HyTunnel-CS
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CFD and FEM study of hydrogen tank rupture on tunnel structure

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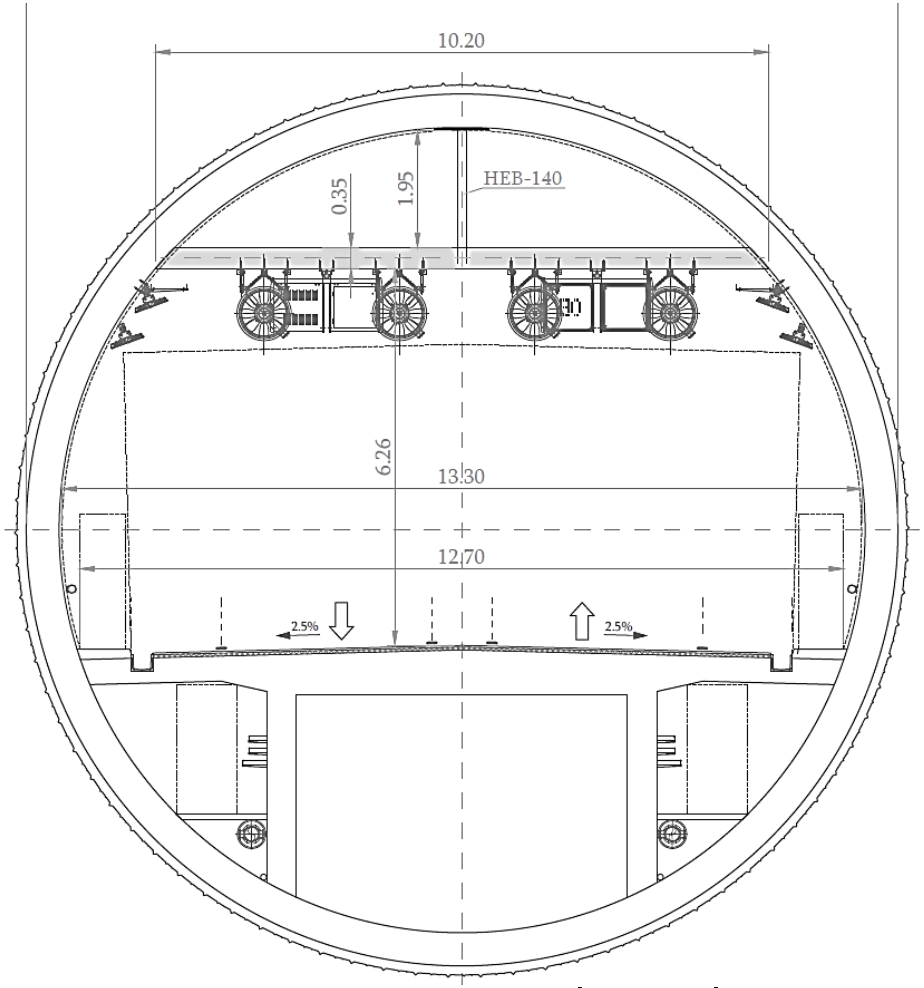
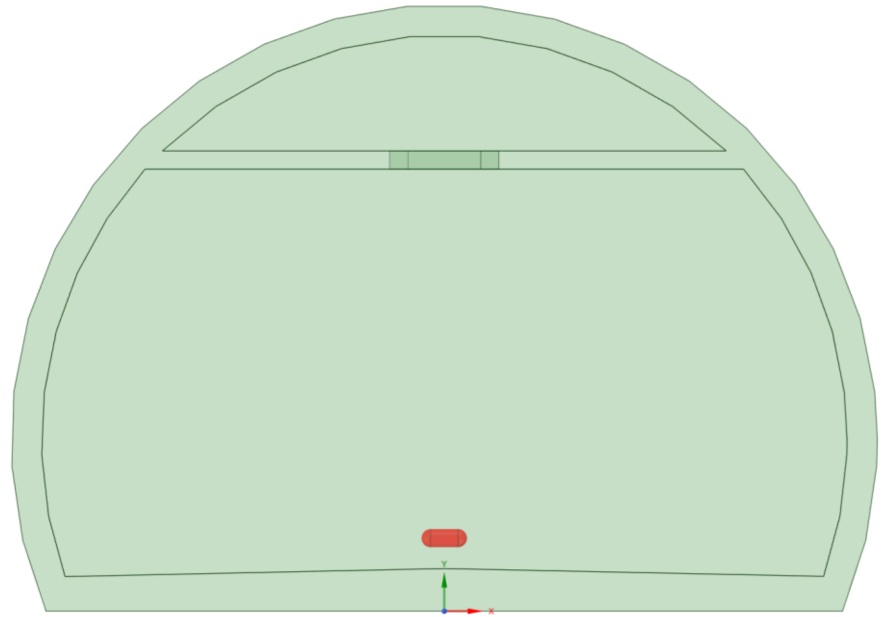
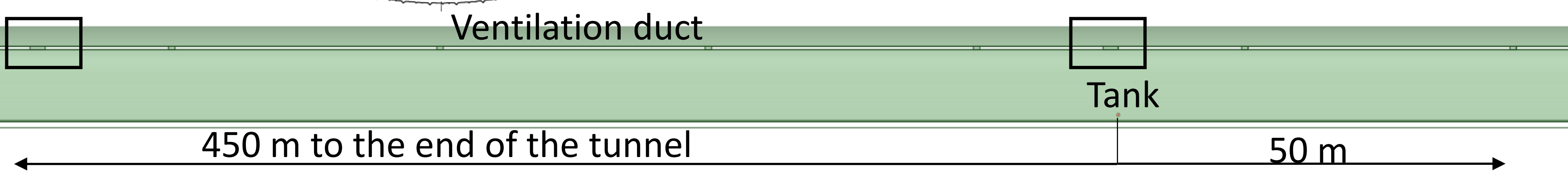
Blast wave in a tunnel (CFD/FEM)

Problem formulation



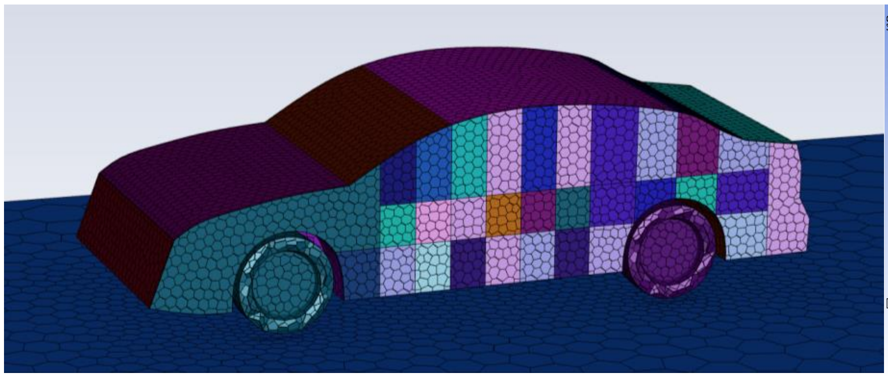


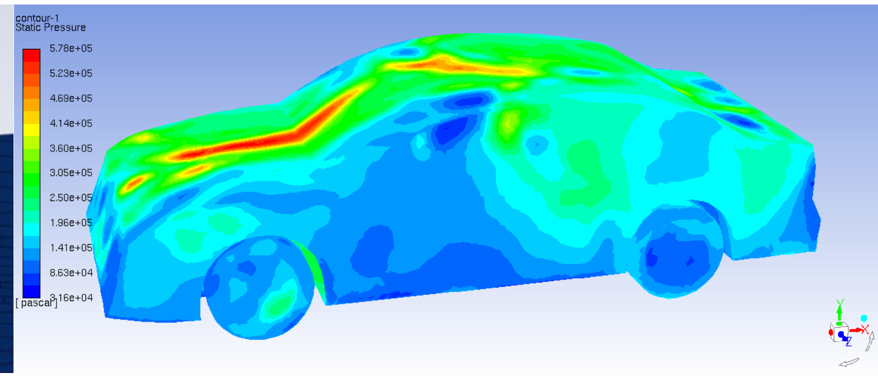


BW in a tunnel

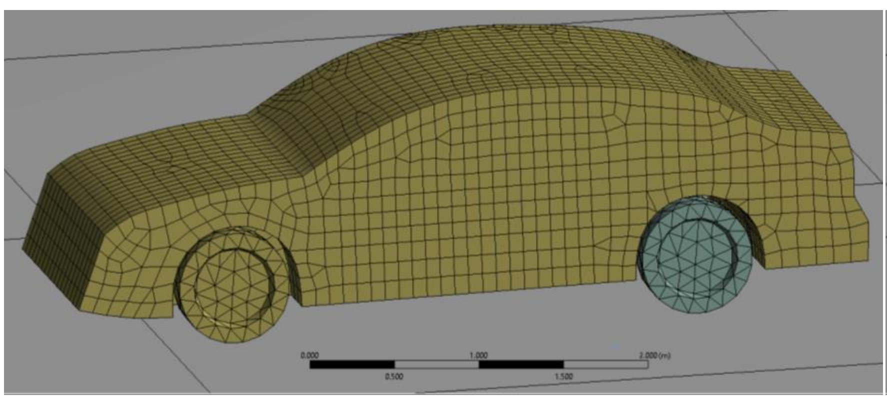
Problem formulation

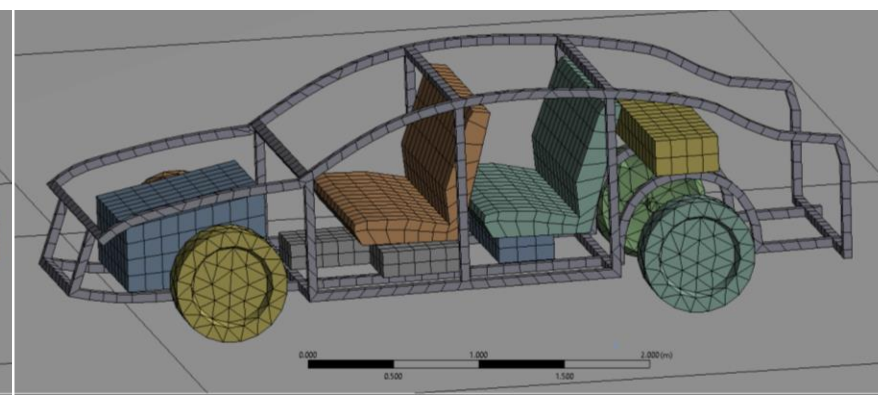
CFD: ANSYS Fluent model, mesh and solution





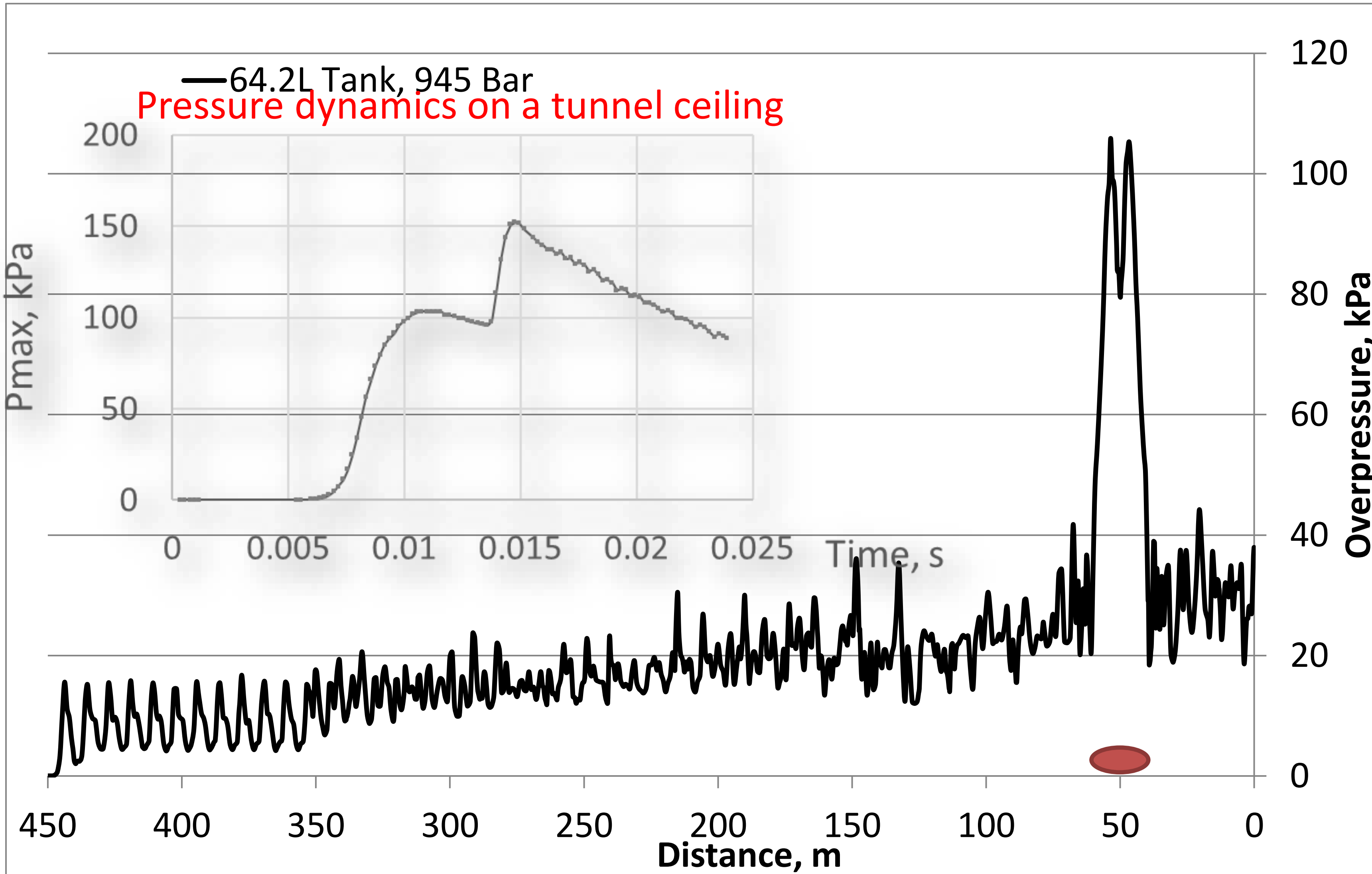
FEM: ANSYS Explicit Dynamic model and mesh view





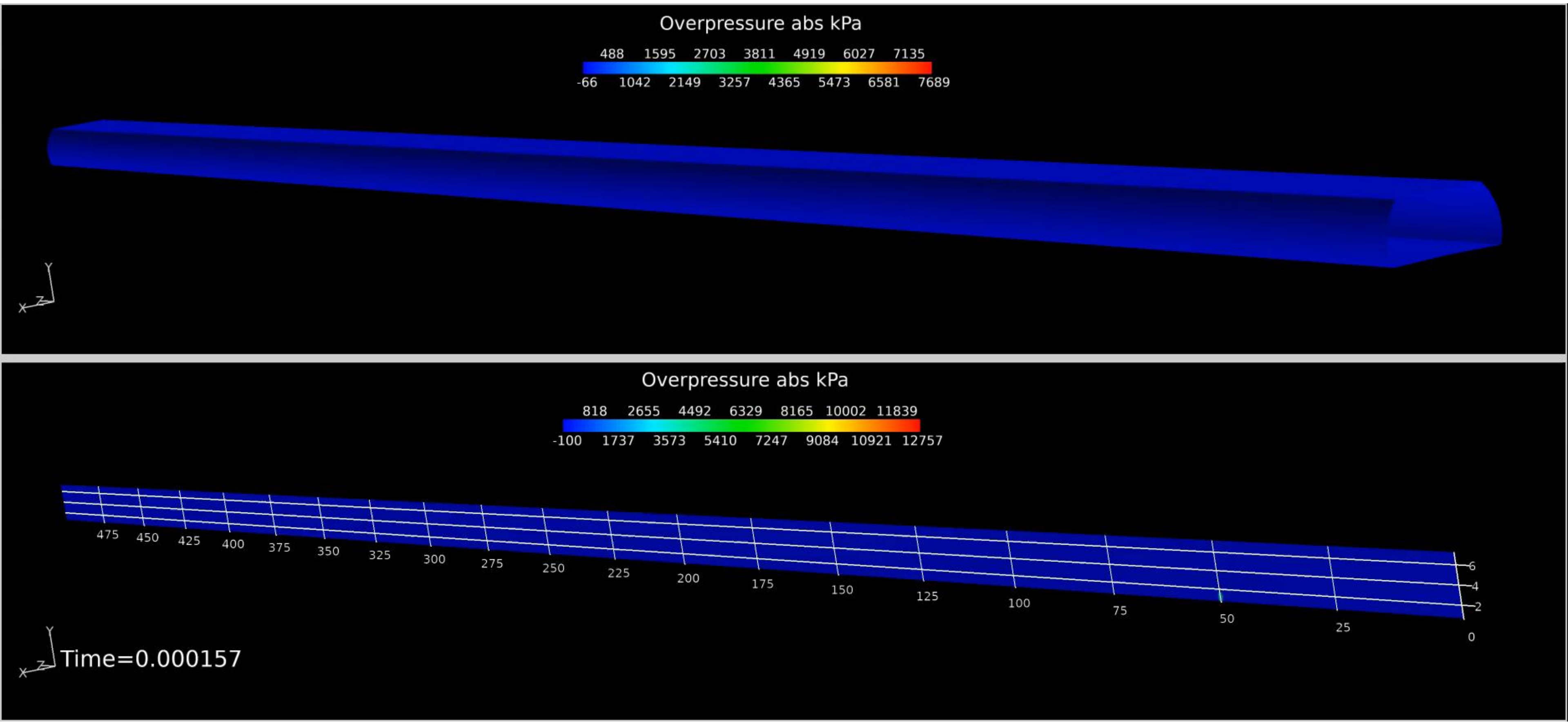
Simulation results (CFD)

Pressure dynamics in tunnel and at the ceiling



Simulation results (inputs to FEM)

Pressure dynamics at the ceiling (video)

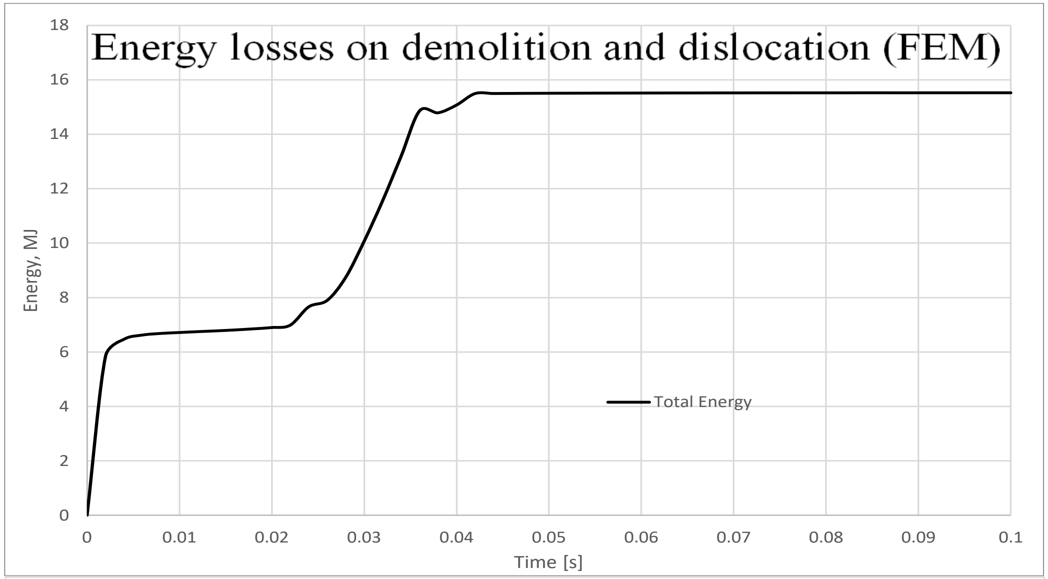


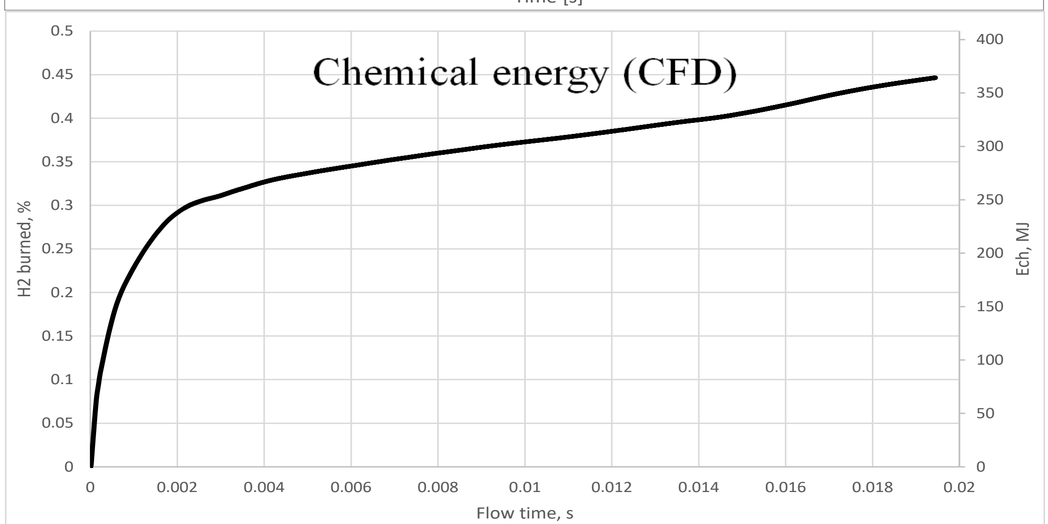
BW effect on vehicle

Pressure dynamics

BW in a tunnel

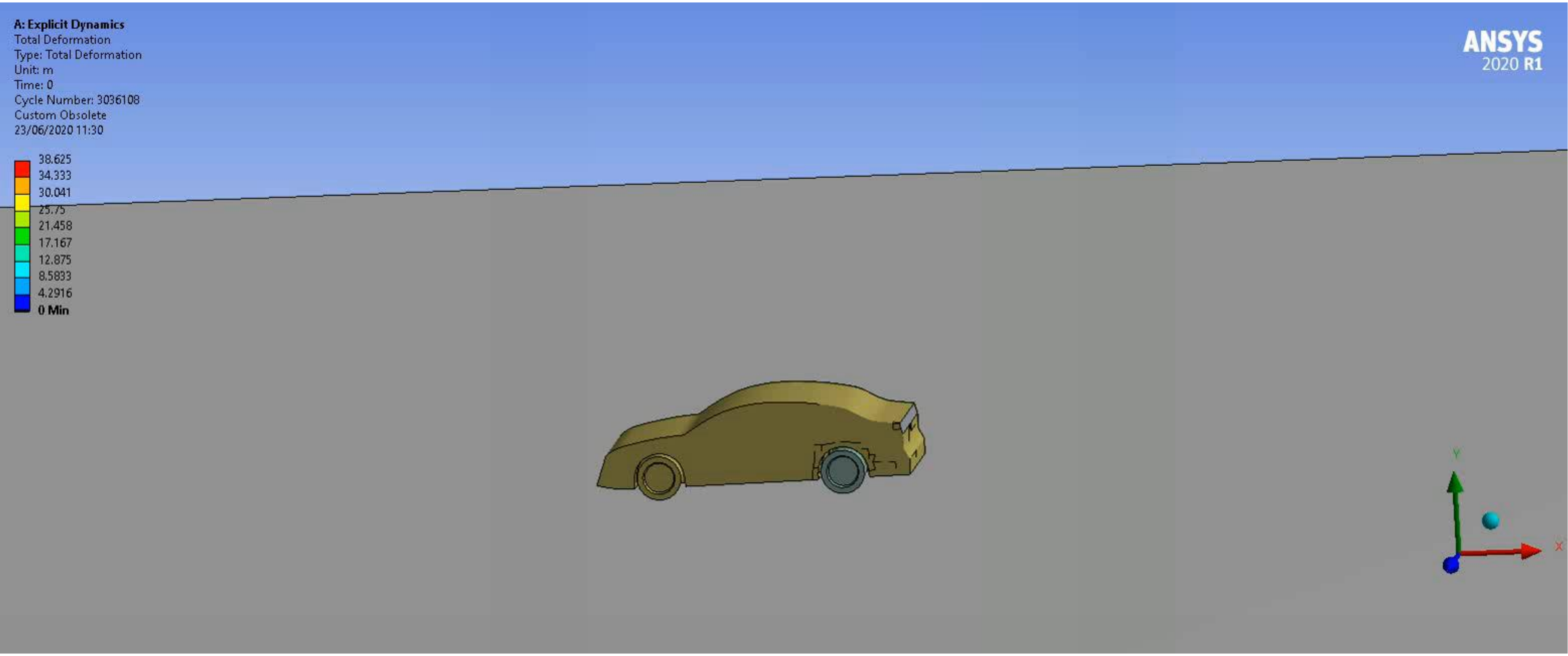
Energy release and losses





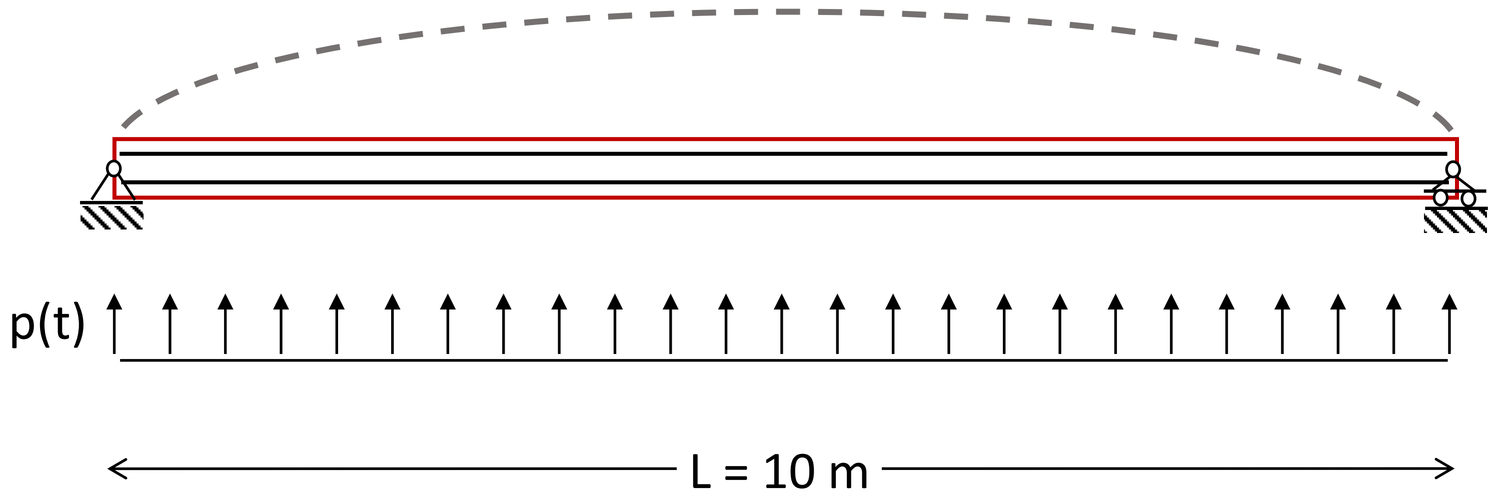
BW in a tunnel

FEM video

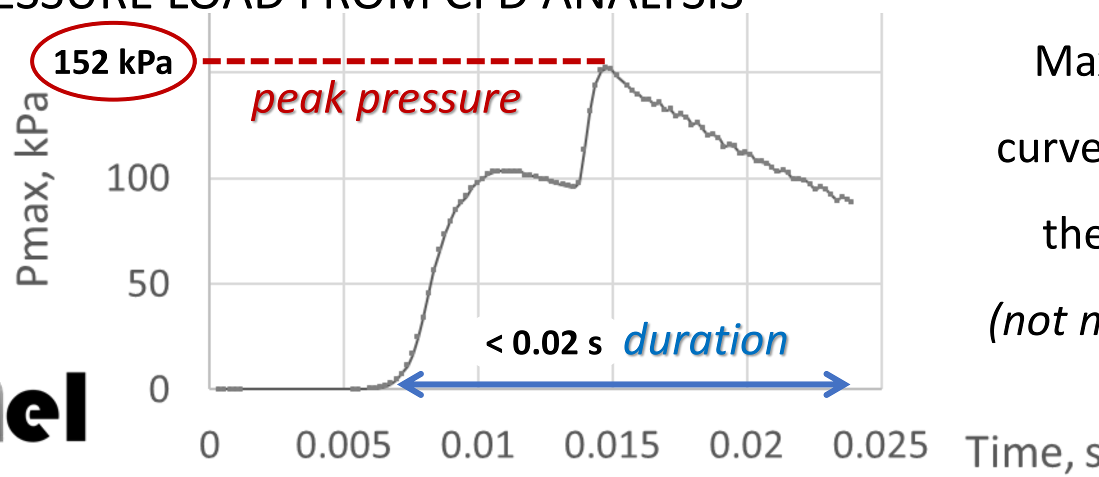


Case study

Boundary conditions



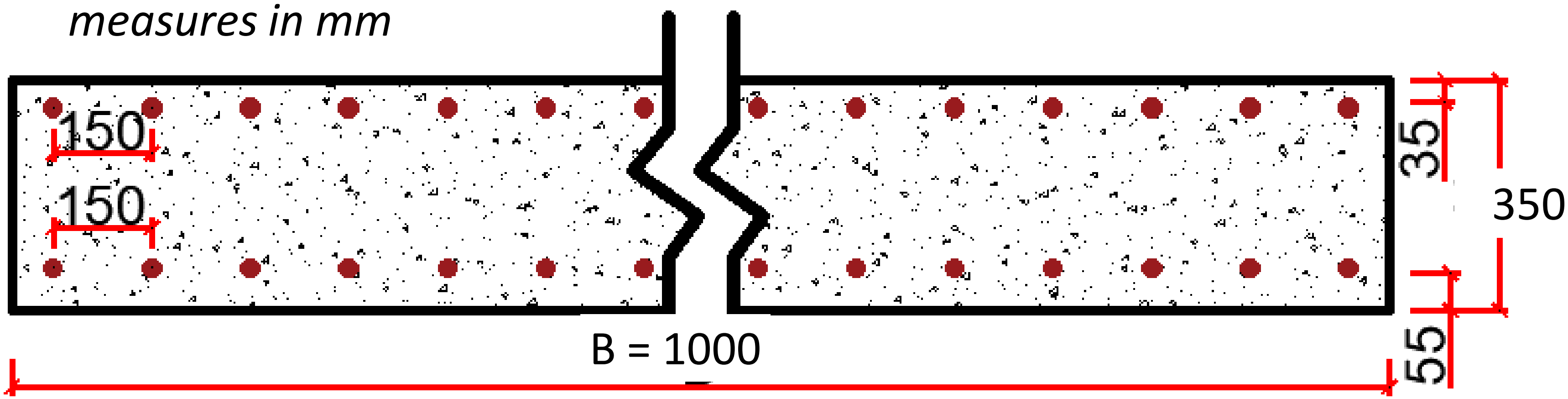
❖ PRESSURE LOAD FROM CFD ANALYSIS



Maximum pressure-time curve is applied uniformly to the slab bottom surface *(not necessarily conservative)*

Case study

Mechanical properties and cross-section geometry



Concrete						Reinforcement			
f_{ck} (MPa)	f_{ctm} (MPa)	E_{cm} (GPa)	ε_{c1} (%)	ε_{cu1} (%)	ρ_c (kg/m^3)	E_s (GPa)	f_y (MPa)	Bar Ø (mm)	ρ_s (kg/m^3)
35	2.2	34	0.225	0.35	2400	200	500	16	7850

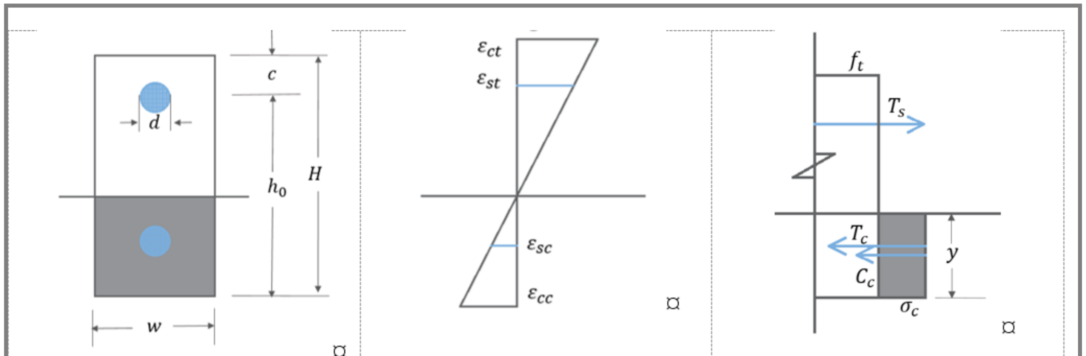
Case study

Static capacity of the slab

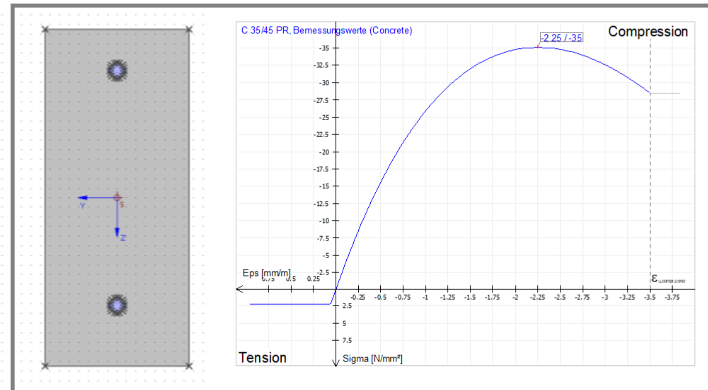
http://www.u-pfeiffer.de/inca2/inca2-09.html

Simplified analytical calculation
(concrete tensile strength is neglected)

Sectional analysis INCA2
(concrete tensile strength is considered)



(a) Cross-section (b) Strain distribution (c) Stress distribution



	Hand calc.		INCA2 www.u-pfeiffer.de	
	w = 0.15 m	B = 1 m	w = 0.15 m	B = 1 m
M_u (kNm)	31.7	211.3	32.34	215.6
R_u (kN)	25.4	169.0	25.9	172.5
p_u (kN/m)	2.5	16.9	2.6	17.3

152 kN/m

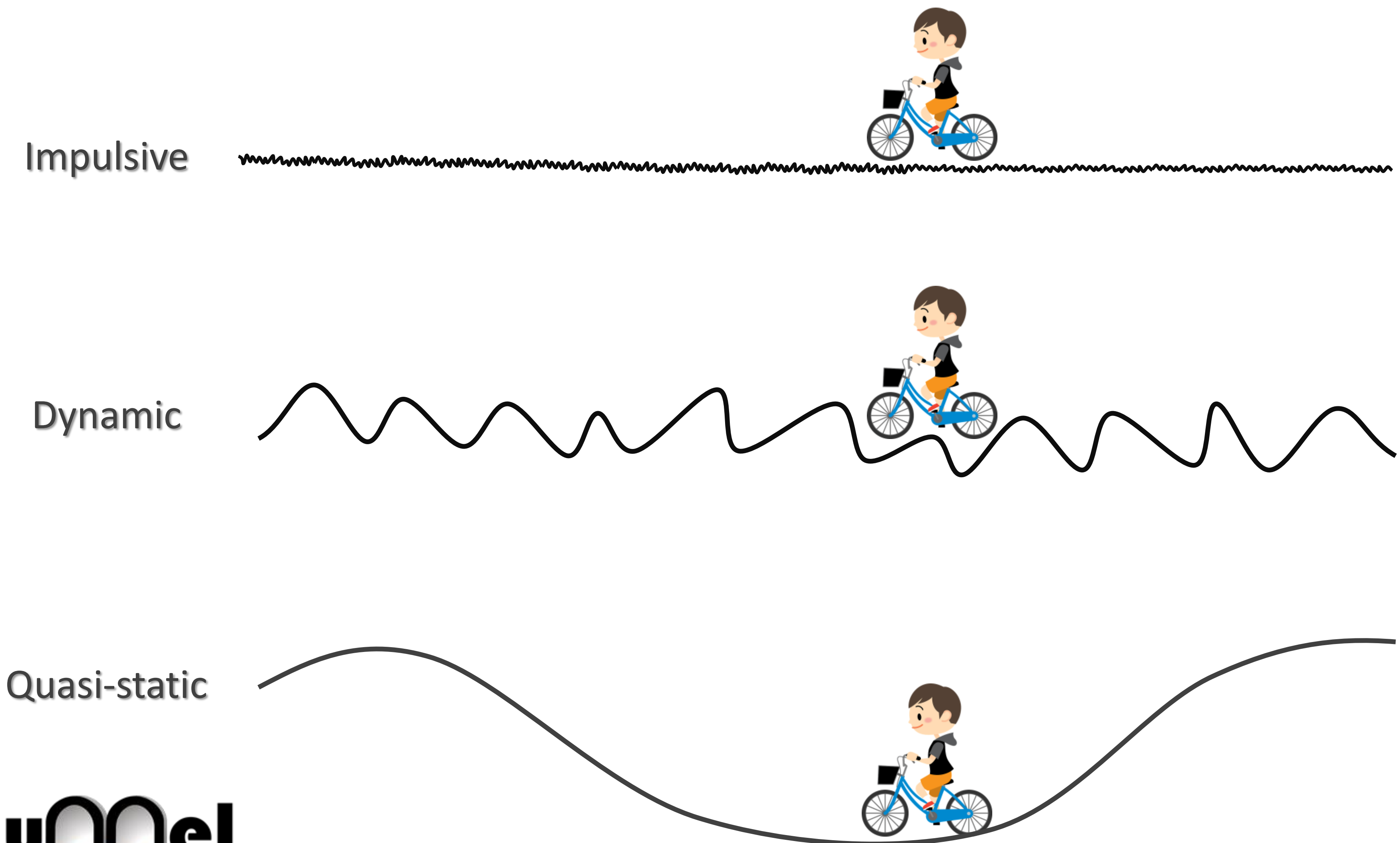
peak pressure

>>

static load capacity

Case study

Dynamic regimes



Case study

Natural period of vibration

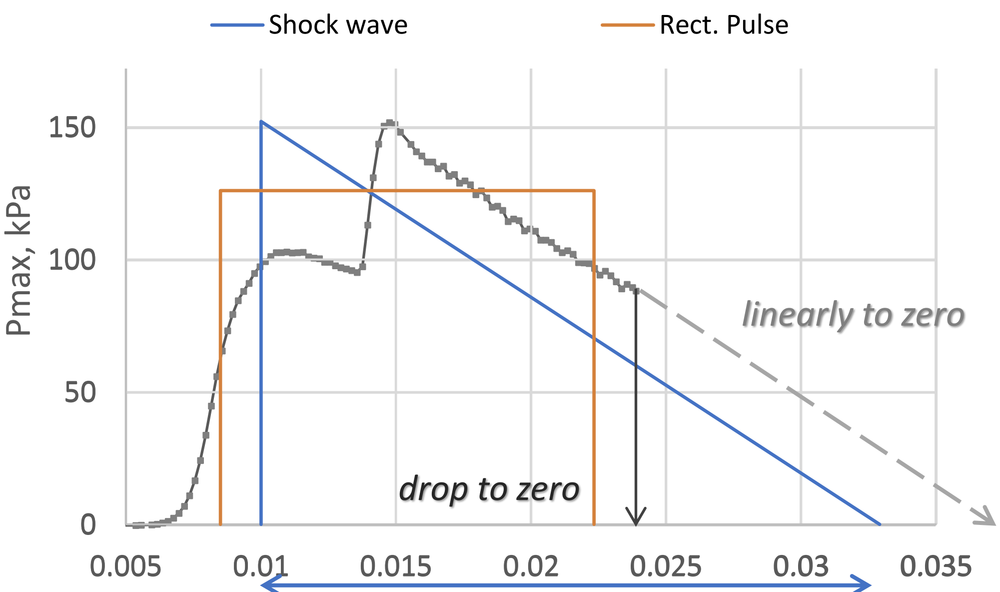
natural period (elastic) $T = 2\pi (m/k)^{0.5}$

Beam model	Natural period T (s)	
	ANSYS	Analytical
Reinfor. only	0.125	0.125
Concrete only	0.167	0.167
R.C. beam	0.165	-

Dynamic load >> Static capacity

Load duration << Natural period

$DAF = u_{max,dyn} / u_{st} < 1$



$t_p = 0.023$ s

$t_p / T = 0.14 < 0.3$ → impulsive regime

Dynamic response

Results

<u>Limits for deflection</u>:

- **Service:**

  δ_{max} = L/250 = 0 .02 m

- **Fire collapse** (BS476):

  δ_{max} = L/20 = 0.25 m

- **Fire collapse** (ISO 834-1):

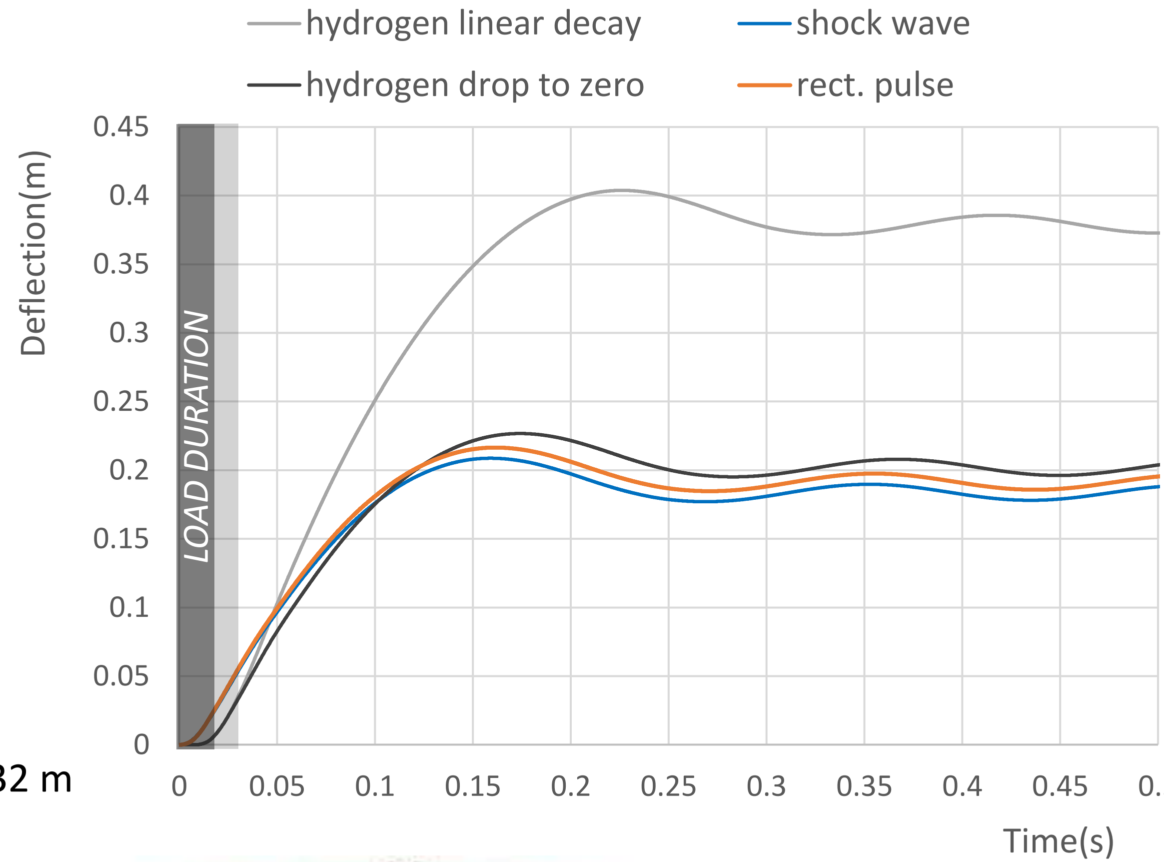
  $\delta_{max} = L^2/(400*H)$ = 0.18 m

  (with H = section height)

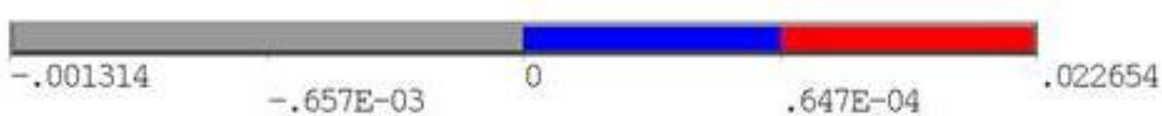
- **Plastic rotation** (GSA, 2013):

  θ_{max} = 0.063 rad → δ_{max} = 0.32 m

  → $\delta_{max} = \theta_{max}$ L = 0.315 m



STRAIN AT MAX DEFLECTION (linear decay)



Conclusion

RESULTS

- CFD+FEM can be used a contemporary tool for essessment of structural responce of the buildings and vehicles, energy balance and hazards associated with projectiles
- Due to the short duration of the explosion, the response of the slab does not show a runaway of the displacements (collapse) despite the pressure is much higher than the static bendig capacity of the slab
- However, the slab mid-span undergoes a significant deflection, which, in case of a linear drop (40 cm) exceeds collapse limits indicated in literature. Furthermore, the large residual deflection indicates a permanent damage of the slab.

HIGHLIGHTS

- Due to the short duration of the action, the response of the slab depends primarily by the impulse and is not much affected by the shape or peak value of the pressure function
- Simplified pressure function having the same area can be used with good approximation

LIMITATIONS

- Longer duration of the explosion (e.g. longer pressure decay, longer delay between subsequent tank explosions, etc.) are plausible to cause the collapse of the slab
- The assumption of a uniform pressure on the slab width is not necessarily conservative
- The study of the response of the slab in the direction of the tunnel has not been investigated

→ FURTHER STUDIES ARE NEEDED

tunnel HP

Clean Hydrogen Partnership

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