Impact Simulation of Extreme Wind Generated Missiles on Radioactive Waste Storage Facilities

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Outline of the presentation

- Introduction
- Formulation of the problem
- Model validation
- Hard impact simulation
- Soft impact simulation
- Conclusions

Design of safety-related nuclear structures

Highly severe performance criteria have to be satisfied in the design of temporary storage facilities for radioactive waste

- earthquakes
- floods
- explosions
- extreme winds
  - wind pressure
  - generated missiles

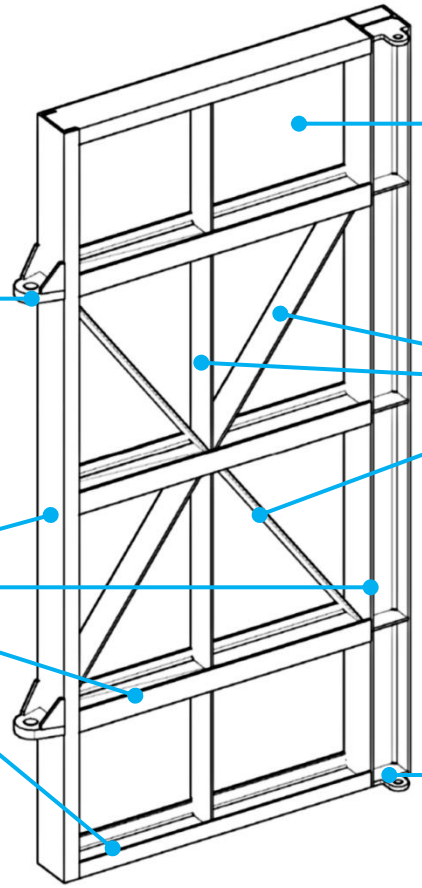
small objects – high impact velocity
cylindrical steel tube

large objects – low impact velocity
automobile

		automobile	steel tube
mass	[kg]	1000.00	35.0
velocity	[m/s]	12.25	24.5
kinetic energy	[kJ]	75.00	10.5
linear momentum	[kg m/s]	12250.00	857.5

Introduction – the door structure

Internal side view



shielding panel
10 mm thick plate

supporting hinge

stiffening ribs

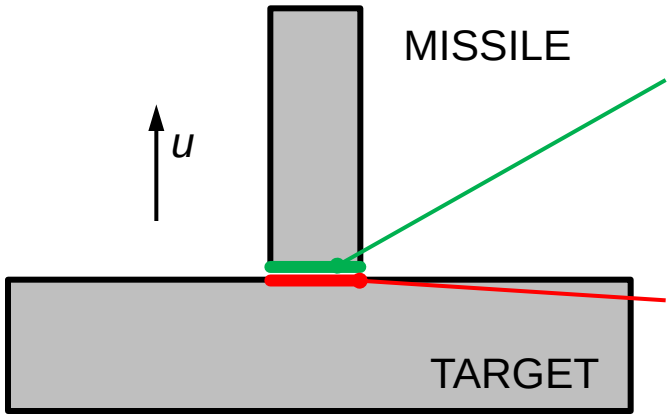
structural frame
UPN, IPE and HEA beams

bracket pin-hole

door size
2.1 × 4.0 m (L × H)

Formulation of the problem

Use of the “general extrusion” tool



genext2 definition surface

$$\Delta_M(u) = g = u_T - u_M = \text{genext1}(u) - u$$

genext1 definition surface

$$\Delta_T(u) = g = u_T - u_M = u - \text{genext2}(u)$$

Contact force (penalty formulation)

$$F_c(g,\dot{g}) = \left(k_c g + c_c \dot{g}\, h(\dot{g})\right) h(g)$$

unit step function

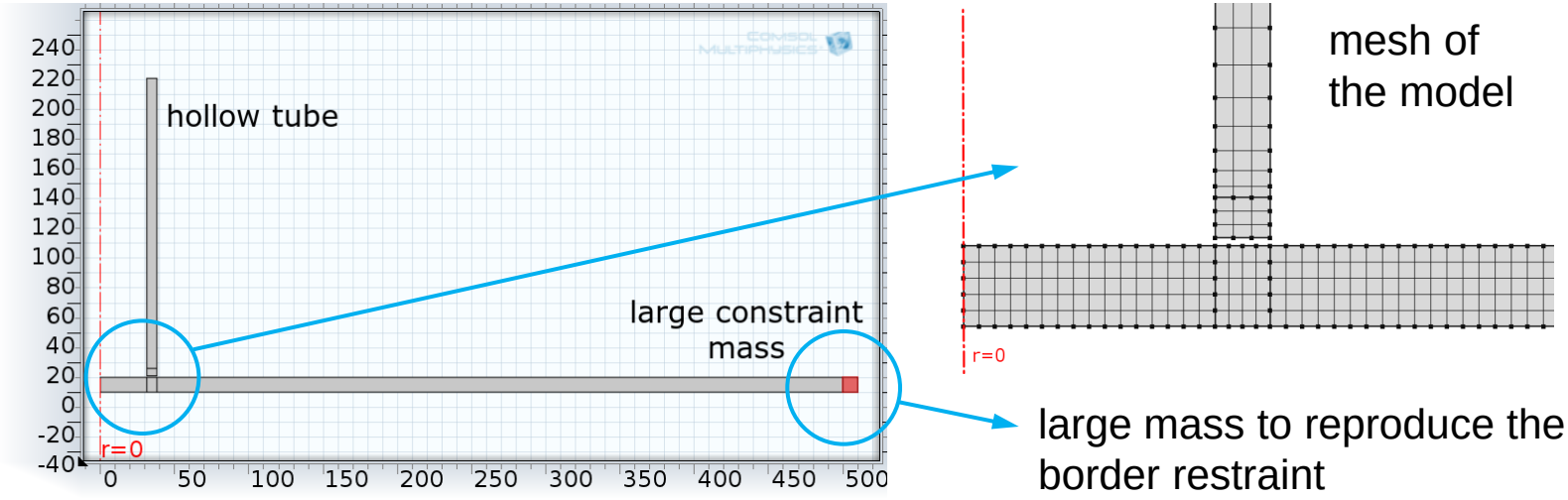
penalty parameters $c_c = 2\,\xi\sqrt{k_c m}$

Dynamic equilibrium equations solved via a step-by-step time integration algorithm based on second order backward difference scheme

Model validation – 2D axisymmetric test case

Circular plate hit by an hollow steel tube – 2D axisymmetric model

Check of linear momentum conservation principle

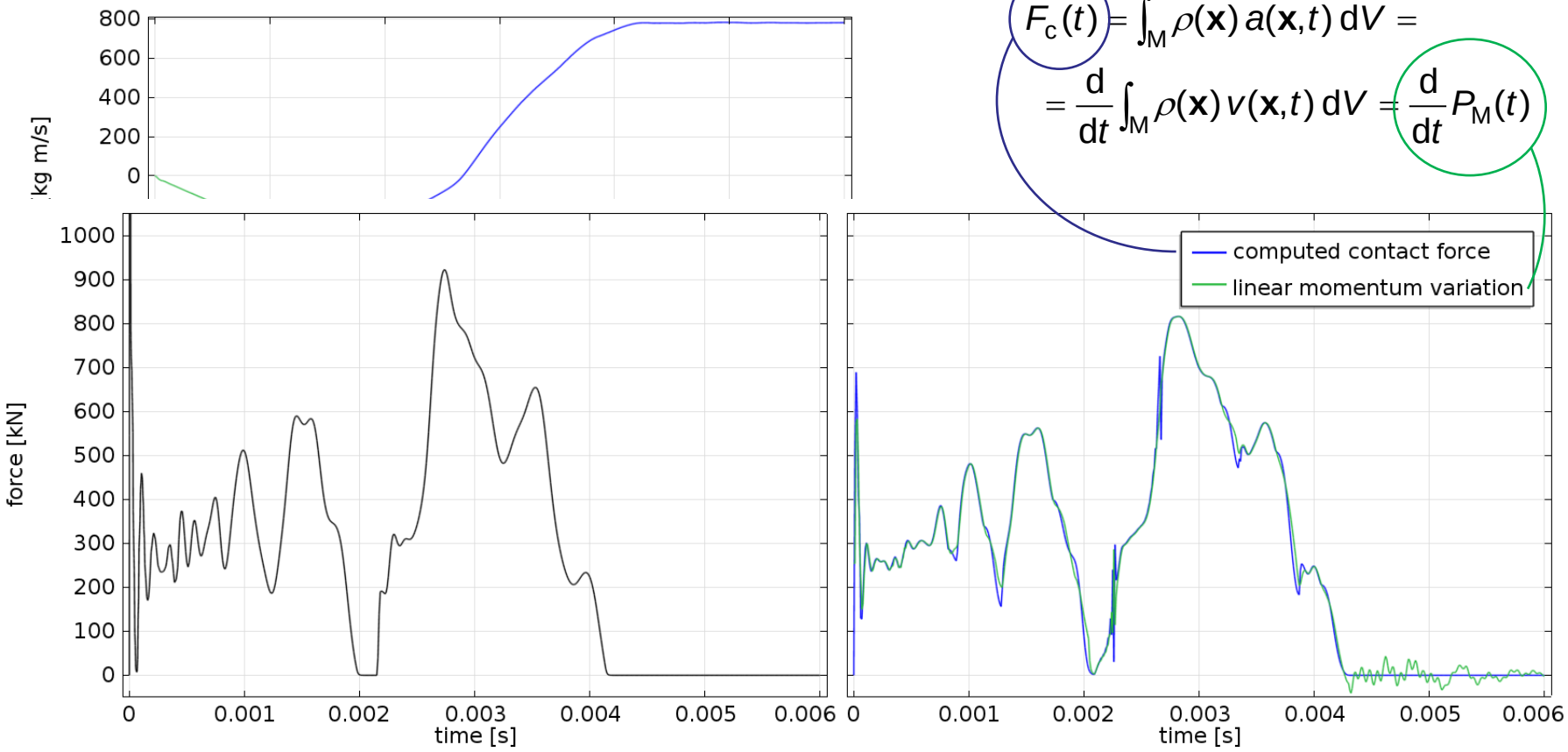


Model validation – 2D axisymmetric test case

Linear momentum balance

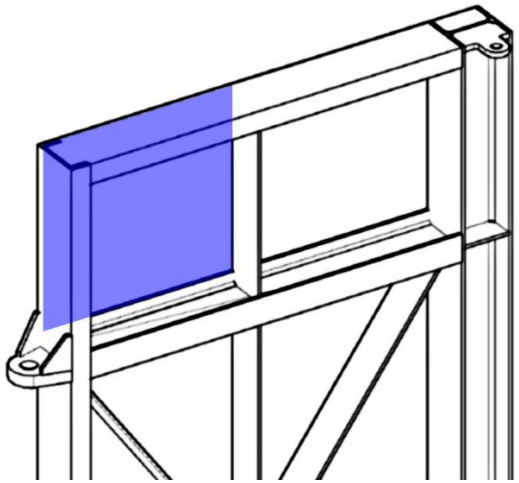
$$F_c(t) = \int_M \rho(\mathbf{x})\, a(\mathbf{x},t)\, dV =$$

$$= \frac{d}{dt}\int_M \rho(\mathbf{x})\, v(\mathbf{x},t)\, dV = \frac{d}{dt} P_M(t)$$

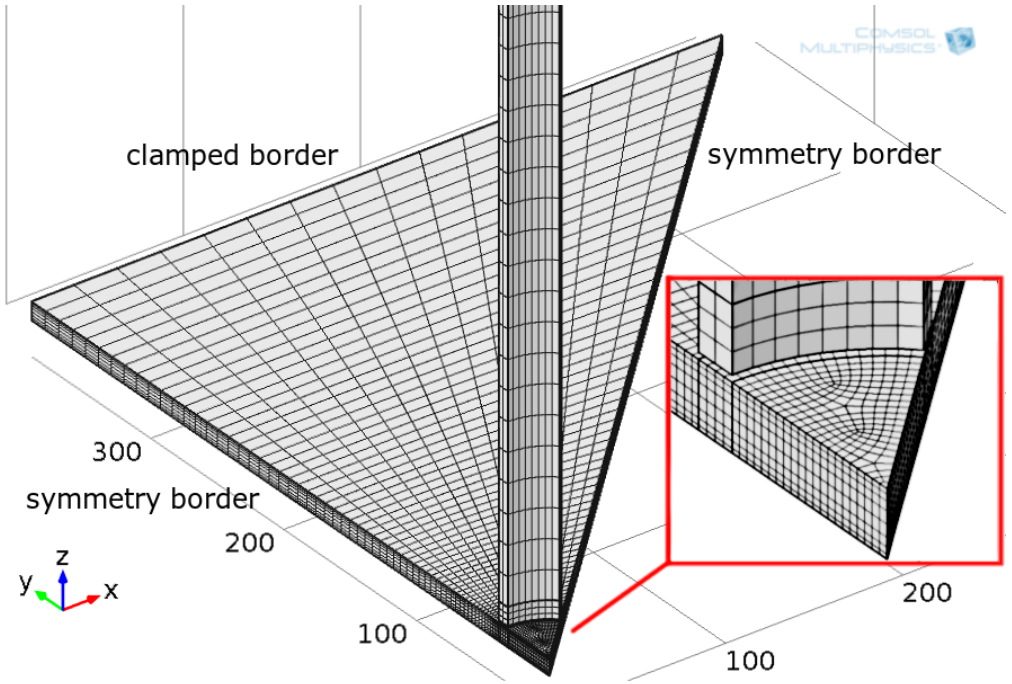


Hard impact simulation – steel tube collision

Local model of a single square frame of the shielding panel



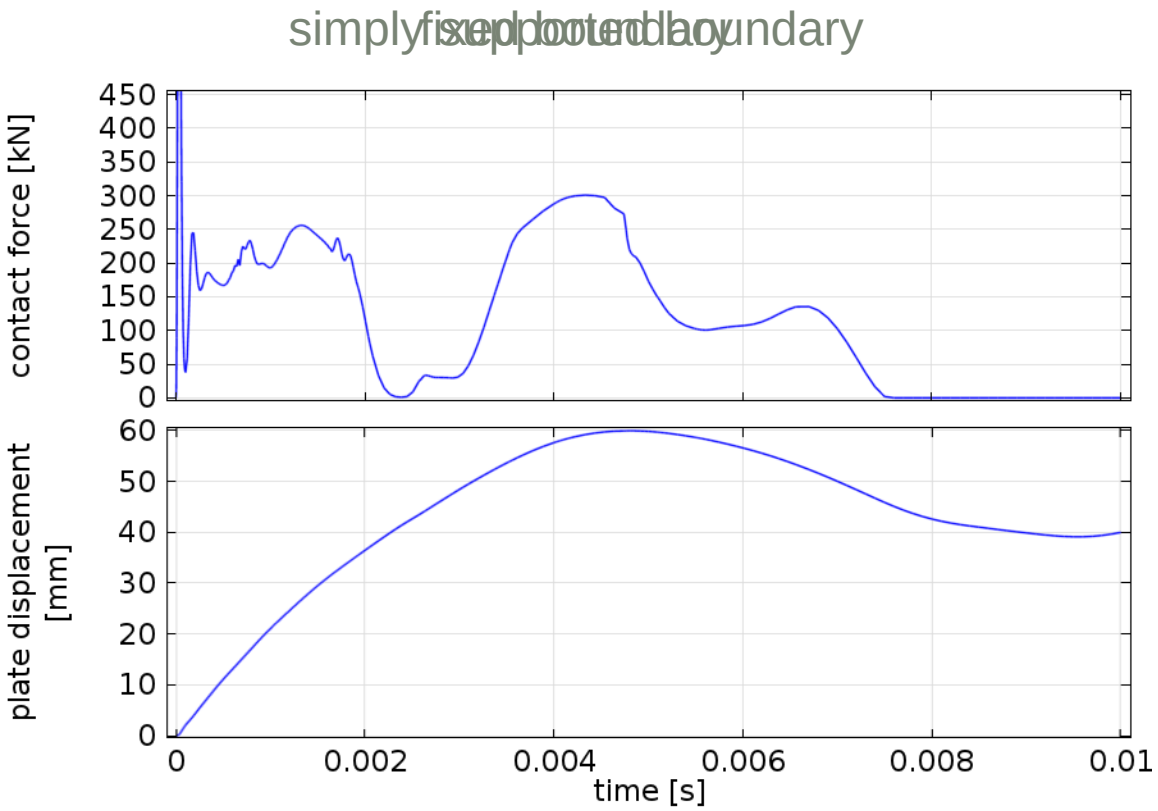
frame size
780 × 780 mm



Young modulus	E	210000 MPa
Poisson modulus	v	0.3
yielding stress	$\sigma_{y,0}$	410 MPa
hardening modulus	E_{iso}	654 MPa

Hard impact simulation – steel tube collision

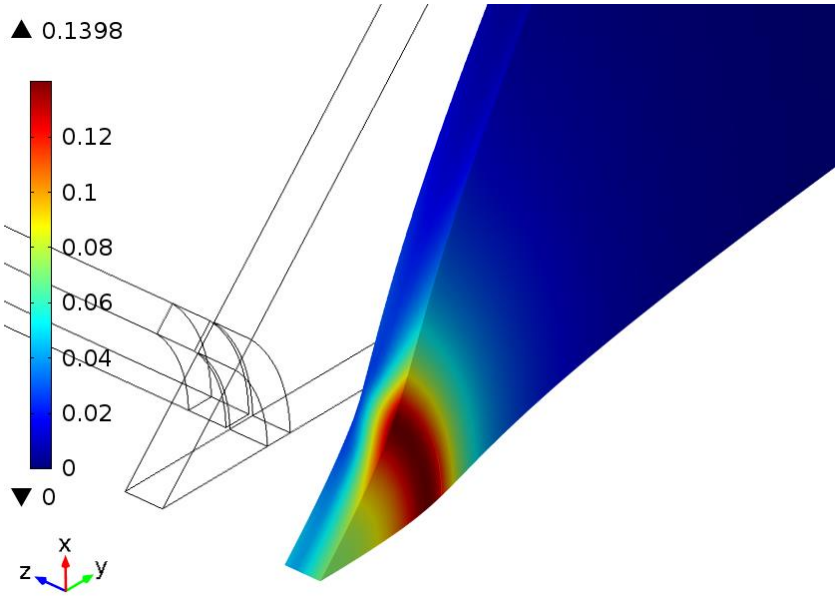
Computed contact force and plate displacement



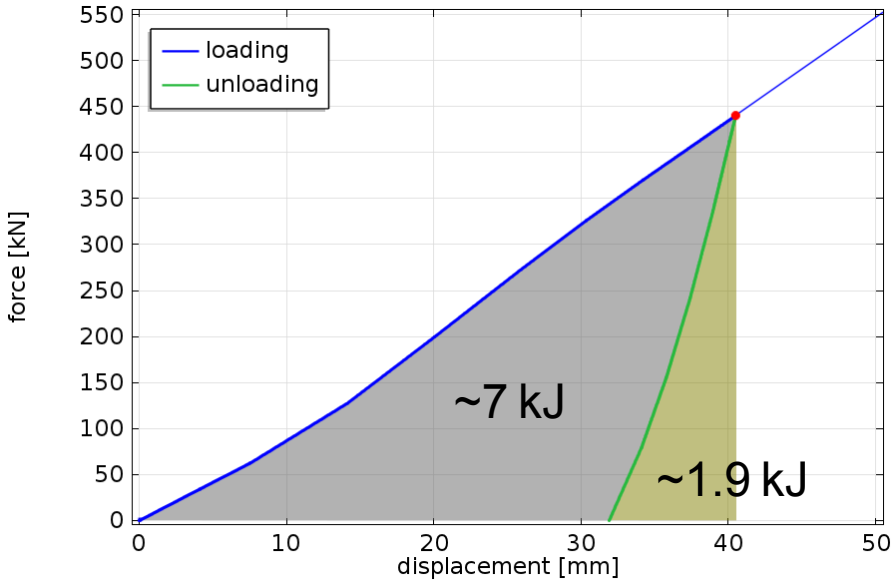
Hard impact simulation – steel tube collision

Energy dissipation (fixed boundary model)

Comparison with a quasi-steady non-linear analysis (push-over)



effective plastic deformation at t = 3 ms



missile kinetic energy: 10.5 kJ

Missile rebound velocity is 6.1 m/s, residual kinetic energy is 0.65 kJ

Soft impact simulation – automobile collision

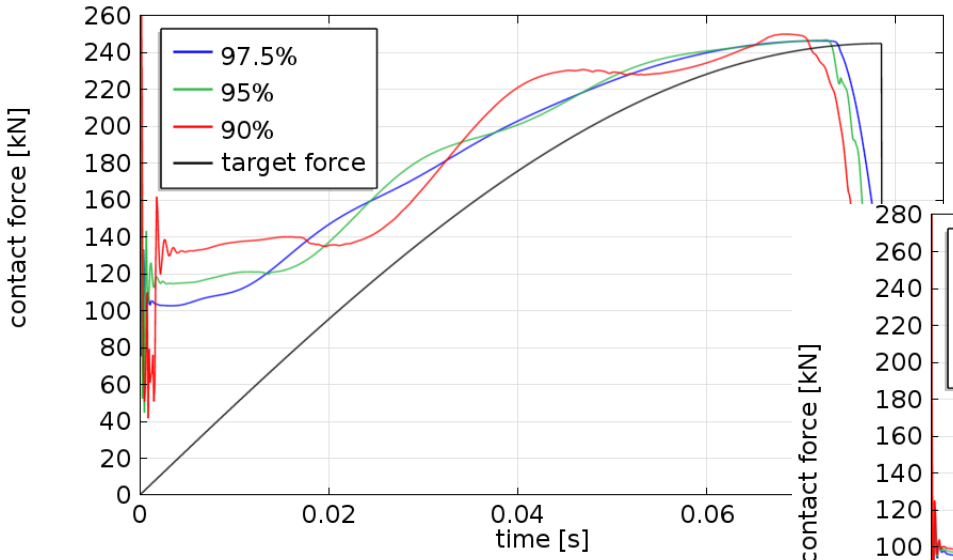
- The missile is modeled as a solid block having the same global mass and velocity of the reference automobile
- Dimensions of the block are $1 \times 1.6 \times 4$ m (H × L × P), H × L being the impact area
- The progressive damage of the automobile structures and the resulting internal energy dissipation is globally reproduced by tuning the non-linear material characteristics of the missile
- Material parameter are set in order to reproduce the experimental force time history of a car crash into a rigid wall, which can be analytically approximated as

  $$Q(t) = 20\ s^{-1}\ m\ v_0 \sin(20t)$$

  with an impact duration of 0.0785 s
- This implies the assumption of a perfectly inelastic collision

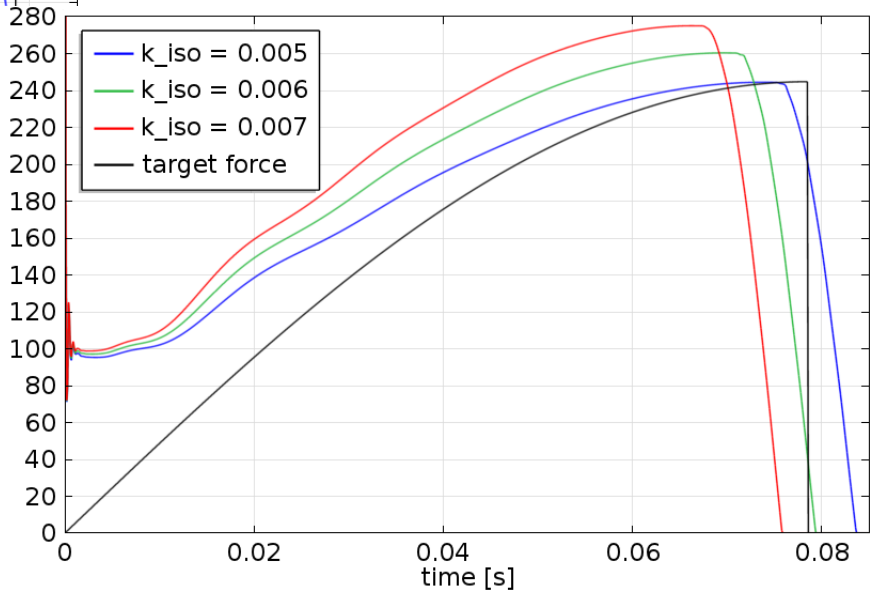
Soft impact simulation – missile calibration

Automobile crash into a rigid wall – parameter tuning



mass distribution
(percent refers to the amount of mass concentrated in the face opposite to the impact side)

isotropic hardening modulus $E_{iso} = k_{iso} E$



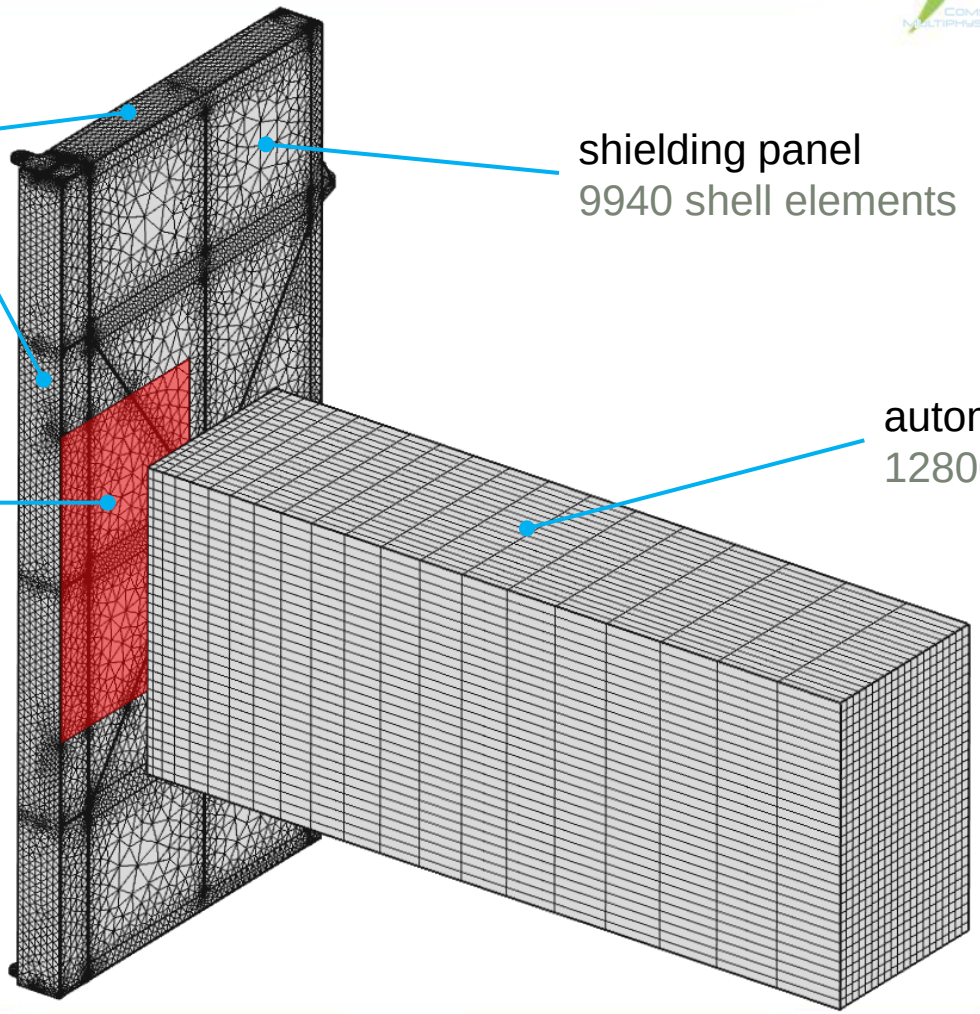
Soft impact simulation – the global model

structural frame and
stiffening ribs
76738 brick elements

shielding panel
9940 shell elements

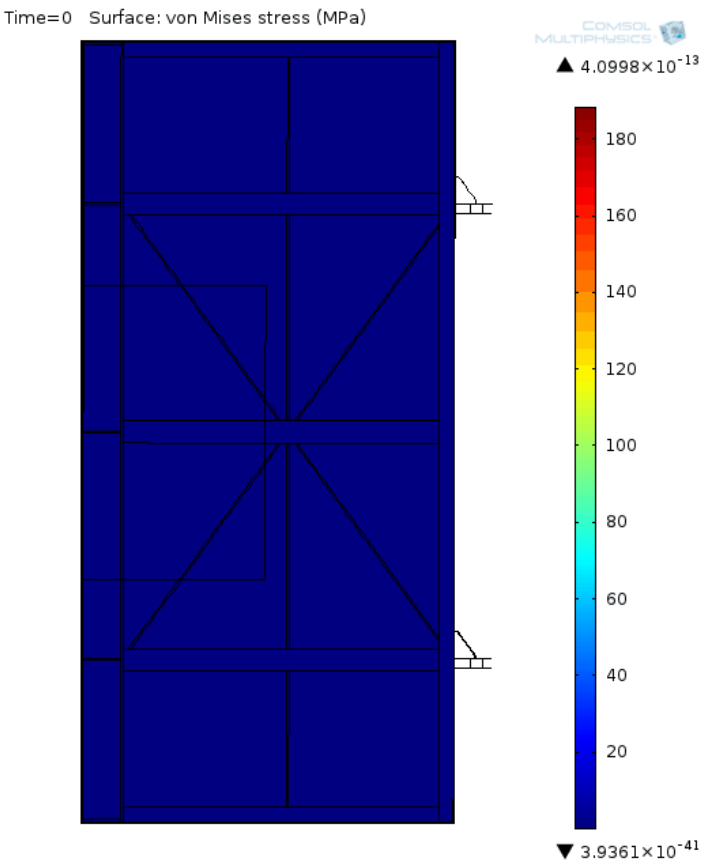
automobile solid block
12800 brick elements

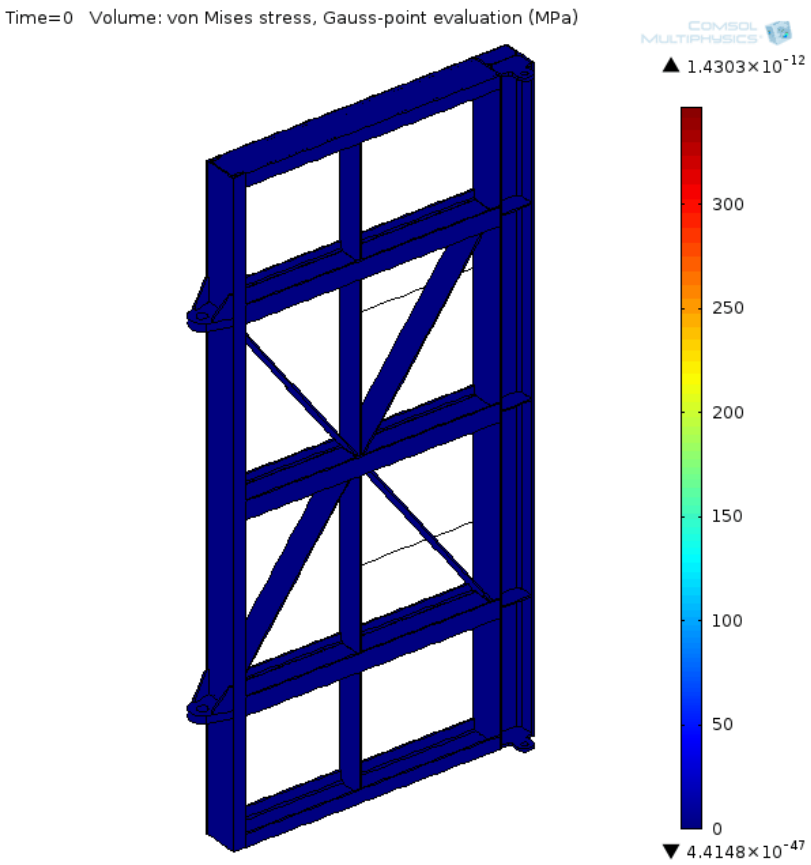
impact area



Soft impact simulation – results

Von Mises stress contour plot (elastic case)



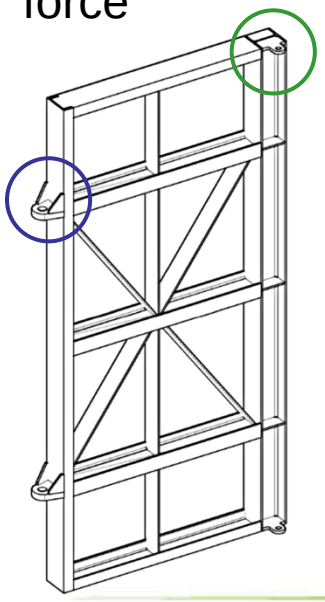


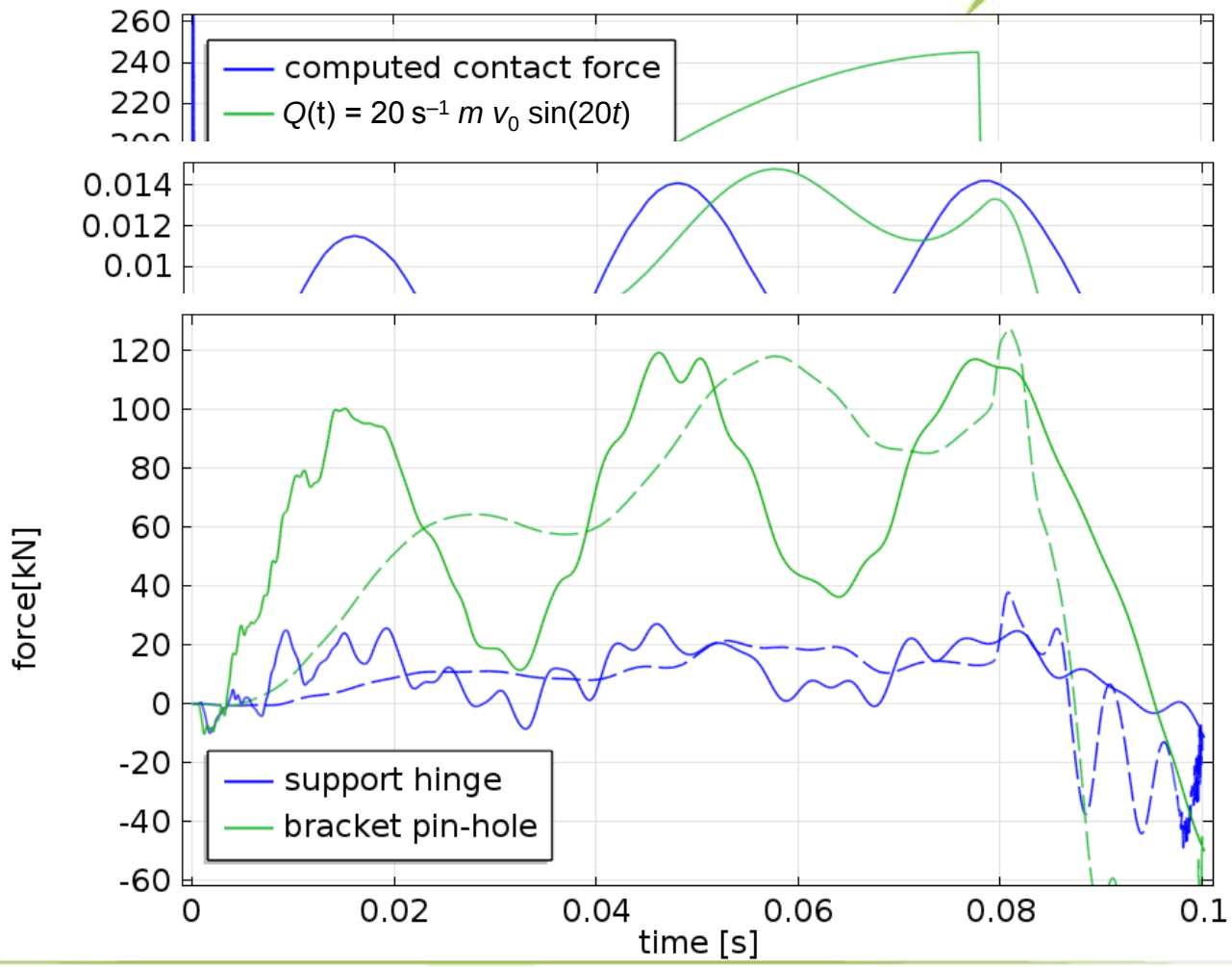
Soft impact simulation – results

impact force

maximum displacement

reaction force





Conclusions

- A procedure for the dynamic simulation of impact phenomena, with the explicit modeling of the mutual exchange of contact forces between the impacting objects is presented and tested
- Validation tests on a simple case are performed
- A real-life example of a steel door subject to the impact of extreme wind generated missiles is analyzed and the results are shown, giving evidence that Comsol Multiphysics is a useful tool also for the dynamic simulation of impact problems