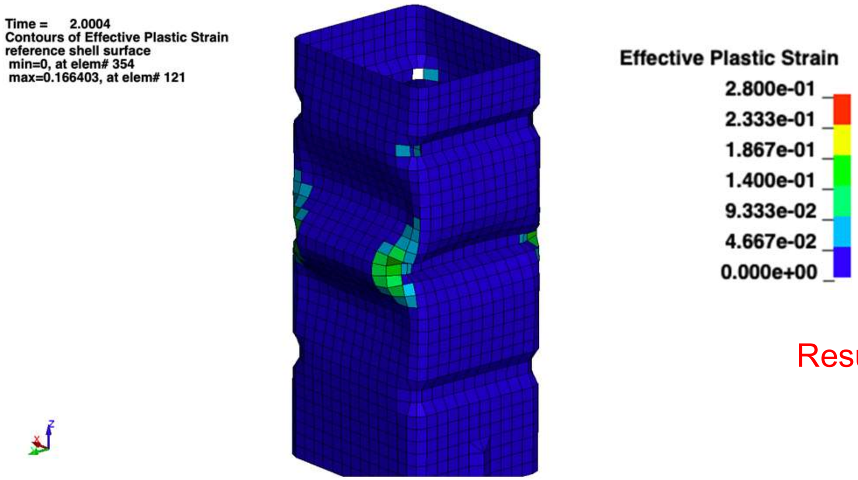


Tube model

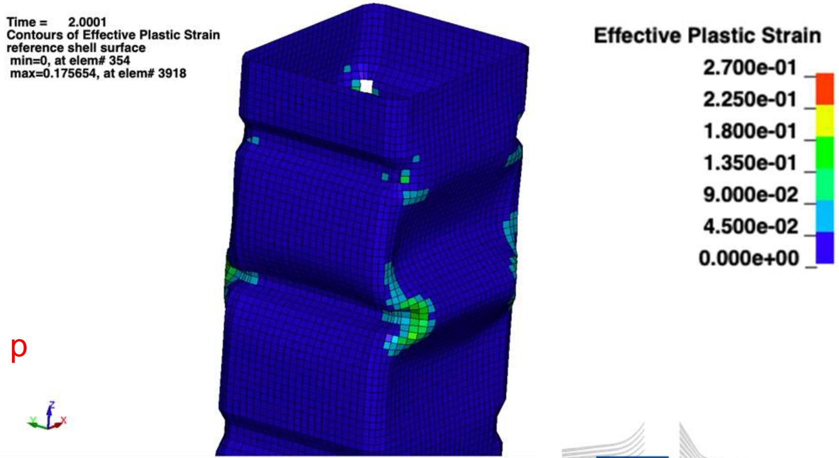
Deformation at 2 ms







Results without C and p coefficients



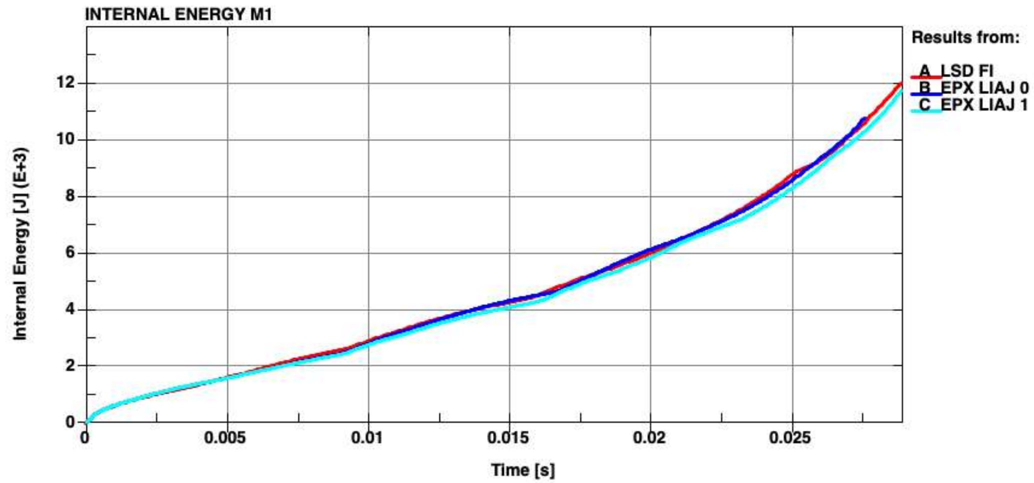
Crushing tube - results – M1

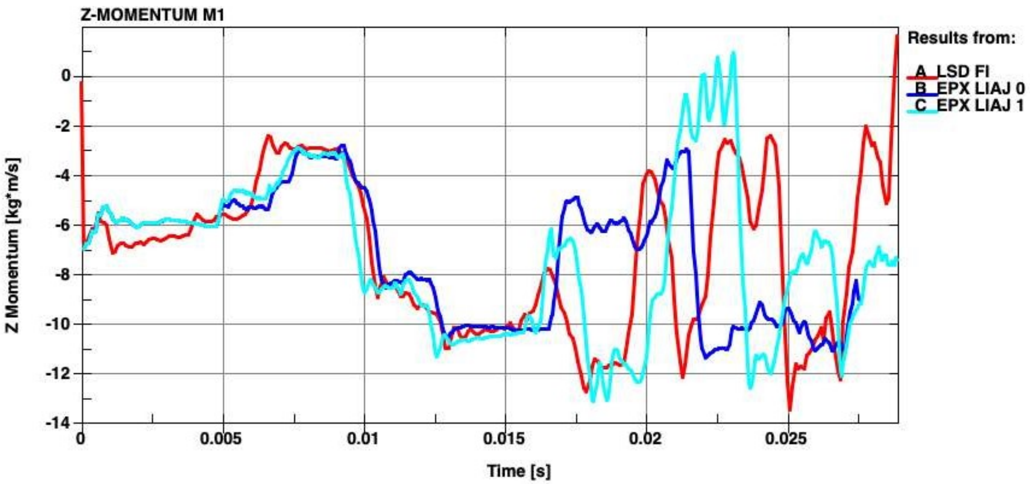
Initial momentum is not the same:

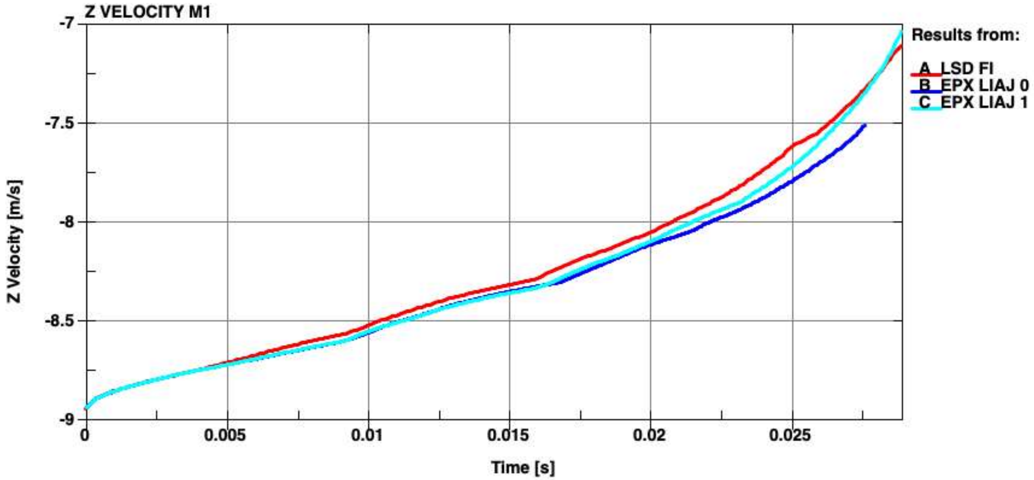
- LS-Dyna = -2.166e-01 kg*m/s
- EPX = -6.924 kg*m/s

Note:

- EPX first point of the momentum is at t = 1.00e-04 s
- LSD first point of the momentum is at t = 0 s





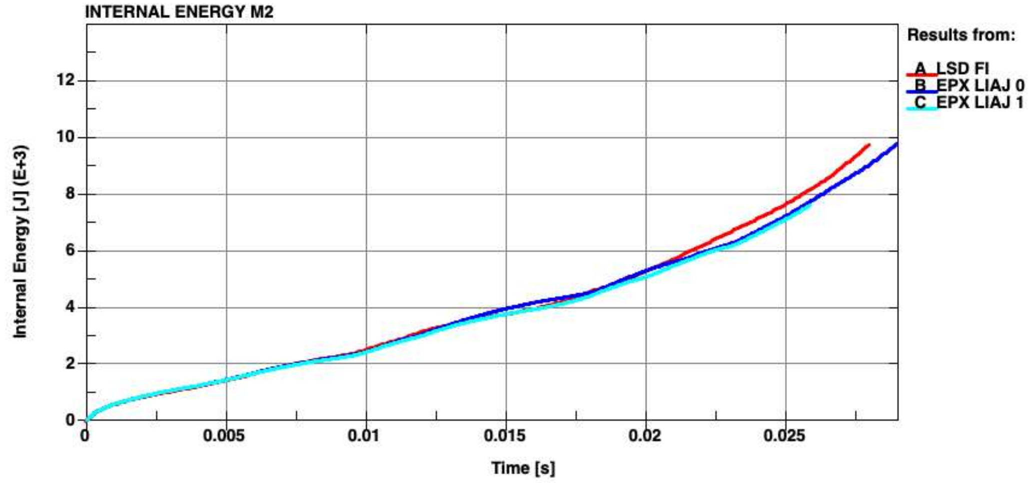


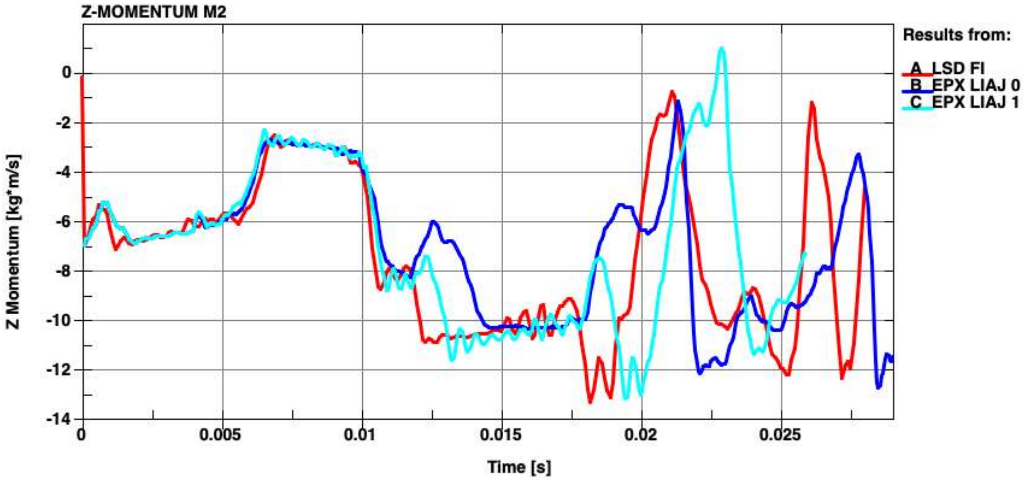
Note: Velocity is extracted from node 3, but it is equal in all top nodes

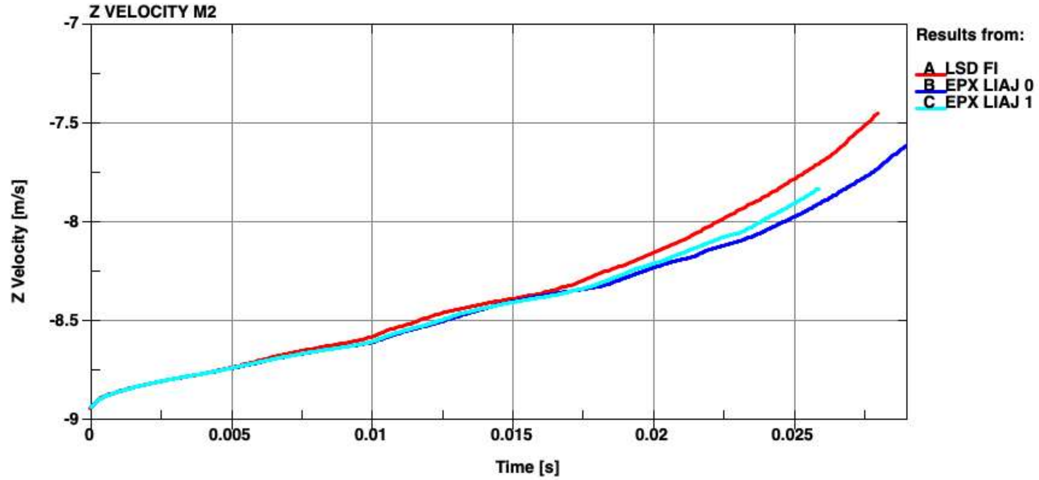
Crushing tube - results – M2

Initial momentum is not the same:
- LS-Dyna = -1.083e-01 kg*m/s
- EPX = -6.256 kg*m/s

Note:
- EPX first point of the momentum is at t = 1.00e-04 s
- LSD first point of the momentum is at t = 0 s







Note: Velocity is extracted from node 3, but it is equal in all top nodes

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EPX comparisons with LS-Dyna

- Contact-impact without friction – **satisfactory**
- Elasto-plastic material – **satisfactory**
- Shell formulation – **EPX could be improved**

EPX testing and development - next steps

- Contact with friction
- Rigid body constraints
- Mechanisms (suspension systems, directions, etc.)

Thank you

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