Rules and methods for dimensioning surface ship embarked materials subjected to underwater explosions.

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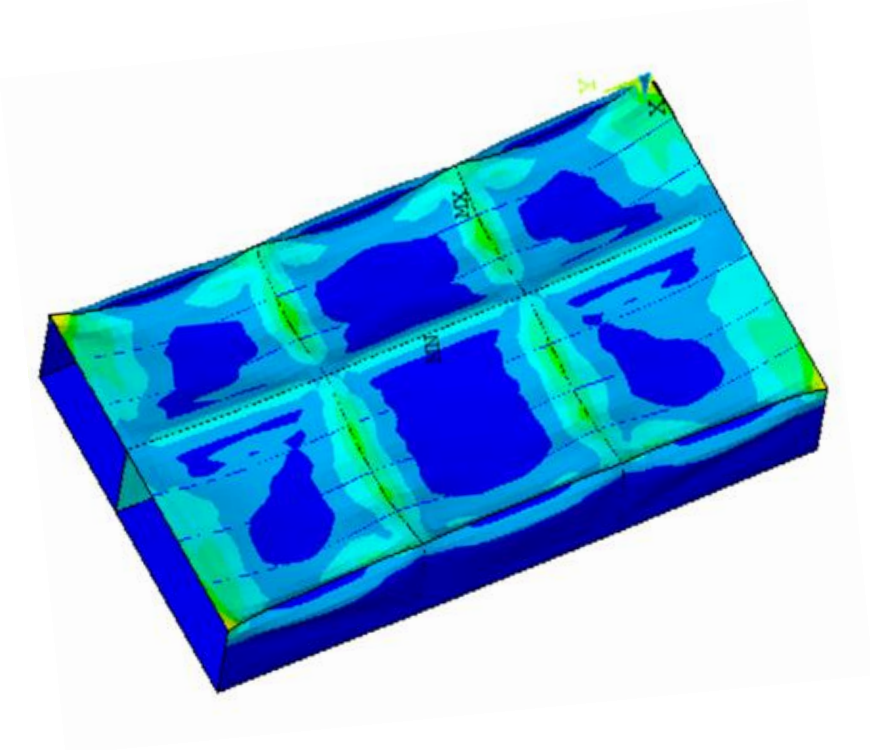
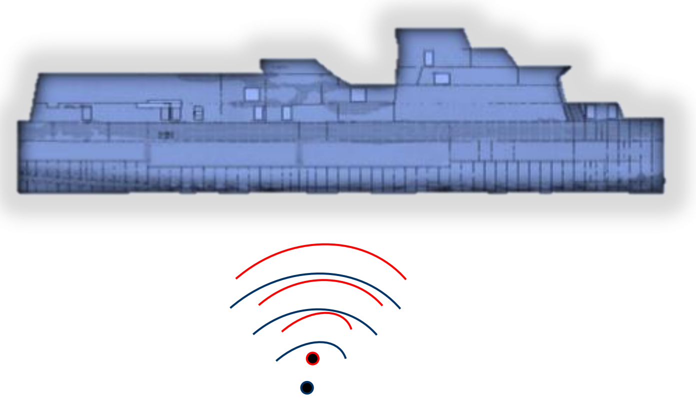


Main parameters: *noncontact underwater explosion*

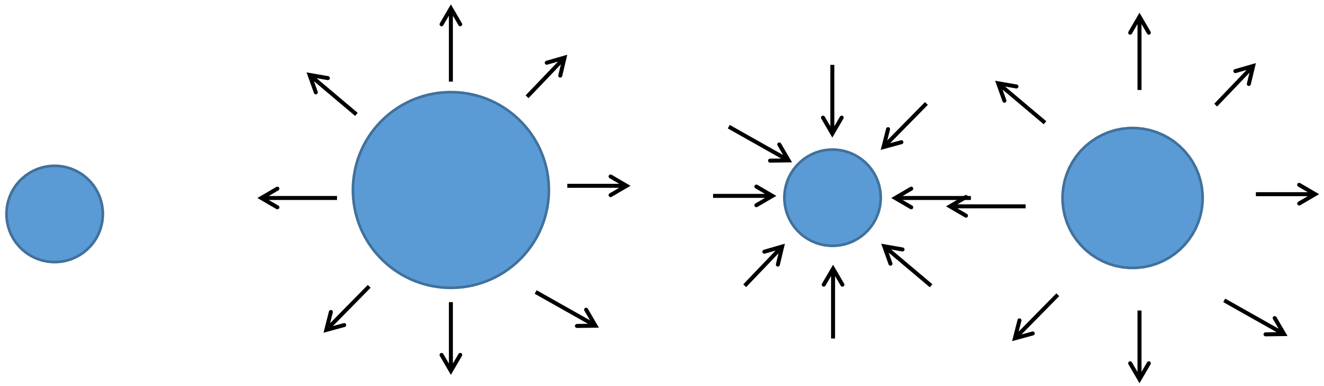


Shock factor: $$SF = \frac{\sqrt{W}}{D}$$

W : Weight of the charge

D : Stand off distance

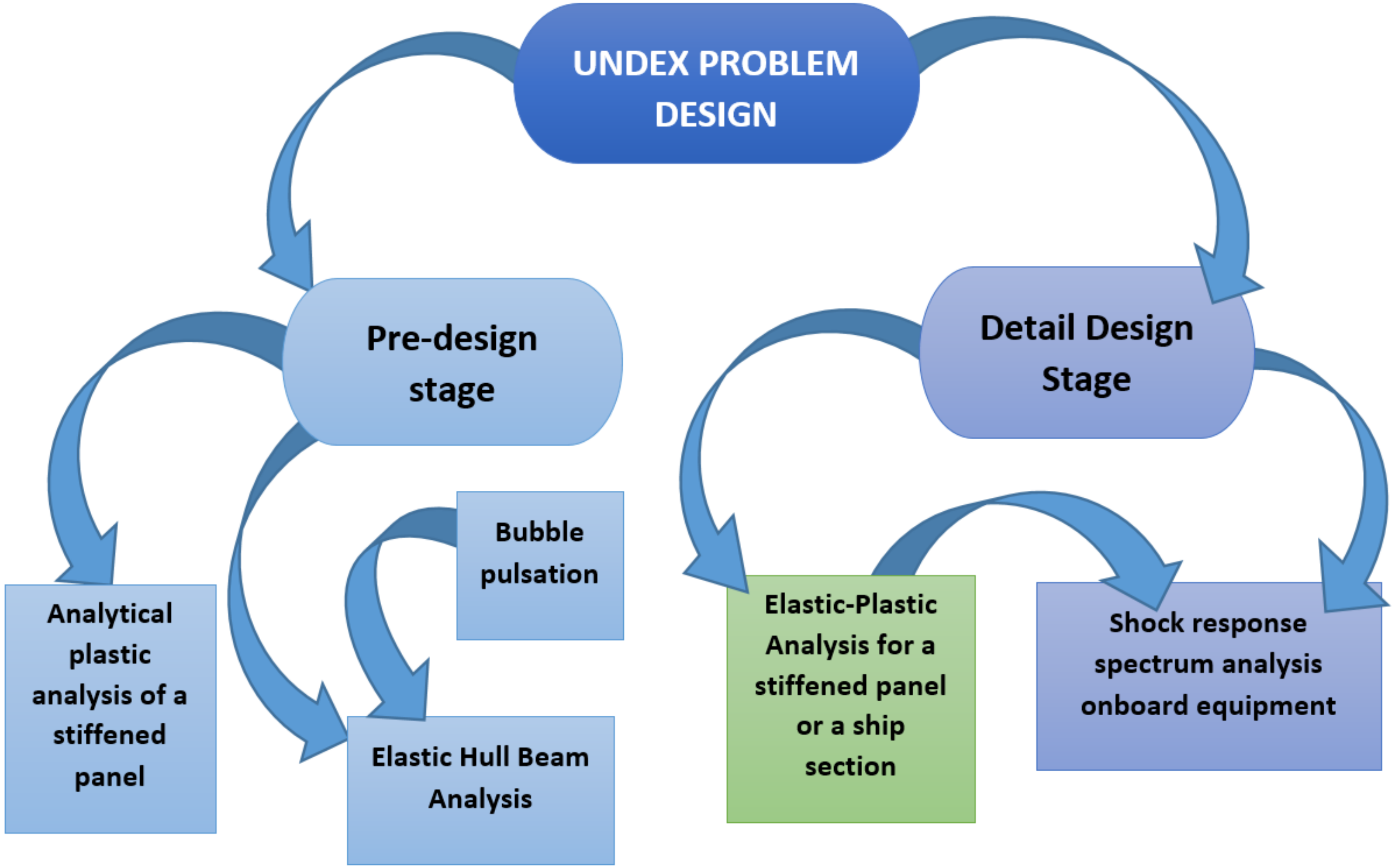
Bubble pulsation effect:



1. Objectives

1. - Key points identification for surface ships submitted to an UNDEX.
2. - Shock response rules for embarked materials.
3. - Simulation of a simplified structure submitted to an UNDEX.

2. Rules review



1. DDAM is the most referenced procedure for embarked materials.
2. BV/043 German rules.
3. French rules.

3. Taylor plate theory

Incident velocity — Reflected velocity — Plate velocity

$$\frac{P_i}{\rho c} = \frac{P_r}{\rho c} + v$$

$$P_r = P_i - \rho c v$$

First term

$$P_t = 2P_i - \rho c v$$

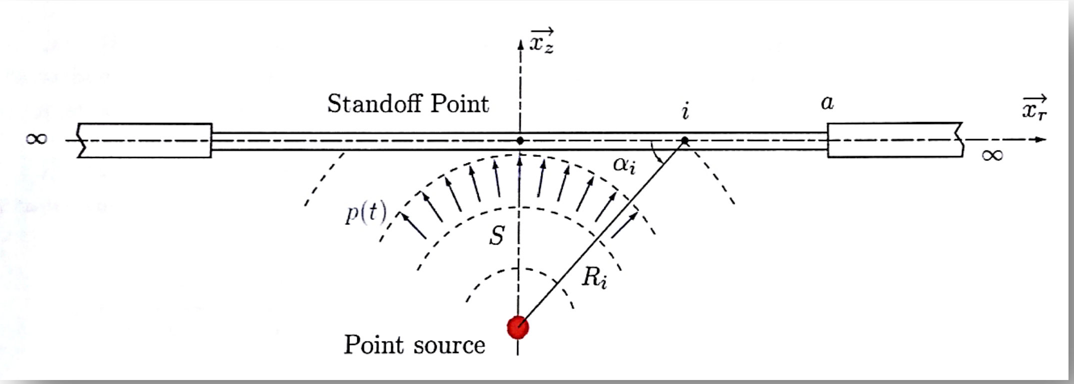
Supposing

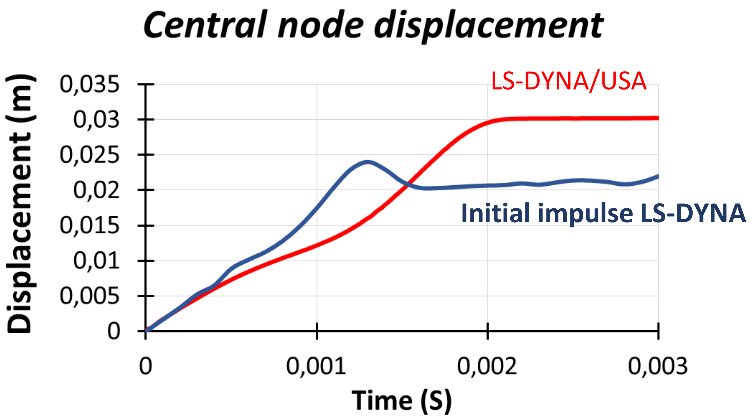
Incident velocity $v_i = v_r$ Reflected velocity

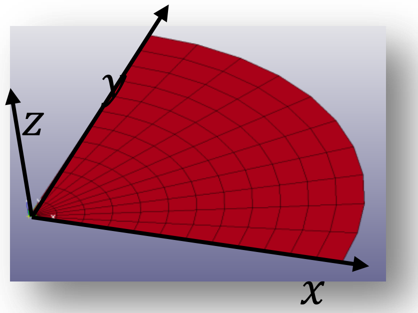
Considering that the surface is fixed

$$\longrightarrow \quad v = \frac{2P_o}{\rho c}\frac{1}{Z-1}\left(e^{-\frac{t}{Z\theta}} - e^{-\frac{t}{\theta}}\right)$$

4. Impulse velocity approximation: *Spherical wave approximation (SWA). (Barras, 2007).*







Pressure balance : $$m\frac{dv_i}{dt} = 2p_{Ii}(t) - \frac{\rho c v_i(t)}{\sin\alpha_i}$$

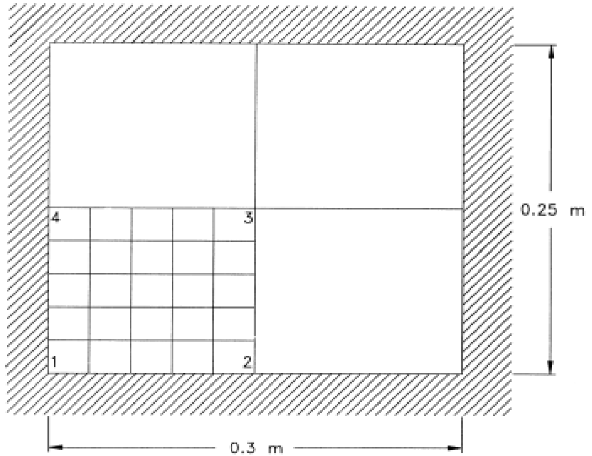
where: $$2p_{Ii}(t) = 2p_0 \sin\alpha_i \, e^{-(t-to)/\theta}$$

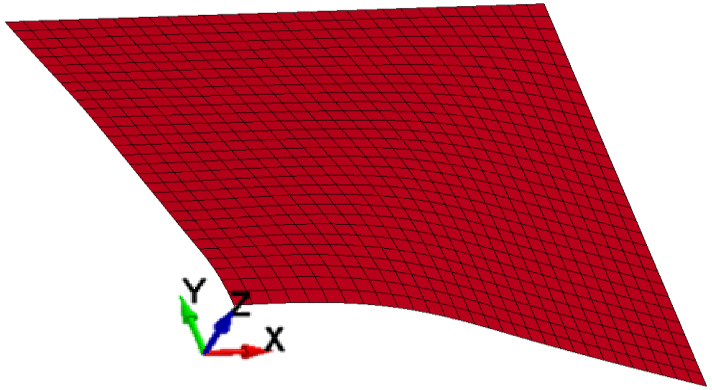
Impulse velocity: $$v_{im} = \frac{2\sin^2\alpha_i \, p_m}{\rho c} \beta_i^{\,1/(1-\sin\alpha_i)}$$

where: $$\beta_i = \frac{\rho c \theta}{m \sin\alpha_i} = \frac{\beta}{\sin\alpha_i}$$

4. Impulse velocity approximation: *Simple plate analysis*

Finite element model





(Ramajeyathilagam, K.; Vendhan, C.P.; Bhujanga Rao, V., 2000)

Objective: verify initial speed approach

Boundary conditions

Along the y axis: $u_x = 0 \quad r_z = r_y = 0$

Along the x axis: $u_y = 0 \quad r_z = r_x = 0$

Full clamped conditions at the border

Materials:

- High strength steel
- Mild steel

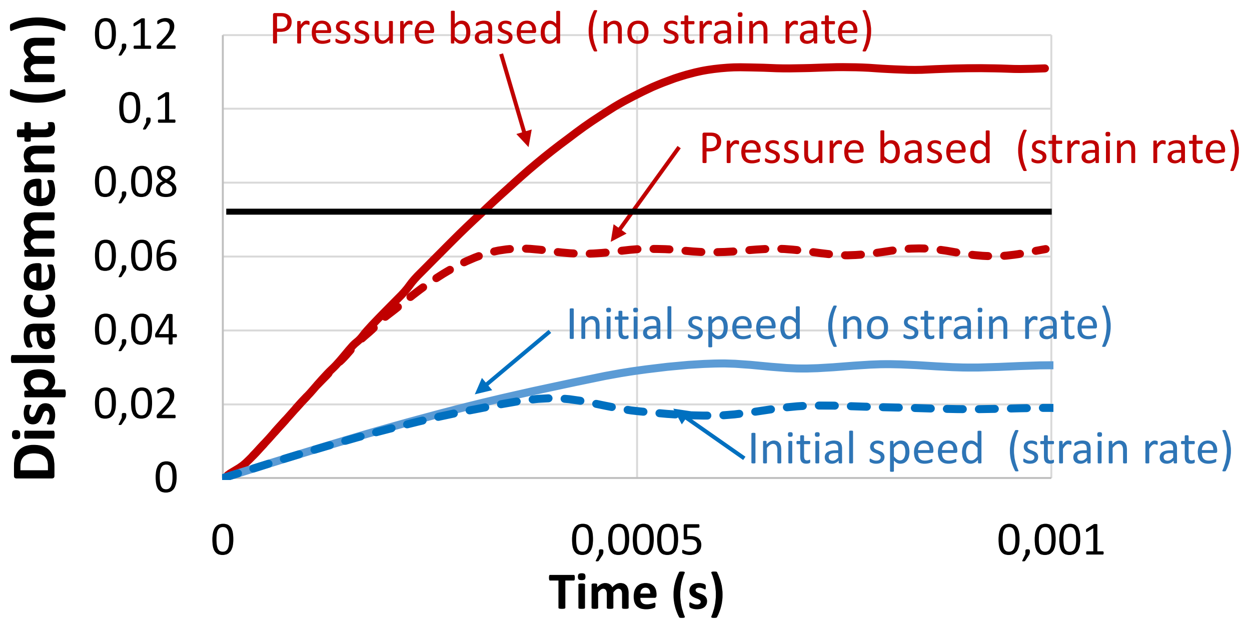
4. Impulse velocity approximation: Strain rate effect

Cowper Symonds material model:

$$\frac{\sigma_{dyn}}{\sigma_{stat}} = 1 + \left(\frac{\dot{\varepsilon}}{D}\right)^{\frac{1}{p}}$$

Strain rate must be considered

Initial speed results

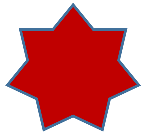


Data

Experimental Displacement (m)	Pressure based Displacement (m)	Shock factor
0,072	0,062	0,794

The initial velocity approximation underestimates the results.

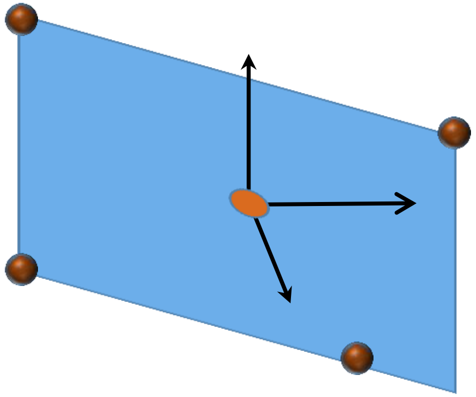
5. Pressure based approximation: *Time history pressure for a single shell element.*

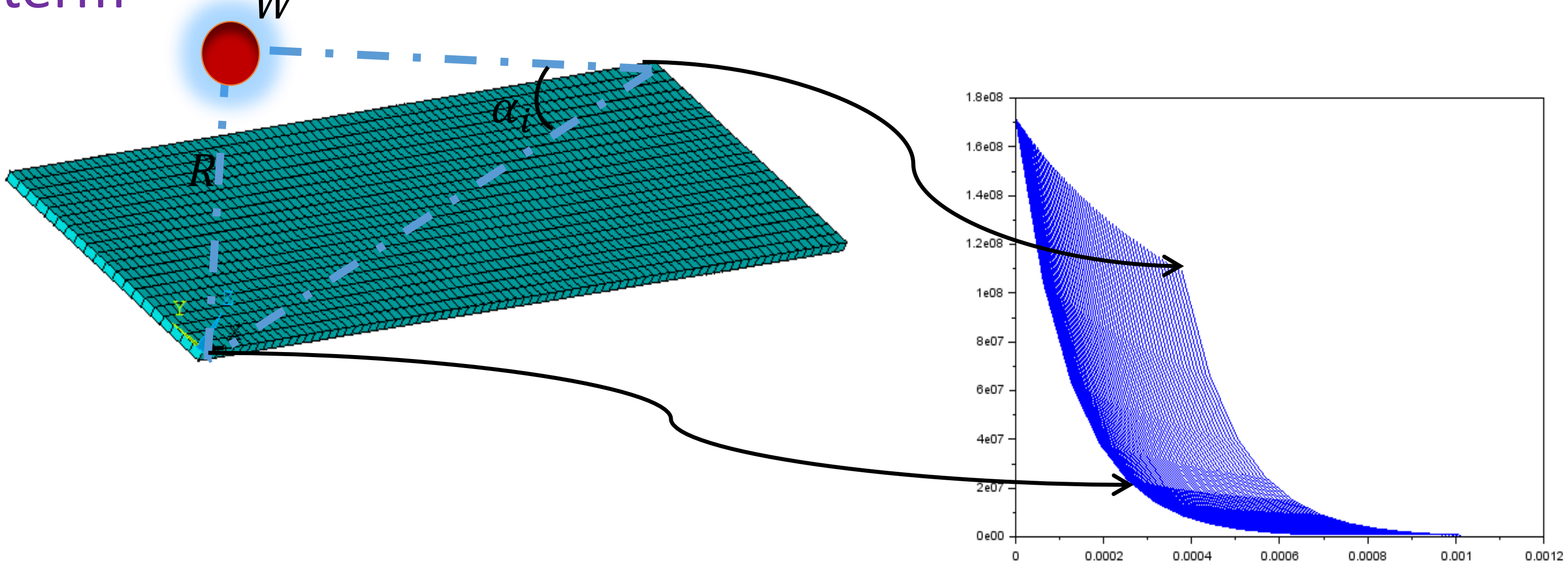


$$P_{element} = 2P_0 \sin\alpha_i \, e^{-(t)/\theta} - \frac{\rho c \dfrac{2\sin\alpha_i \, Po}{m} \dfrac{\theta}{(1-\beta_i)} \left(e^{-\beta_i t/\theta} - e^{-t/\theta}\right)}{\sin\alpha_i}$$

First term

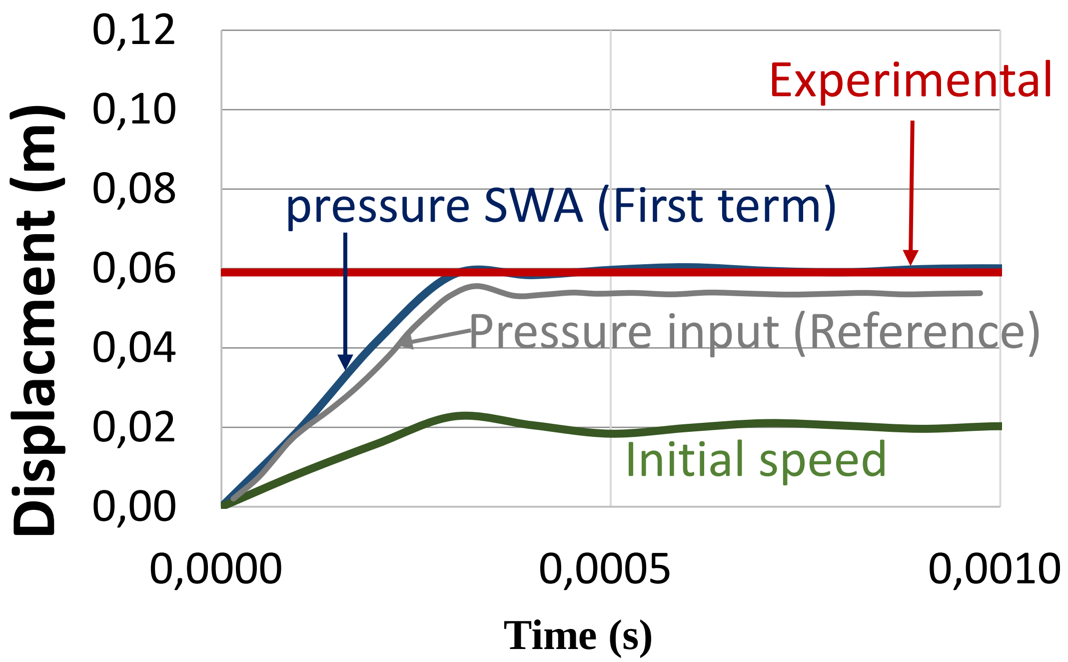
Fluid structure interaction



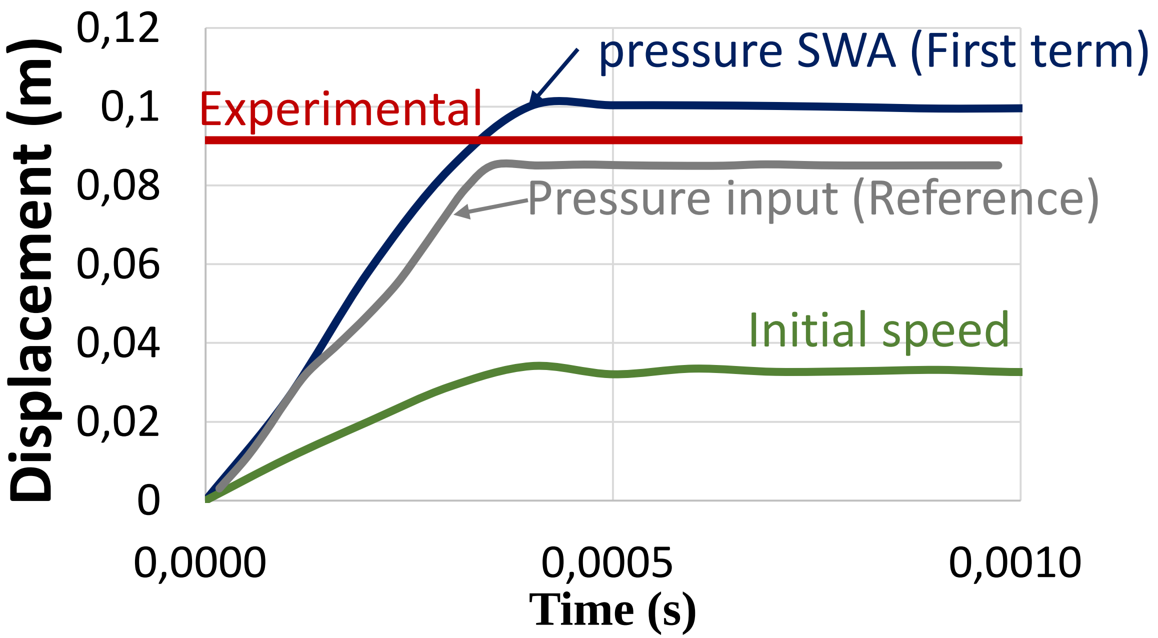


5. Pressure based approximation: *Pressure input first term*

Shock Factor 0,794 High strength steel

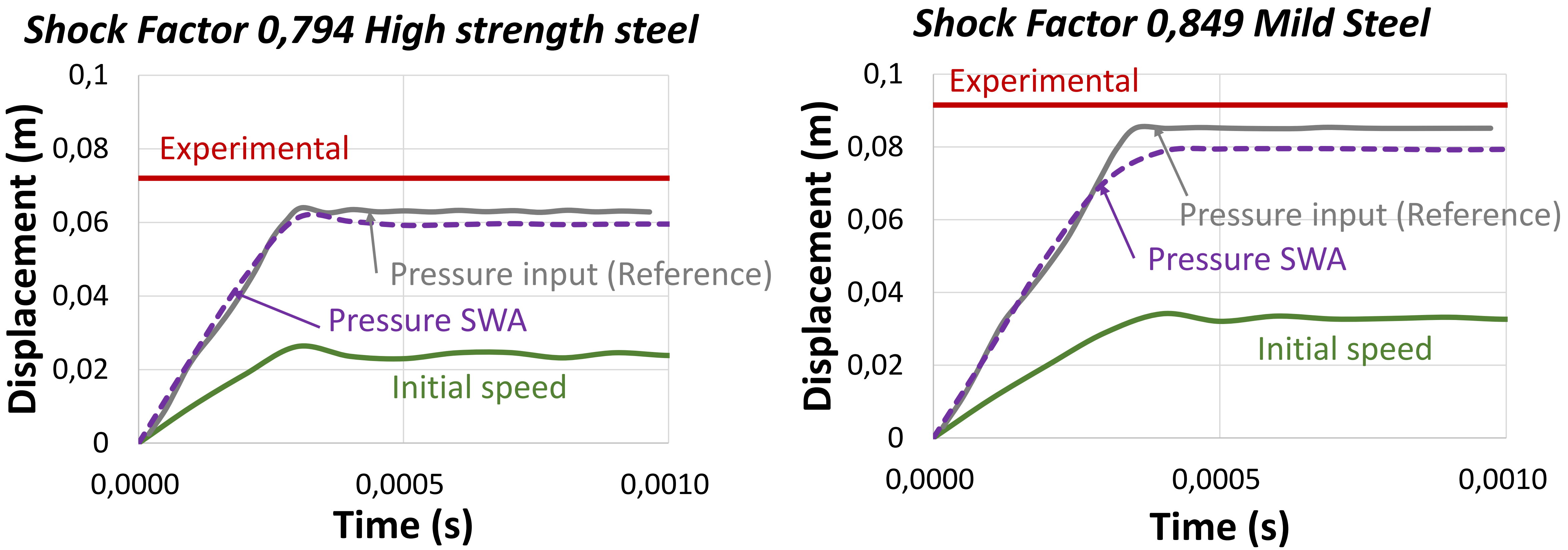


Shock Factor 0,849 Mild Steel



Final deformation (slightly) found above the experimental results.

5. Pressure based approximation: *SWA full equation.*



Results similar to the reference.

5. Pressure based approximation: *ANSYS & LS-DYNA material model.*

- ANSYS does not have explicit solution option (LS-DYNA only)

Full transient simulation.

Implicit solution

ANSYS

Perzyna model

$$\dot{\varepsilon}_{pl} = \gamma\left(\frac{\sigma}{\sigma_o} - 1\right)^{1/m}$$

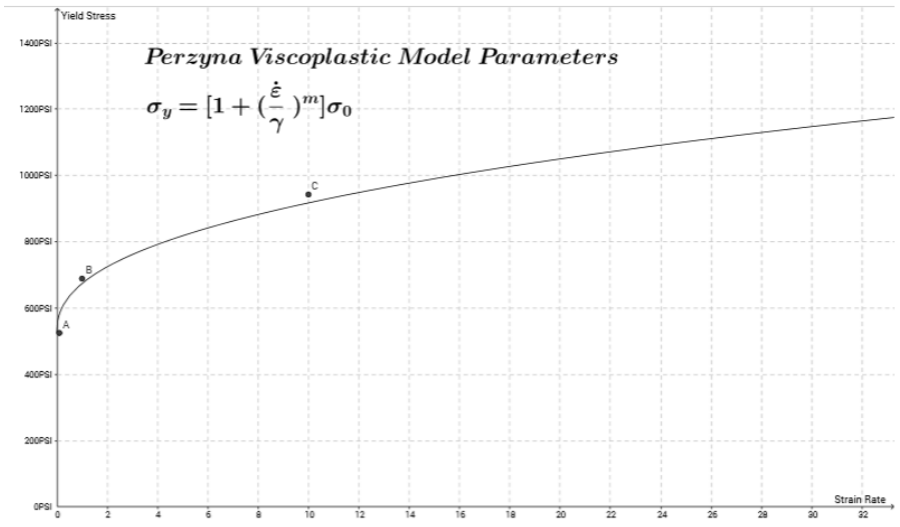
Explicit solution

LS-DYNA

Cowper Symonds

$$\frac{\sigma_{dyn}}{\sigma_{stat}} = 1 + \left(\frac{\dot{\varepsilon}}{D}\right)^{\frac{1}{p}}$$

Yield stress



Strain rate

Taken from: https://www.geogebra.org/m/26707

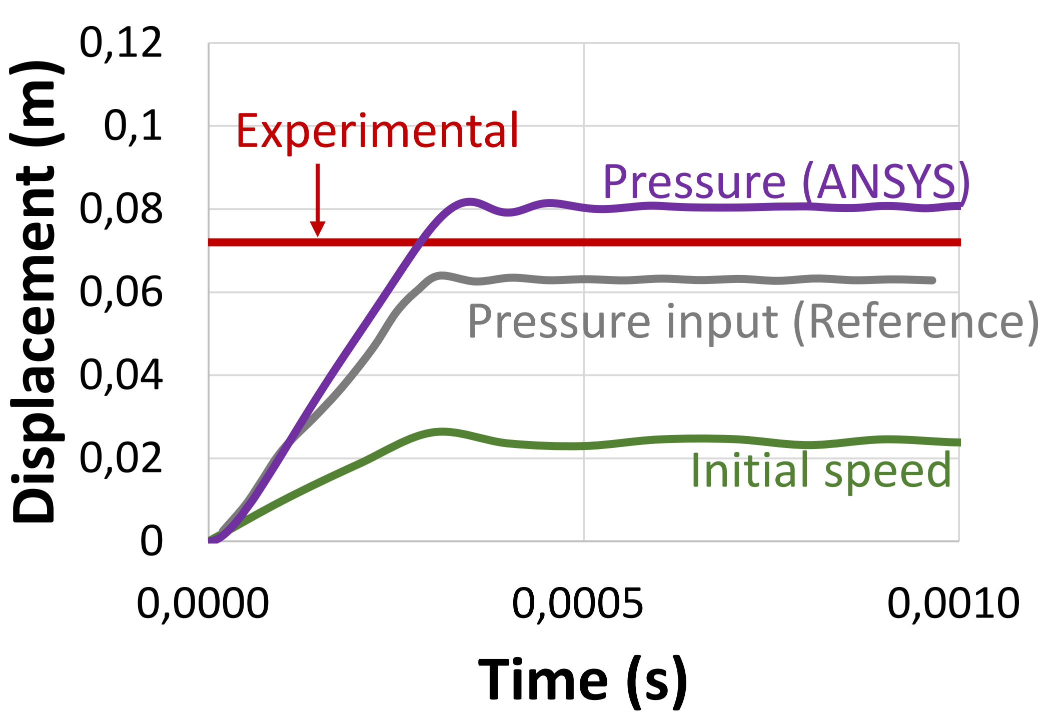
1/p = m and γ = D

D = 40 & m = 5 for steel.

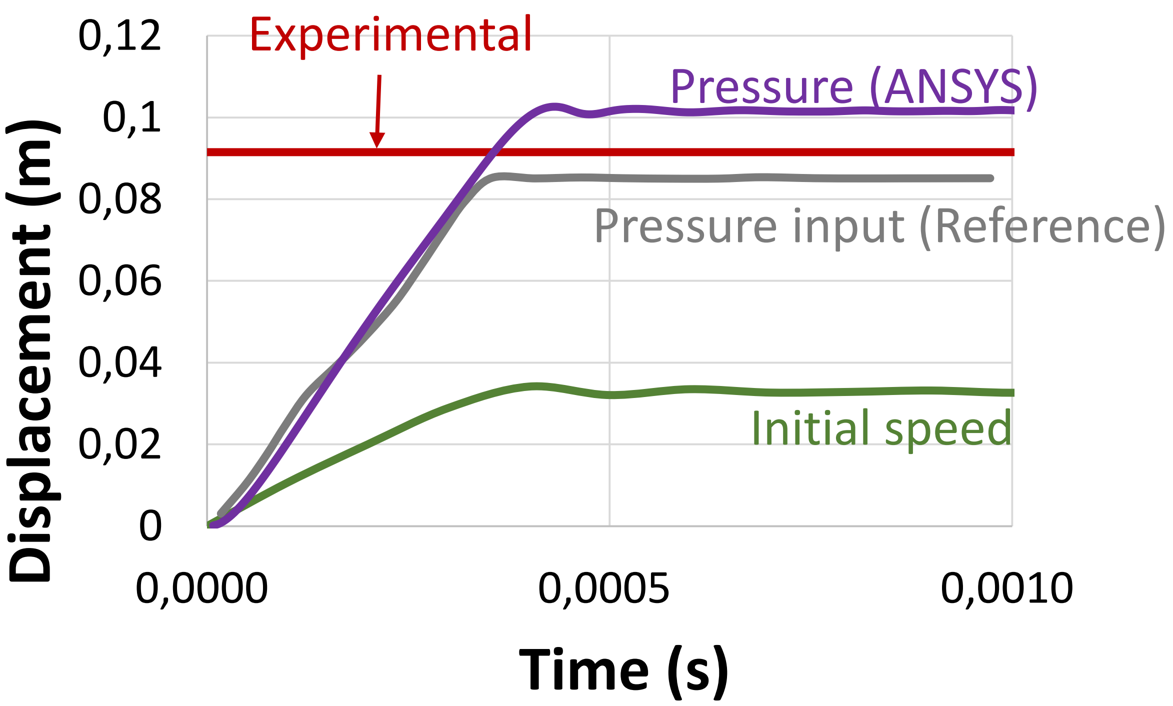
Same equation.

5. Pressure based approximation: *Results validation using ANSYS.*

Shock Factor 0,794 High strength steel



Shock Factor 0,849 Mild steel



Results above the ones obtained using LS-DYNA.

5. Pressure based approximation: *Results summary*

4 loading approaches tested

- Initial impulse
  Largely underestimates the damage
- Initial impulse + added mass
  Underestimates the damage
- Pressure only
  Slightly overestimates but conservative!
- Pressure + FSI
  Oscillates near experimental results.

Hard Strength Steel	Shock Factor (SF)	Experimental (m)	SWA Pressure based input (m)	%Error	Initial impulse formulation (m)	%Error	Pressure based input Two Terms (m)	%Error	Added mass Approach (m)	%Error
	0,424	0,032	0,034	7,19	0,0156	-51,25	0,0349	9,06	0,026	-20,31
	0,671	0,059	0,060	2,20	0,0228	-61,36	0,0525	-11,02	0,038	-35,76
	0,794	0,072	0,074	2,78	0,0263	-63,47	0,0612	-15,00	0,044	-39,17
Mild Steel	**Shock Factor (SF)**	**Experimental (m)**	**SWA Pressure based input (m)**	**%Error**	**Initial speed formulation (m)**	**%Error**	**Pressure based input Two Terms (m)**	**%Error**	**Added mass Approach (m)**	**%Error**
	0,671	0,0675	0,077	14,37	0,0277	-58,96	0,0643	-4,74	0,046	-31,70
	0,794	0,0759	0,093	22,79	0,0322	-57,58	0,0748	-1,45	0,054	-29,51
	0,849	0,0915	0,100	9,29	0,0341	-62,73	0,0795	-13,11	0,057	-38,14

4 Different loading approaches
60 calculations using LS-DYNA or ANSYS

6. Stiffened plate : ANSYS compared to LS-DYNA

Material Properties

	Quench Steel	Mild steel
Young Modulus (MPa)	400	250
Tangent Modulus (MPa)	631	350
Poisson ratio	0,3	0,3

Boundary Conditions

Along the y axis: $u_x = 0 \quad r_z = r_y = 0$

Along the x axis: $u_y = 0 \quad r_z = r_x = 0$

Full clamped conditions at the border

Finite element model

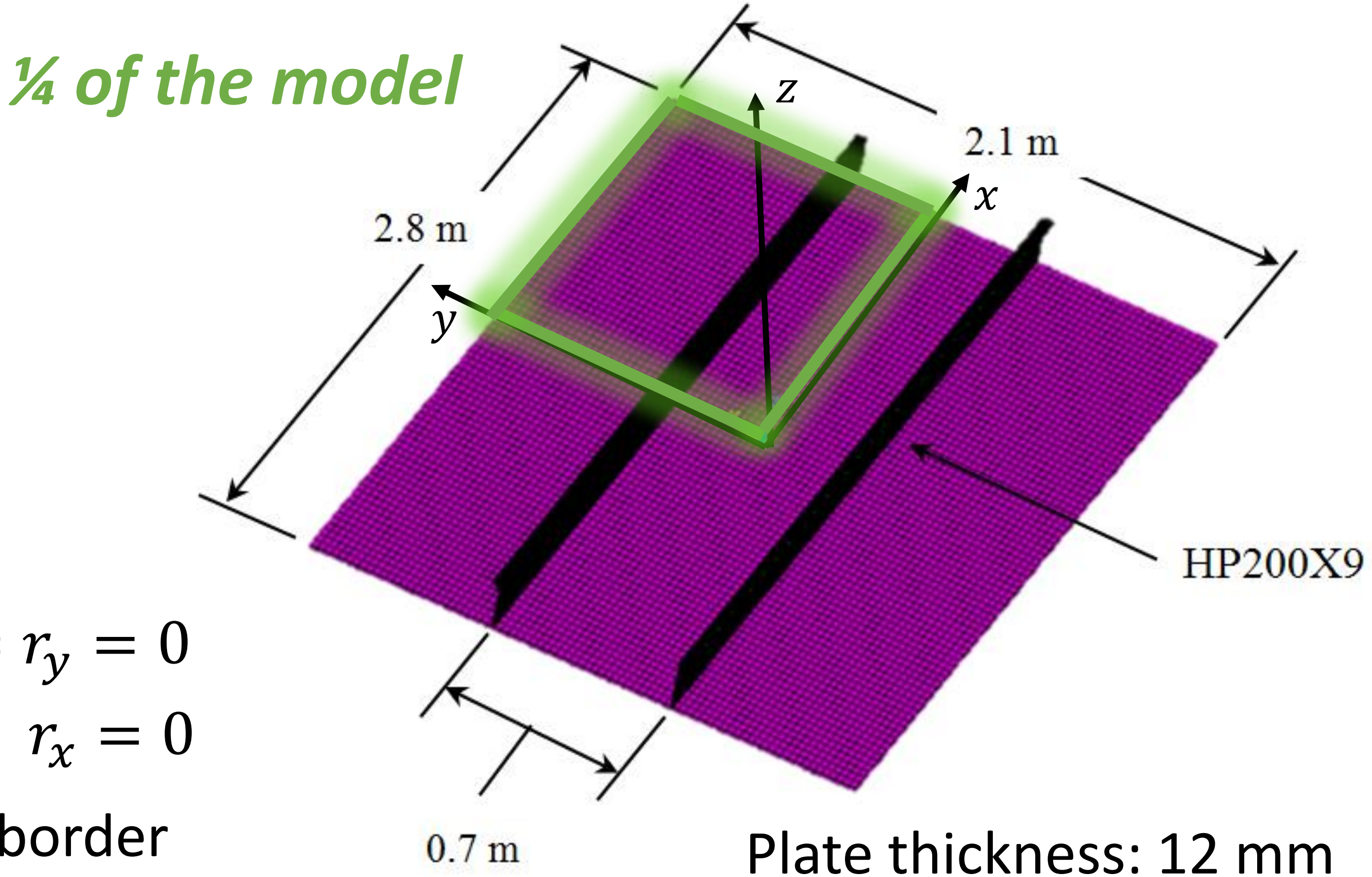


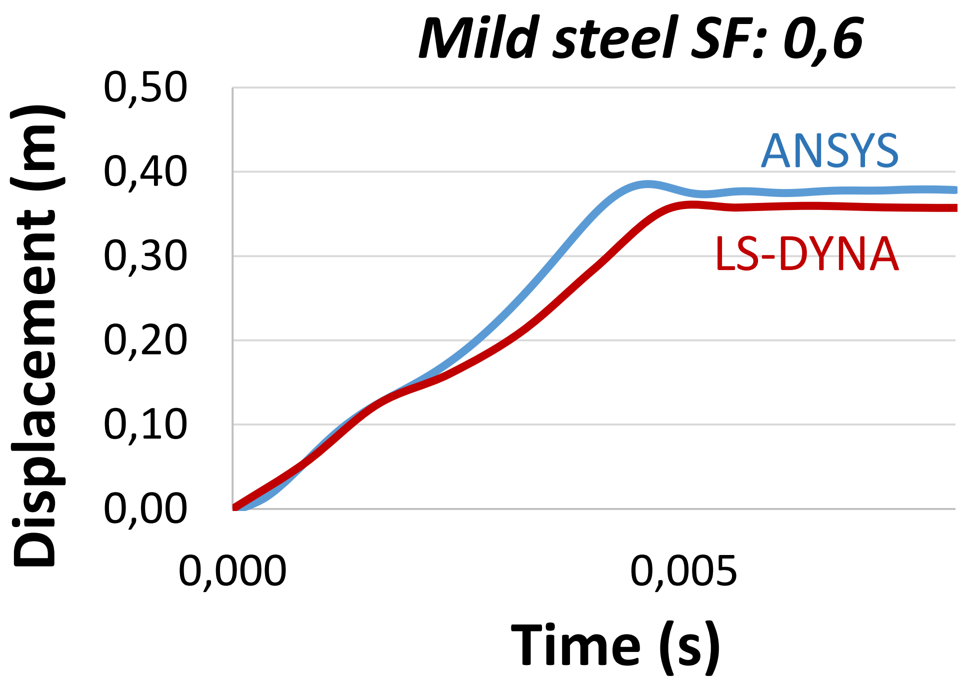
Plate thickness: 12 mm

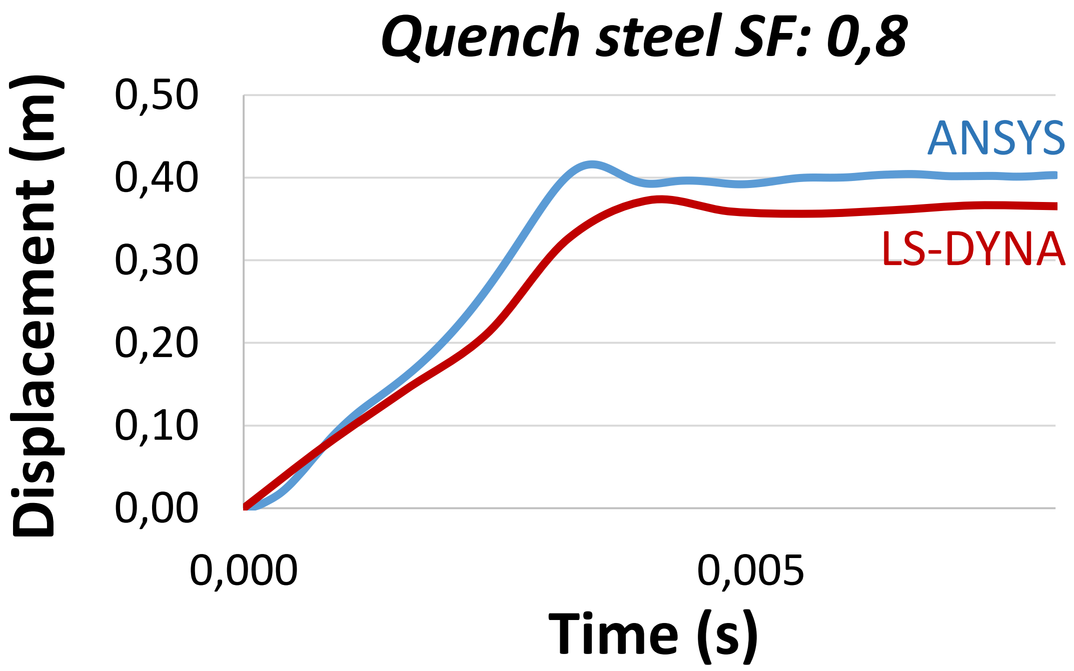
6. Stiffened plate : ANSYS compared to LS-DYNA

Shock factor increased until rupture

Erosive law.

$$Ef = 0.056 + 0.54\ \frac{t}{l_e}$$





Results obtained by the two software are similar.

6. Stiffened plate : ANSYS compared to LS-DYNA

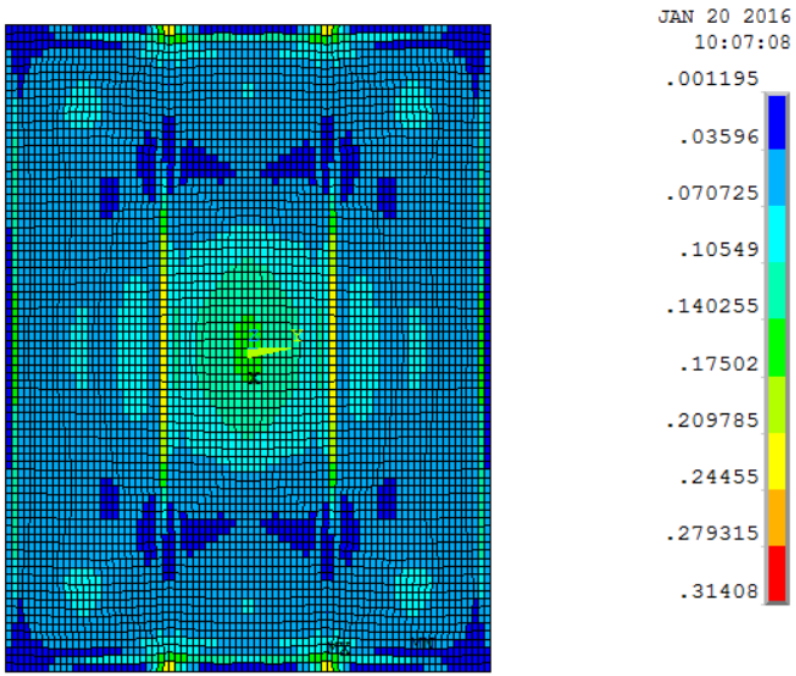
Mild Steel

SF	LS-DYNA	ANSYS	ERROR %
0,44	0,25	0,25	2,89
0,55	0,33	0,34	5,35
0,6	0,36	0,38	6,16

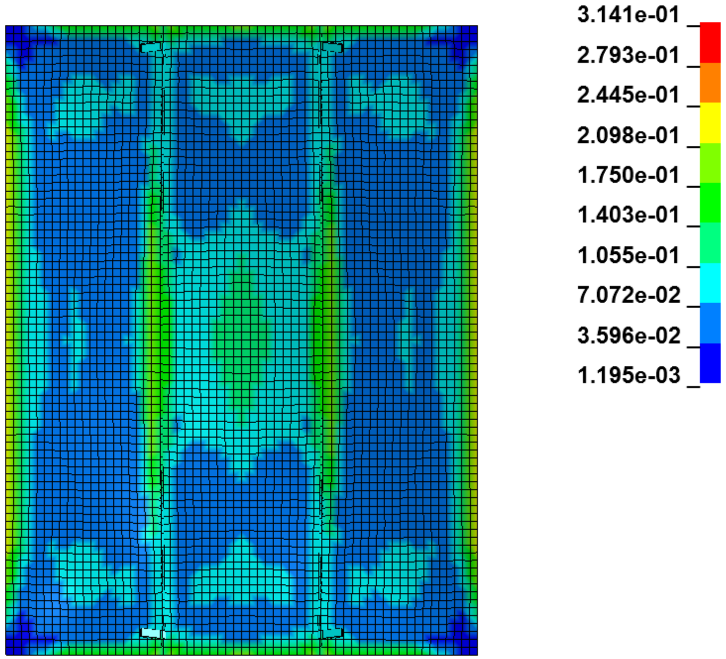
Quench Steel

SF	LS-DYNA	ANSYS	ERROR %
0,66	2,94	3,04	3,40
0,77	0,35	0,36	4,82
0,833	0,36	0,40	9,86

ANSYS results



LS-DYNA results



Similar pattern on the distributions of plastic strains

7. Ship full section: ANSYS compared to LS-DYNA.

Same procedure applied to the stiffened plate.

Boundary Conditions

Restricted displacement at the edges. Rotation is allowed.

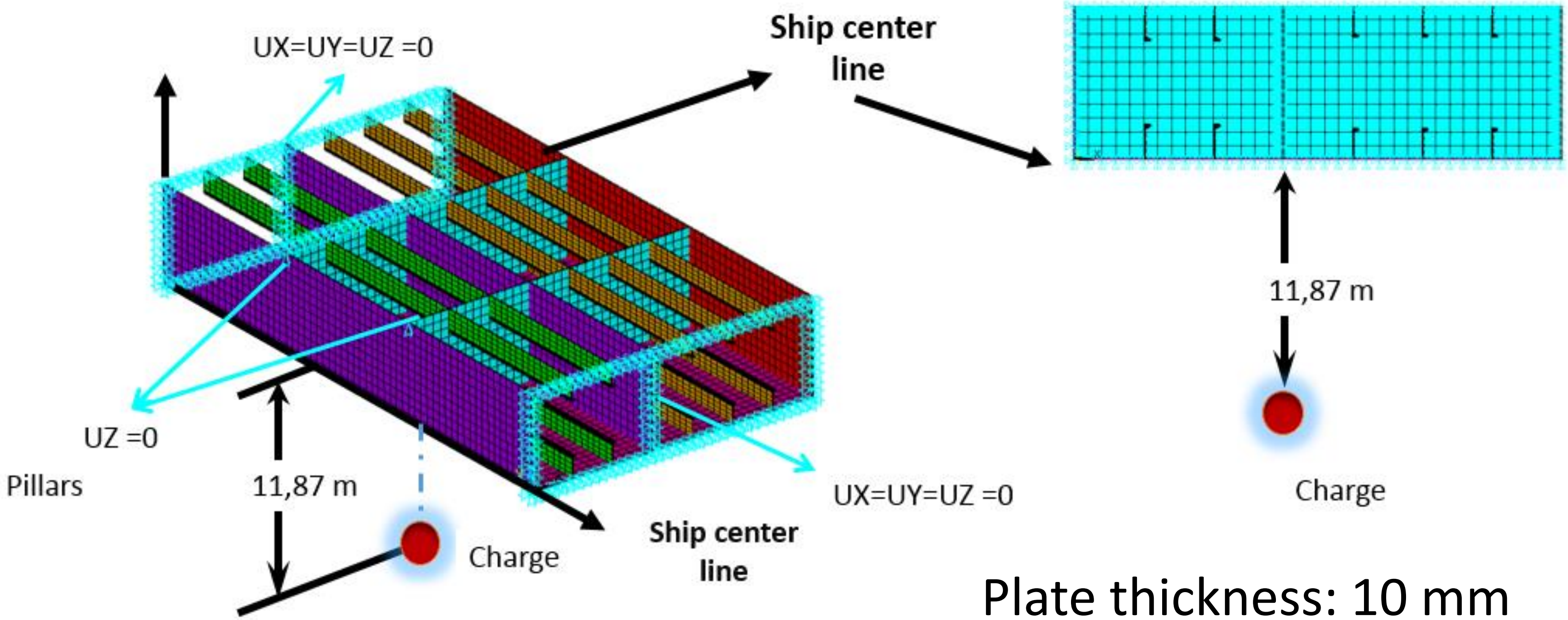
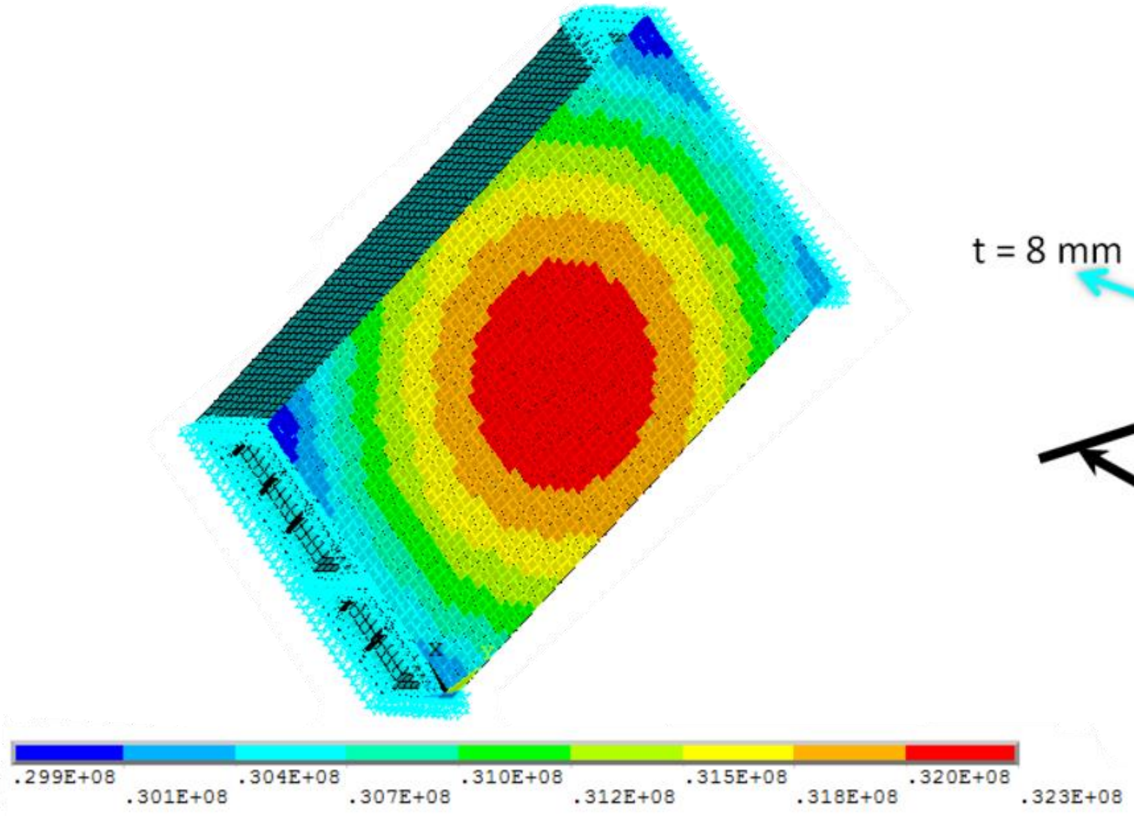


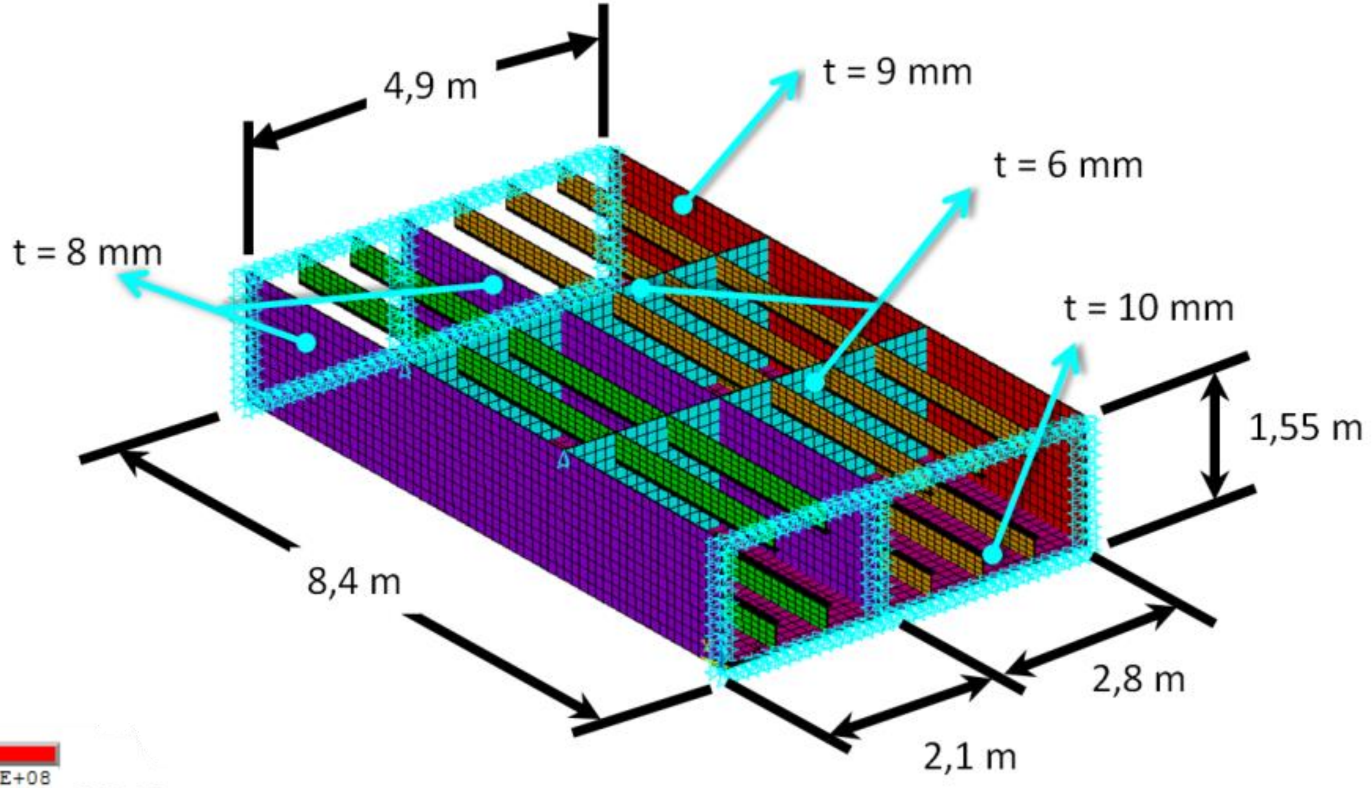
Plate thickness: 10 mm

7. Ship full section: ANSYS compared to LS-DYNA.

First load step

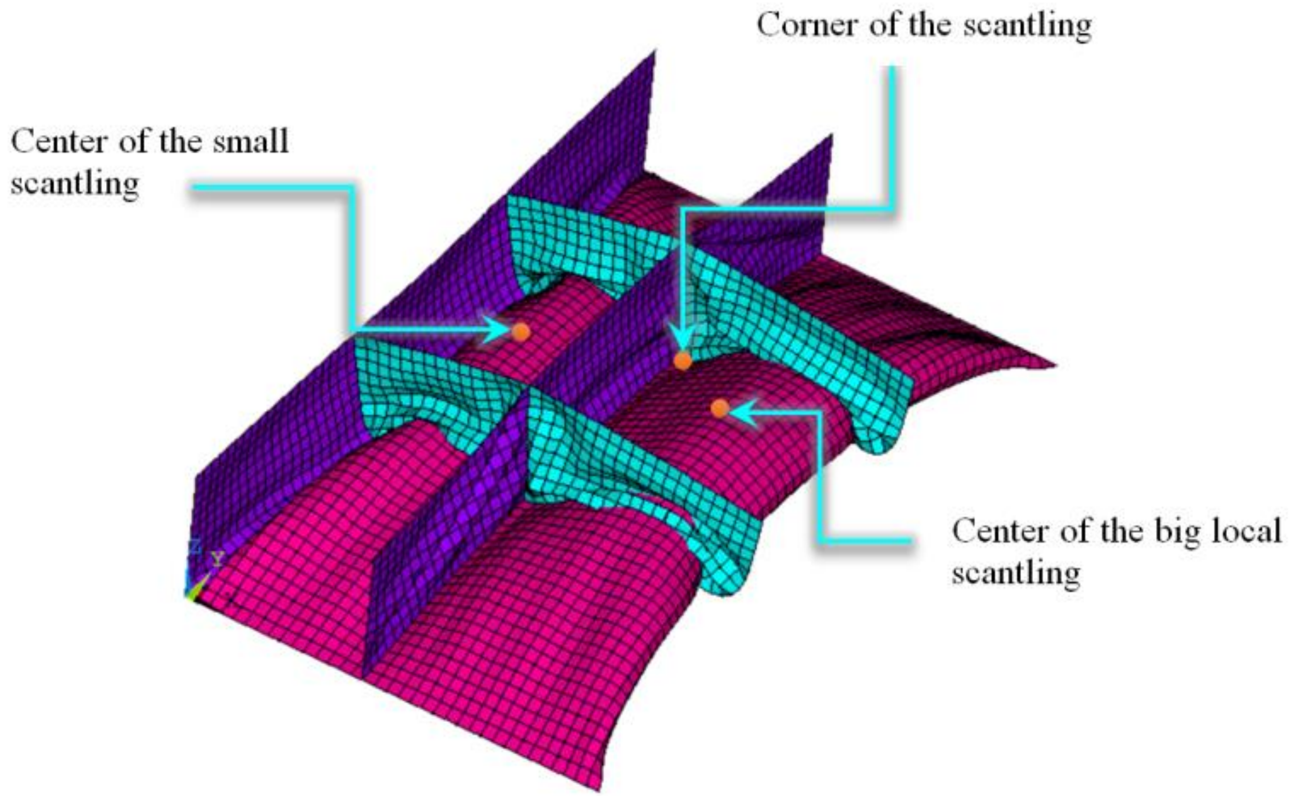


Scantling dimensions



7. Ship full section: ANSYS compared to LS-DYNA.

Points being measured

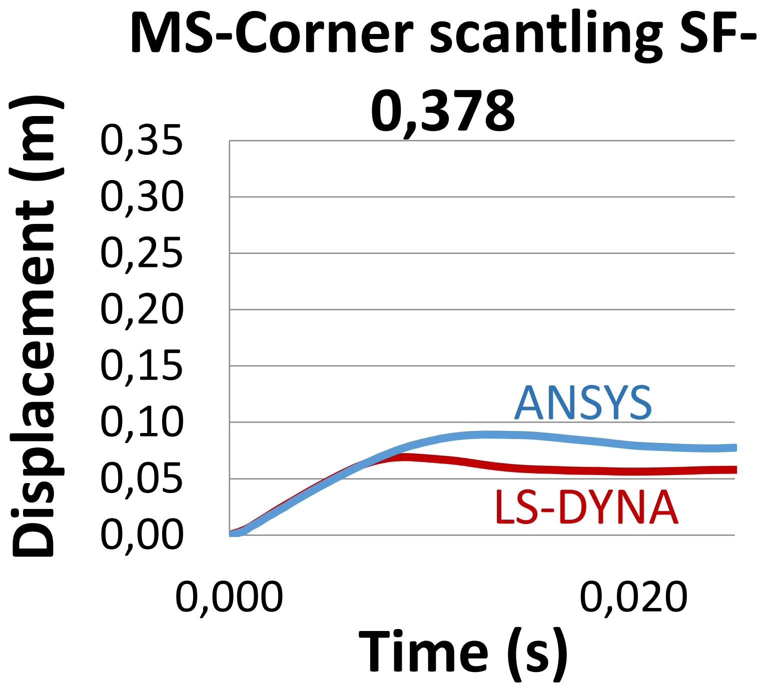


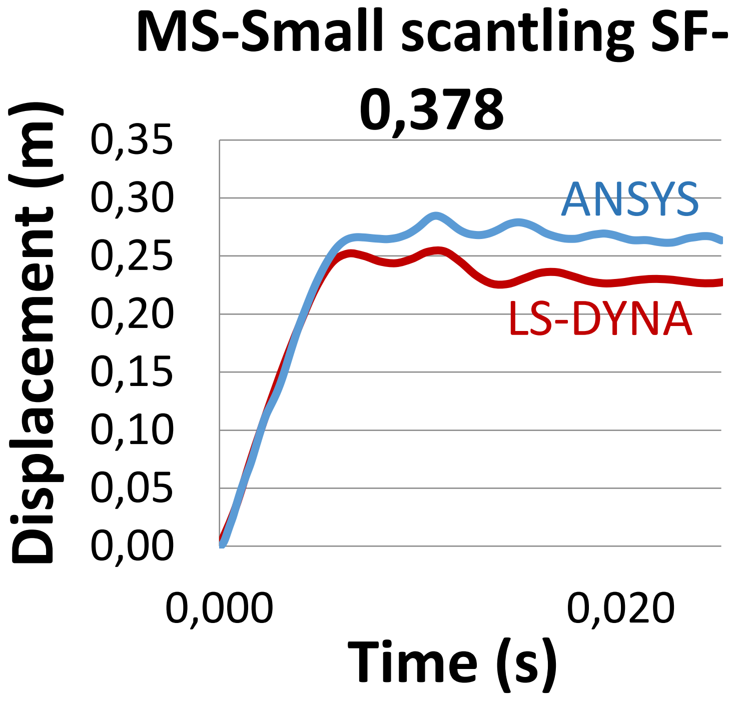
7. Ship full section: ANSYS compared to LS-DYNA.

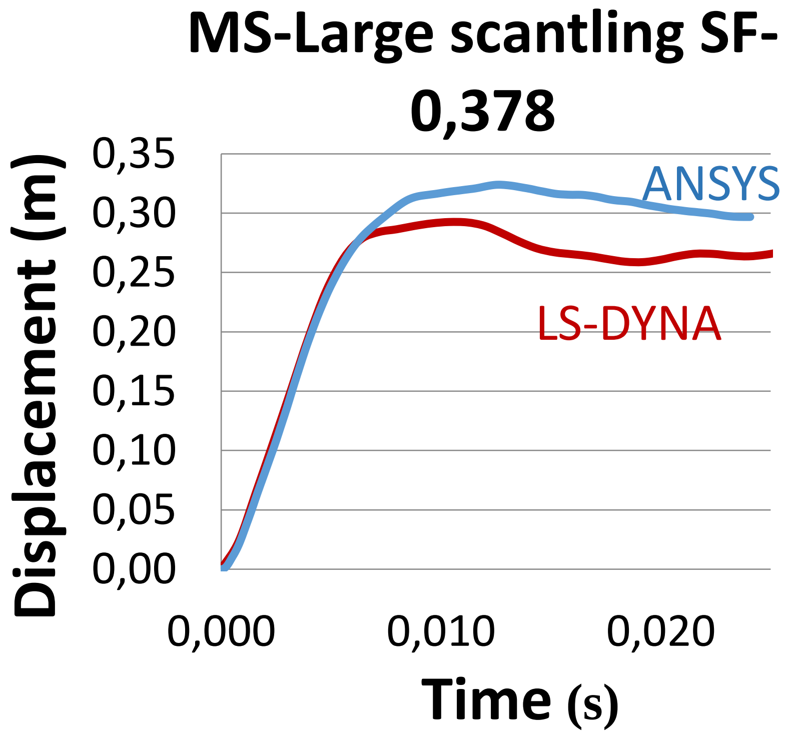
Exact modeling: number of elements – stiffeners – load profile.

Maximum:

Mild Steel SF: 0,378.
Quench Steel SF: 0,489





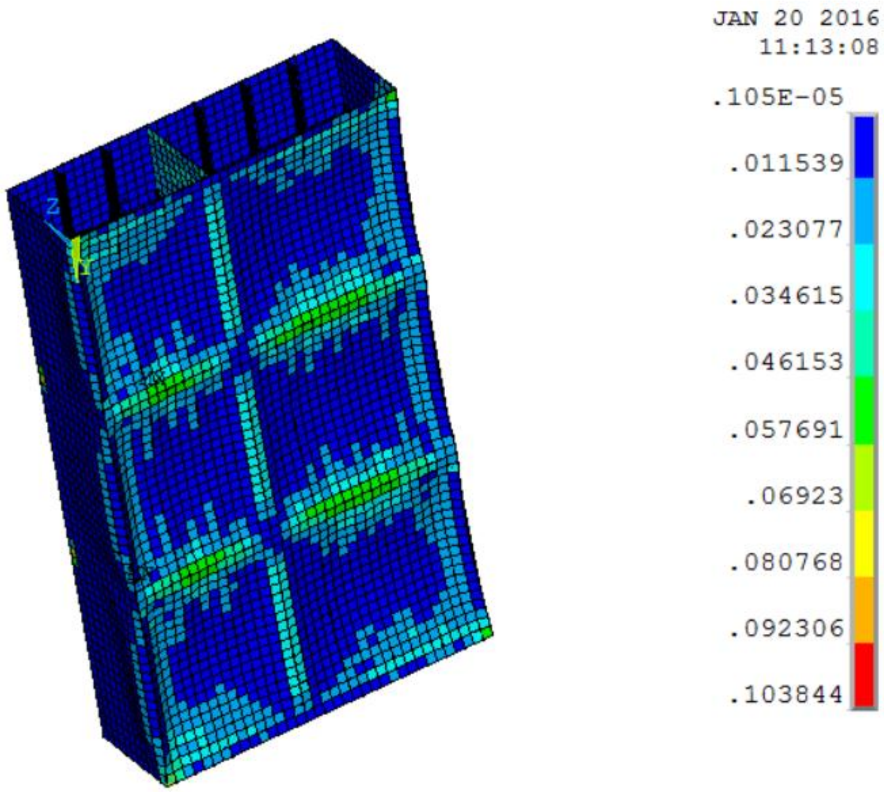


Slightly overshoot possibly due to the element formulation.

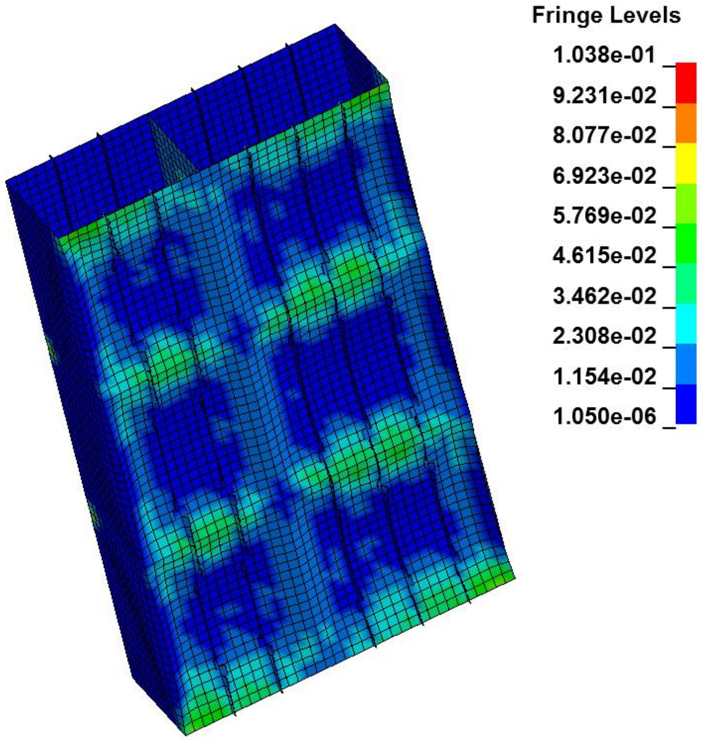
7. Ship full section: ANSYS compared to LS-DYNA.

Plastic strain comparison using Mild Steel S.F.:0,33.

ANSYS results



LS-DYNA results



Plastic strain distribution present the same pattern.

8. Conclusions

- The initial speed approach underestimates the experimental results.
- The results obtained by the pressure, neglecting the second term, overestimate the level of deformation.
- LS-DYNA and ANSYS end up having approximately similar results. Considering the rupture strain of the plate.
- Discrepancies occur between LS-DYNA and ANSYS. Those discrepancies are probably due to the solvers themselves and to the formulation of the shell elements used.

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