Results – Part 1
Simplified vessel model
Undamped (no isolators)

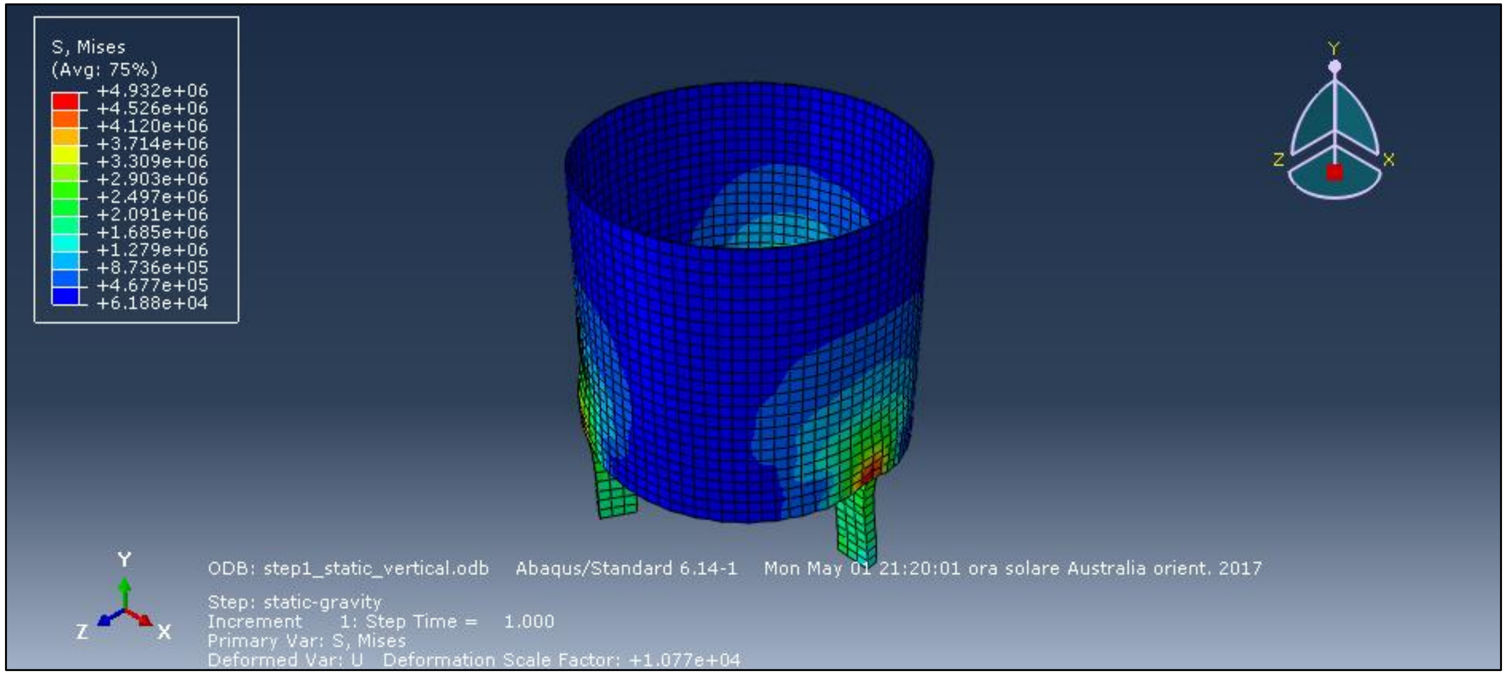
Tiziano Baroncelli

Structural Engineer

UoM

1° analysis: general static analysis – vertical loads only

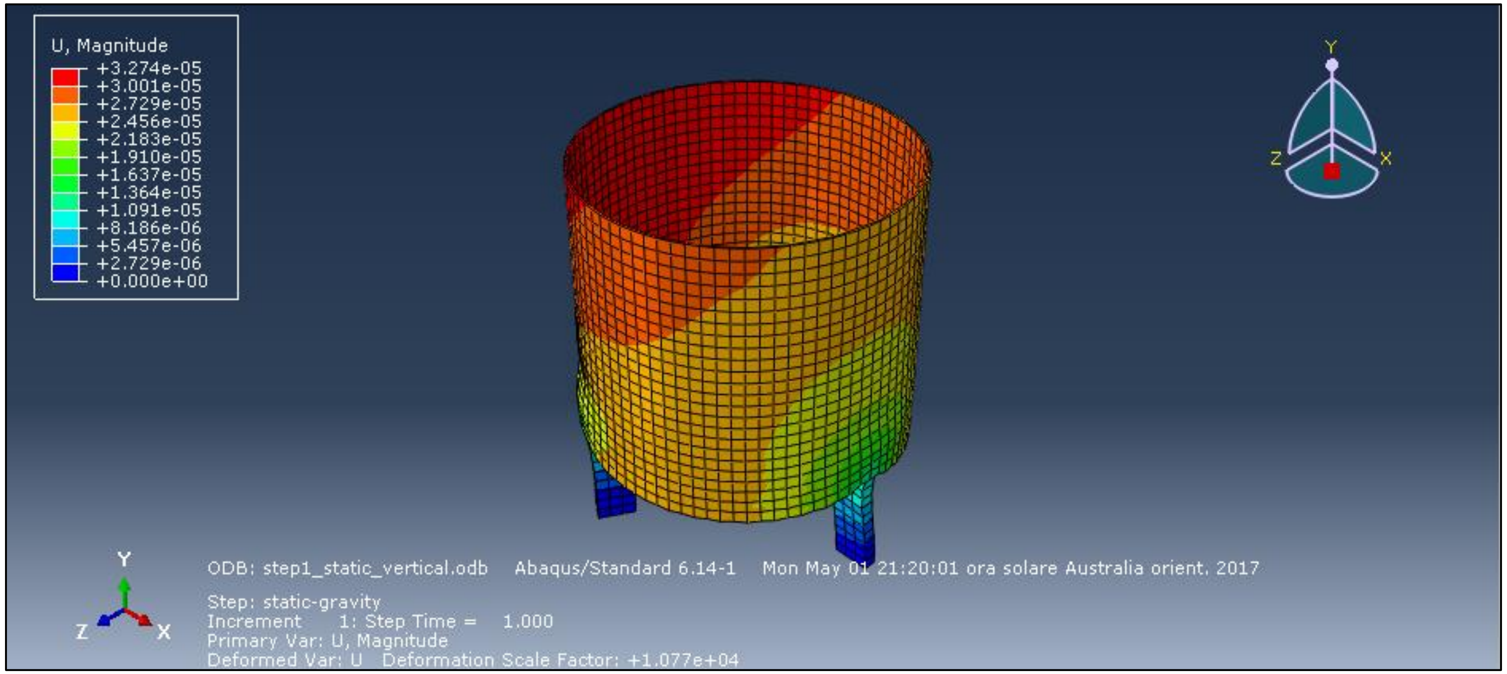
- Von Mises Stress



$\sigma_{VM,max}$ ~ 5 Mpa

1° analysis: General Static Analysis – vertical loads only

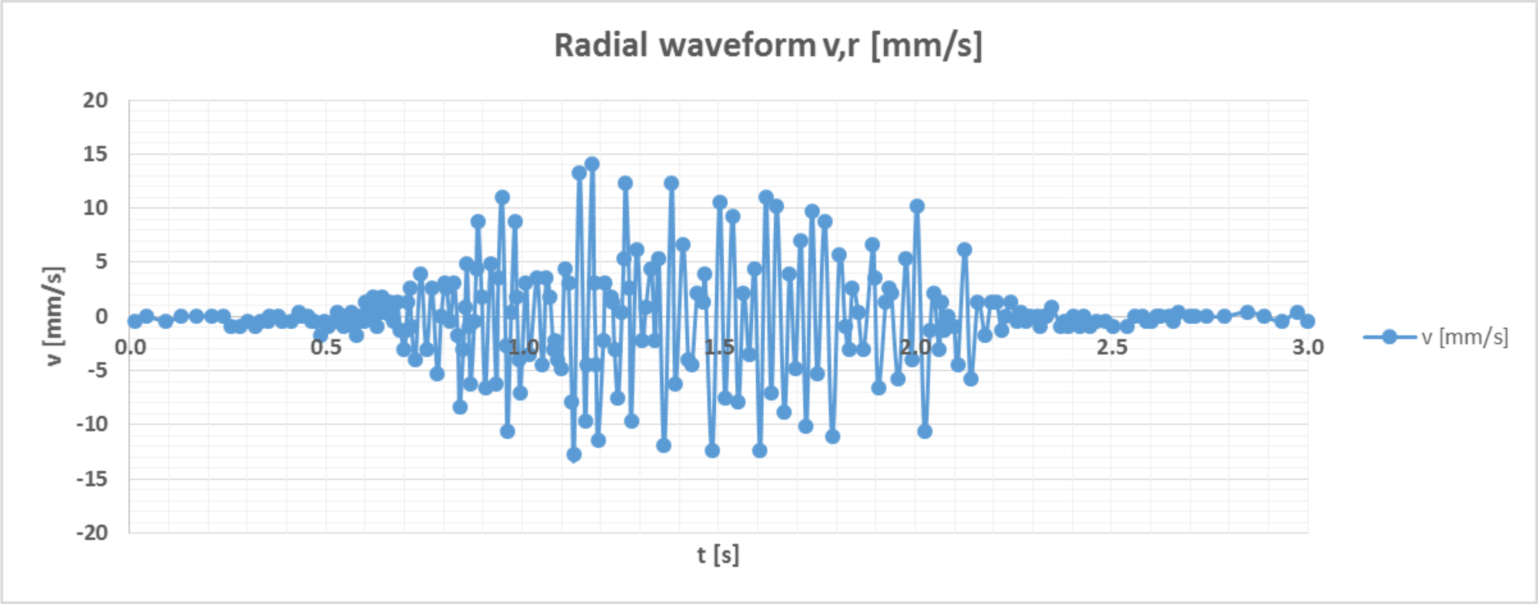
- Total displacement



$u_{tot,max} \sim 0.04$ mm

2° analysis: dynamic implicit
Blast in X,Y,Z direction combined

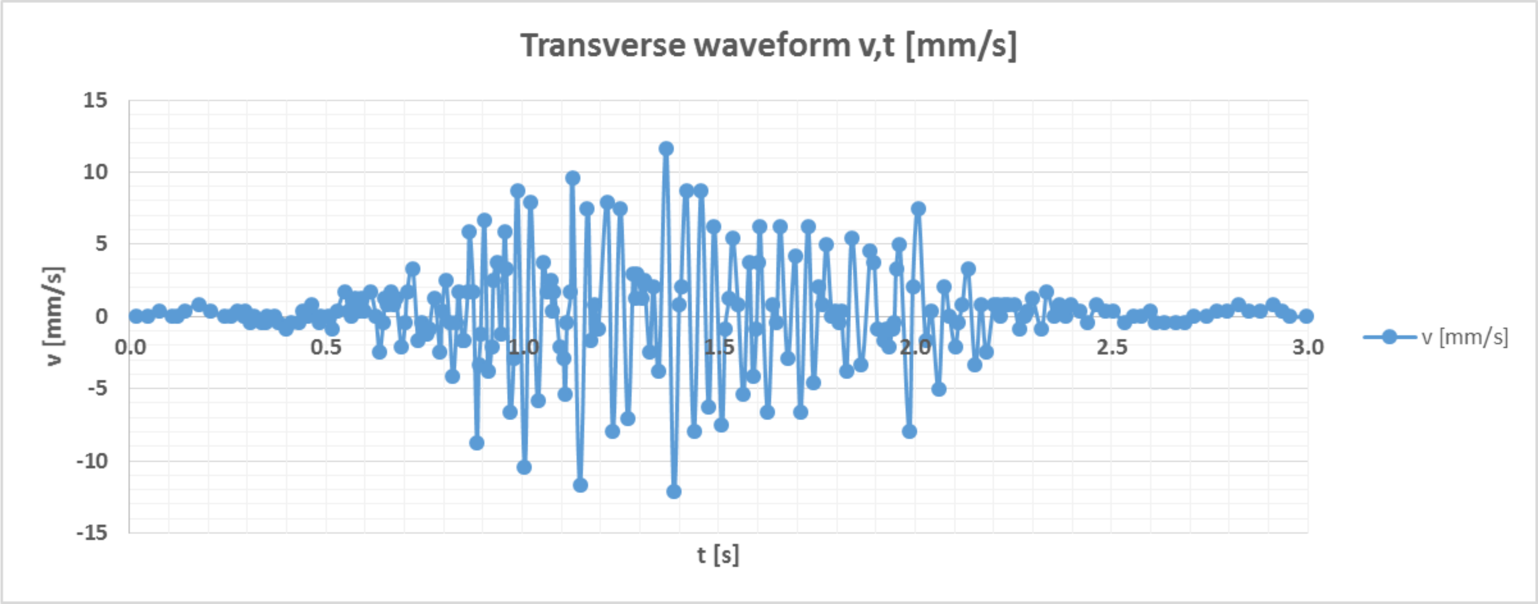
- Waveform data from *«Blast induced vibration monitoring and waveform analysis» by L.W. Armstrong*
- Wave form type: gold mine blast



X (radial) direction

2° analysis: dynamic implicit
Blast in X,Y,Z direction combined

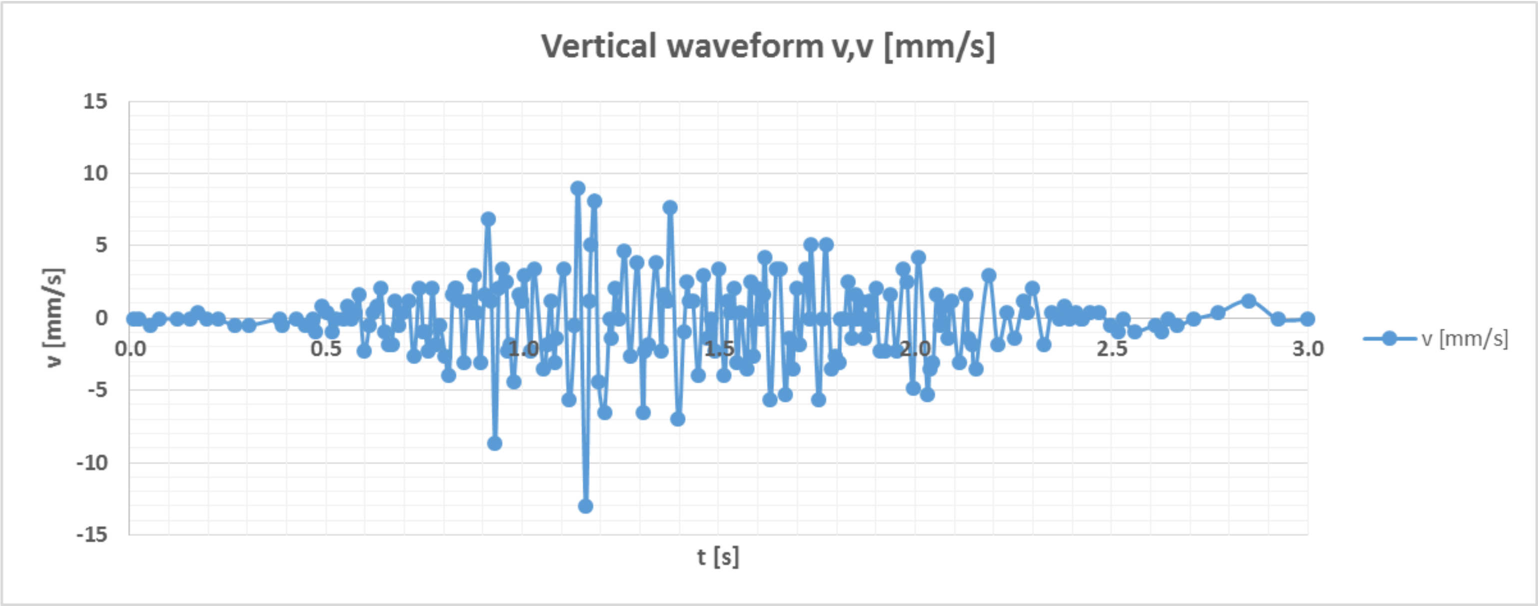
- Waveform data from *«Blast induced vibration monitoring and waveform analysis» by L.W. Armstrong*
- Wave form type: gold mine blast



Z (transverse) direction

2° analysis: dynamic implicit
Blast in X,Y,Z direction combined

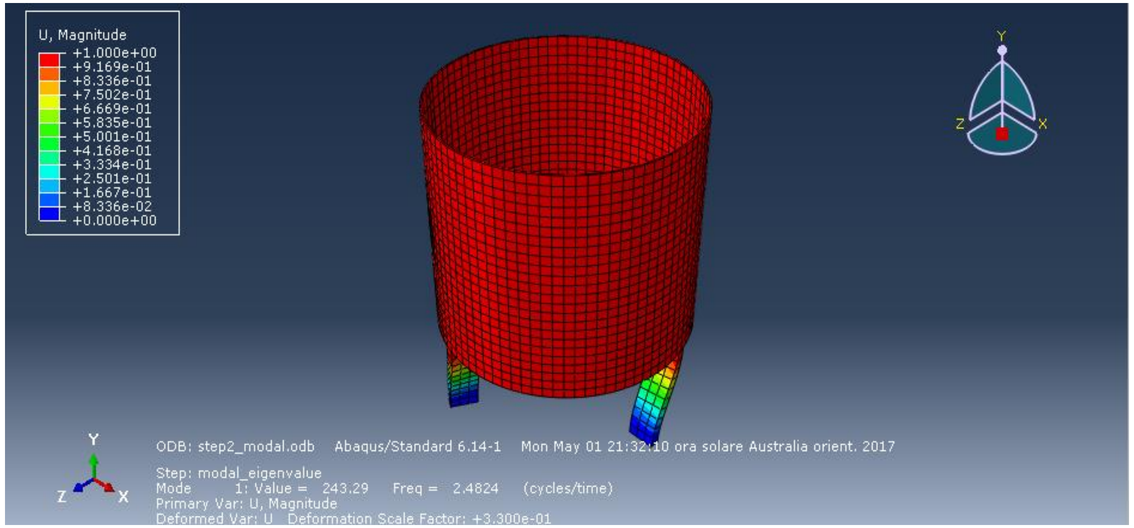
- Waveform data from *«Blast induced vibration monitoring and waveform analysis» by L.W. Armstrong*
- Wave form type: gold mine blast



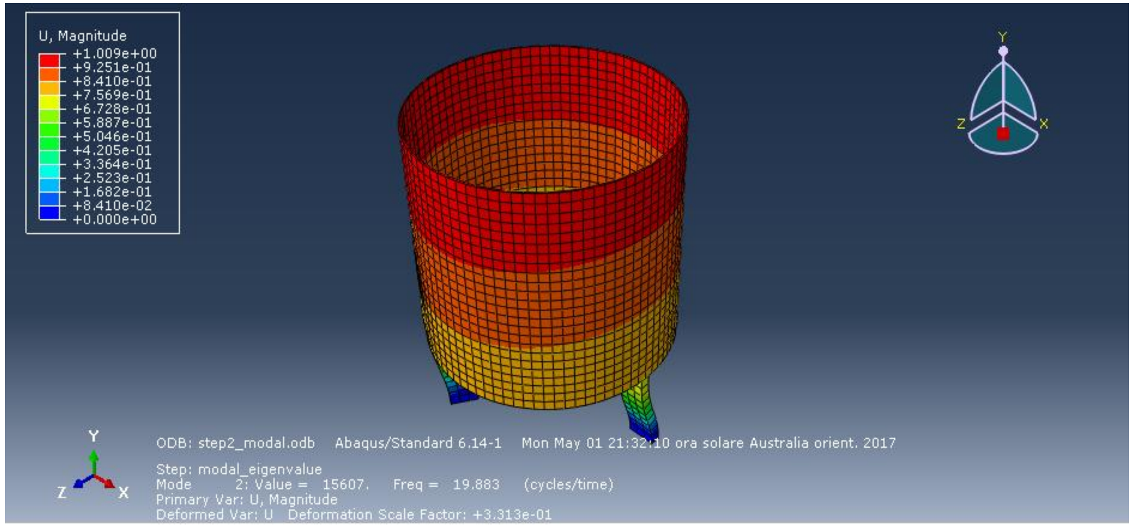
Y (vertical) direction

1° analysis: Modal Eigenvalue Analysis

- Simplified vessel model: no torospherical dished end
- Dynamic implicit performed following modal eigenvalue analysis

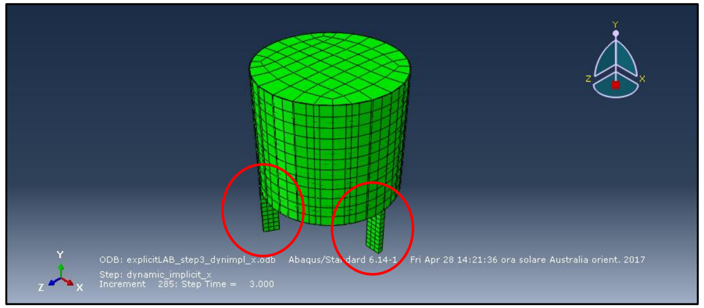


Vibrational mode 1 – Torsional
f = 2.48 Hz, eigenvalue = 243.3

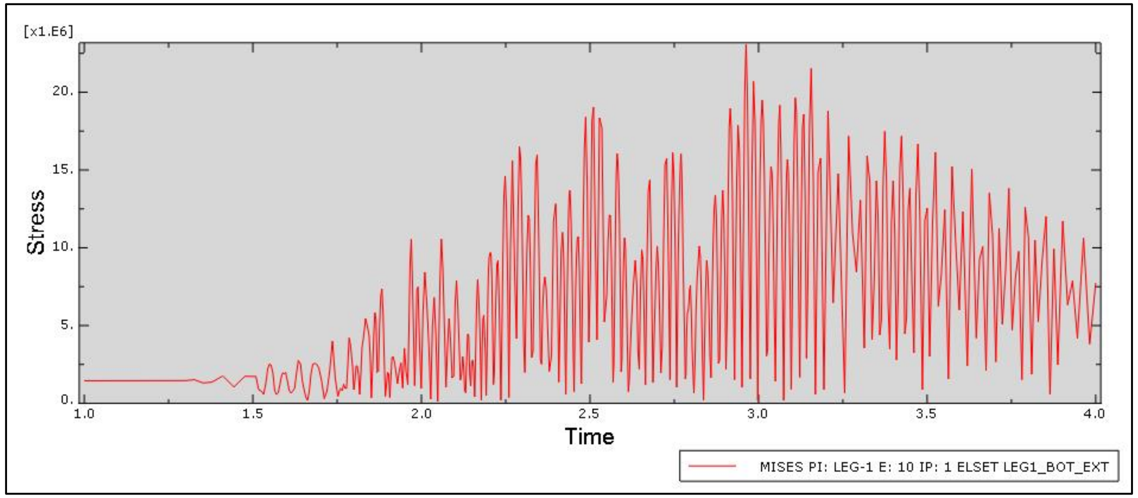


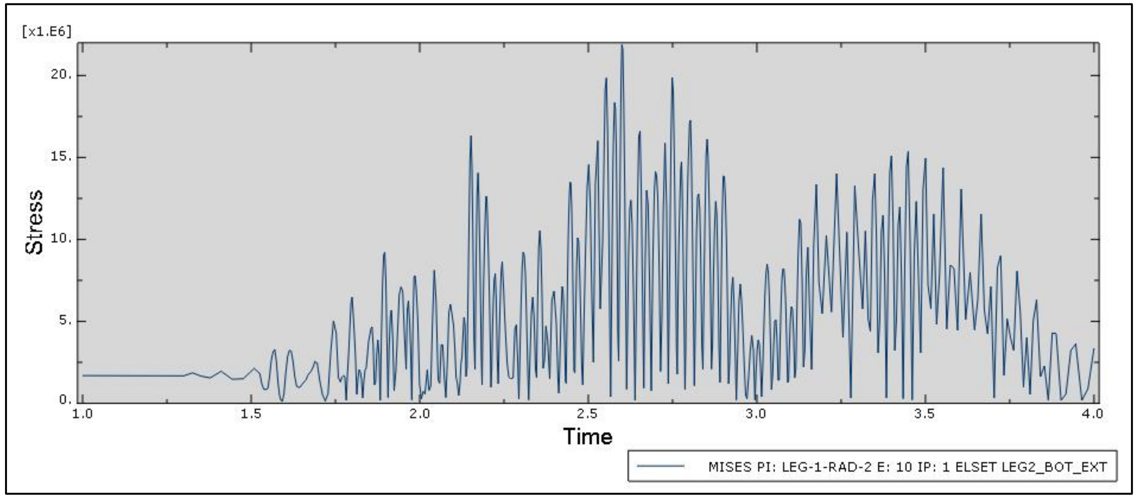
Vibrational mode 2 – Flexural
f = 19.88 Hz, eigenvalue = 15607

1° analysis: Dynamic Implicit
Blast in X,Y,Z direction



- Support system stress history:



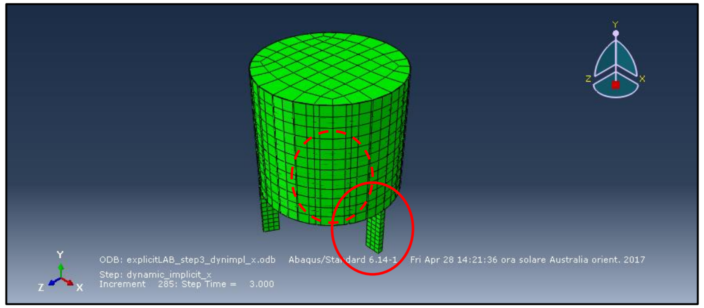


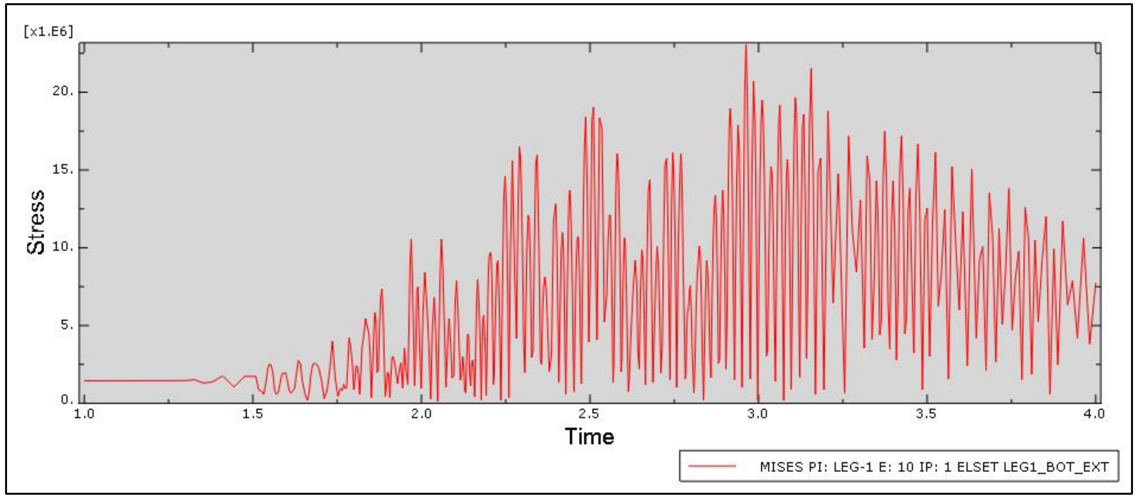
LEG 1
$\sigma_{max,V.M.}$ ~ 26 Mpa

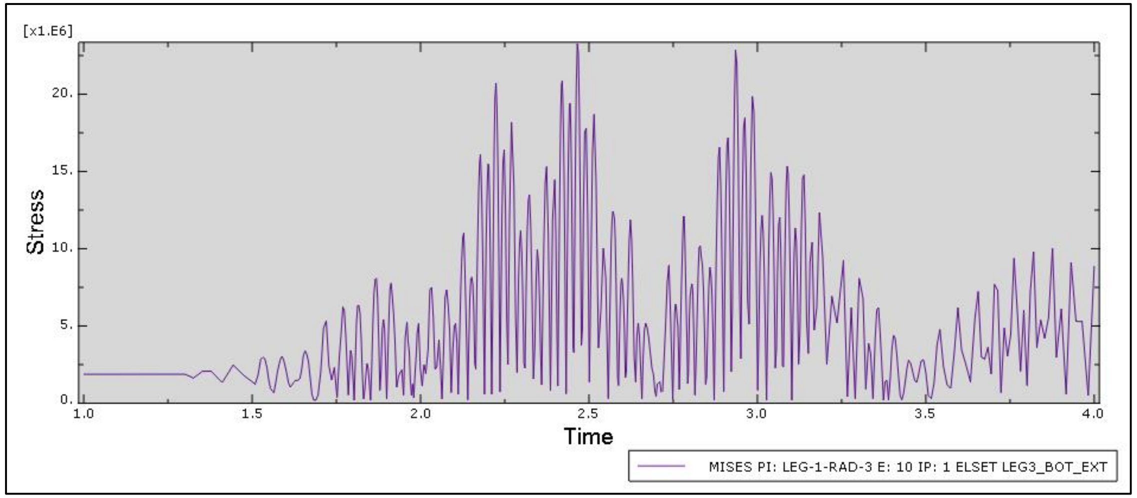
LEG 2
$\sigma_{max,V.M.}$ ~ 25 Mpa

1° analysis: Dynamic Implicit Blast in X,Y,Z direction

- Support system stress history:





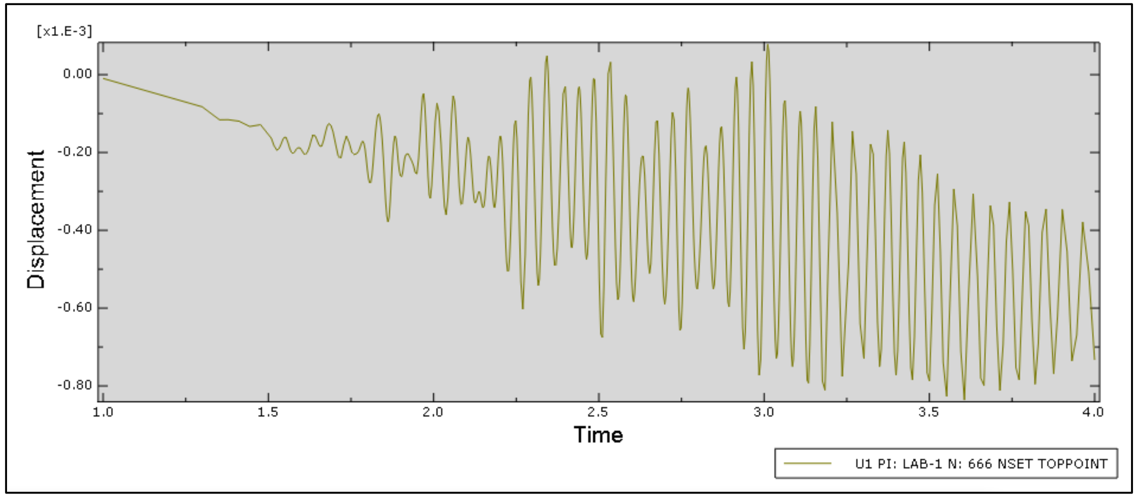


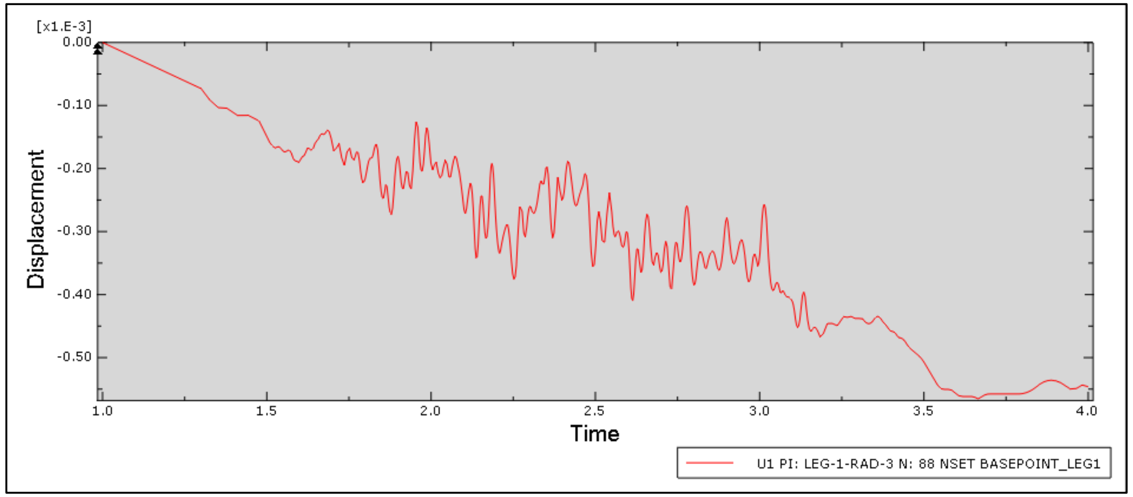
LEG 1
$\sigma_{max,V.M.}$ ~ 26 Mpa

LEG 3
$\sigma_{max,V.M.}$ ~ 27 Mpa

1° analysis: dynamic implicit
Blast in X,Y,Z direction

- Ux displacement time history (radial)



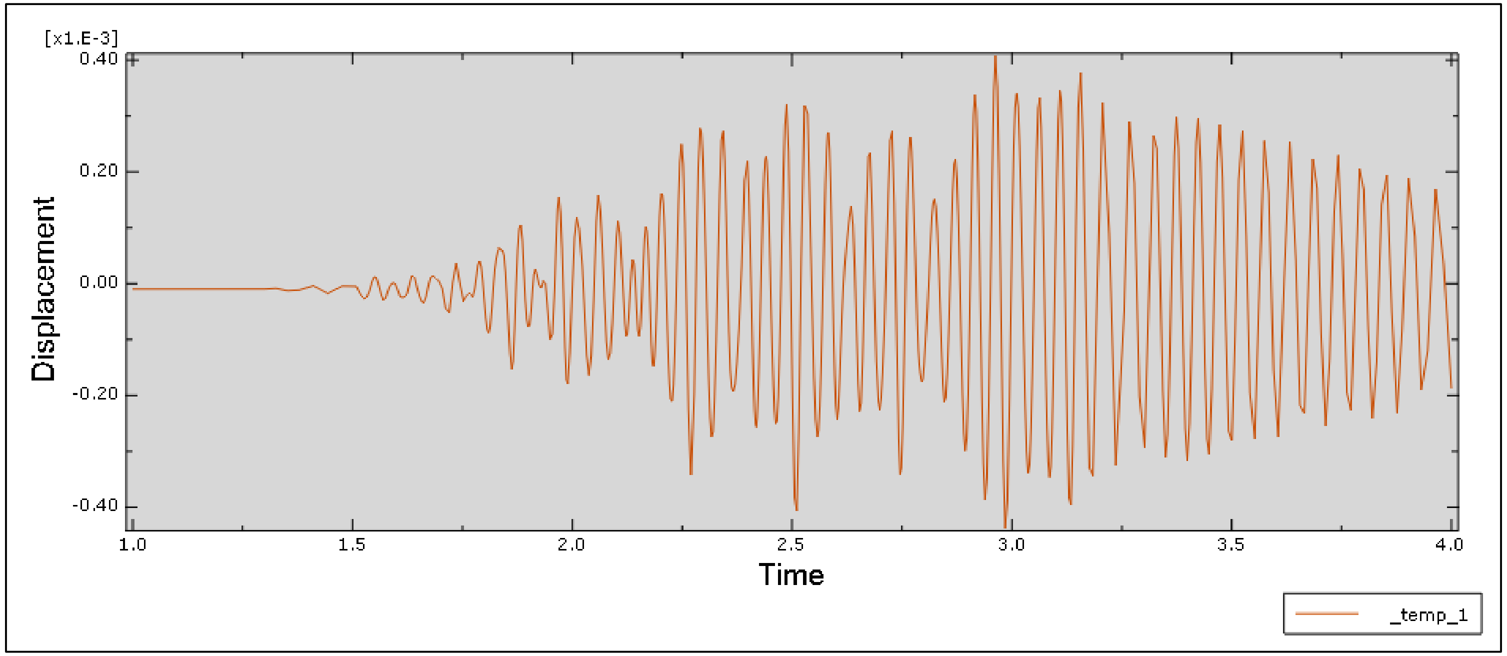


Ux,top displacement
Ux,max ~ 0.85 mm

Ux,bot displacement
Ux,max ~ 0.65 mm

1° analysis: dynamic implicit
Blast in X,Y,Z direction

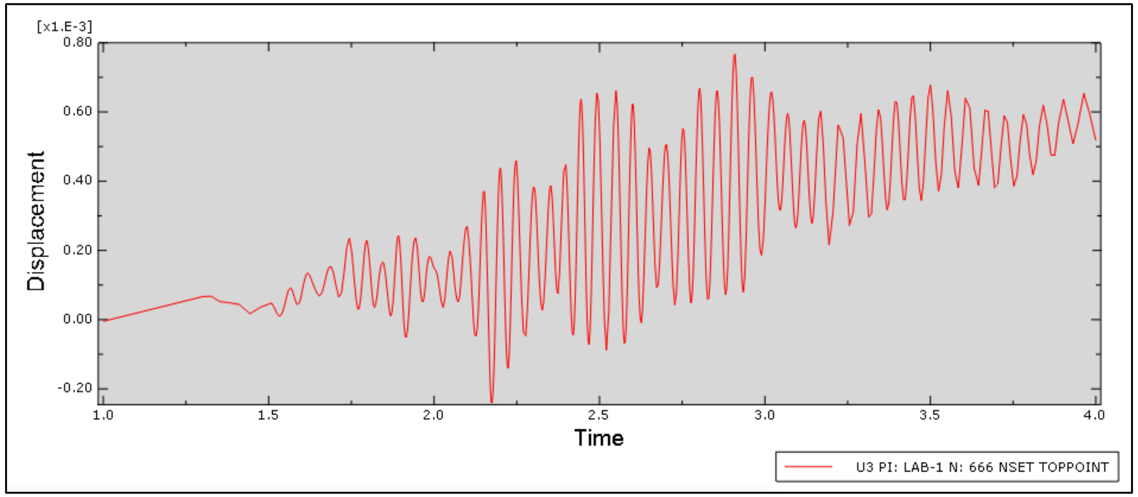
- Ux displacement time history (radial)

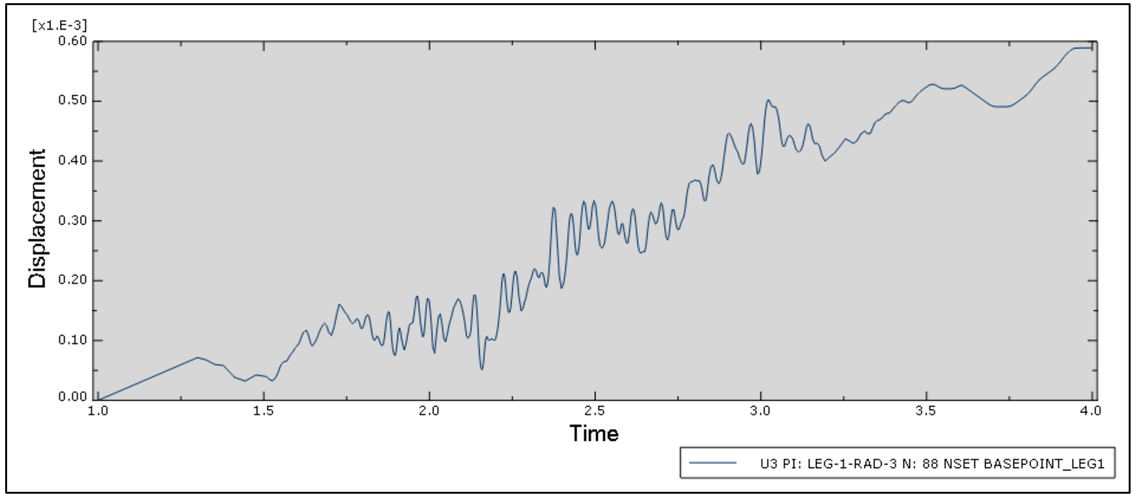


Ux relative displacement
= Ux,top(t) – Ux,bot(t); Ux,max ~ 0.4 mm

1° analysis: dynamic implicit
Blast in X,Y,Z direction

- Uz displacement time history (transverse)



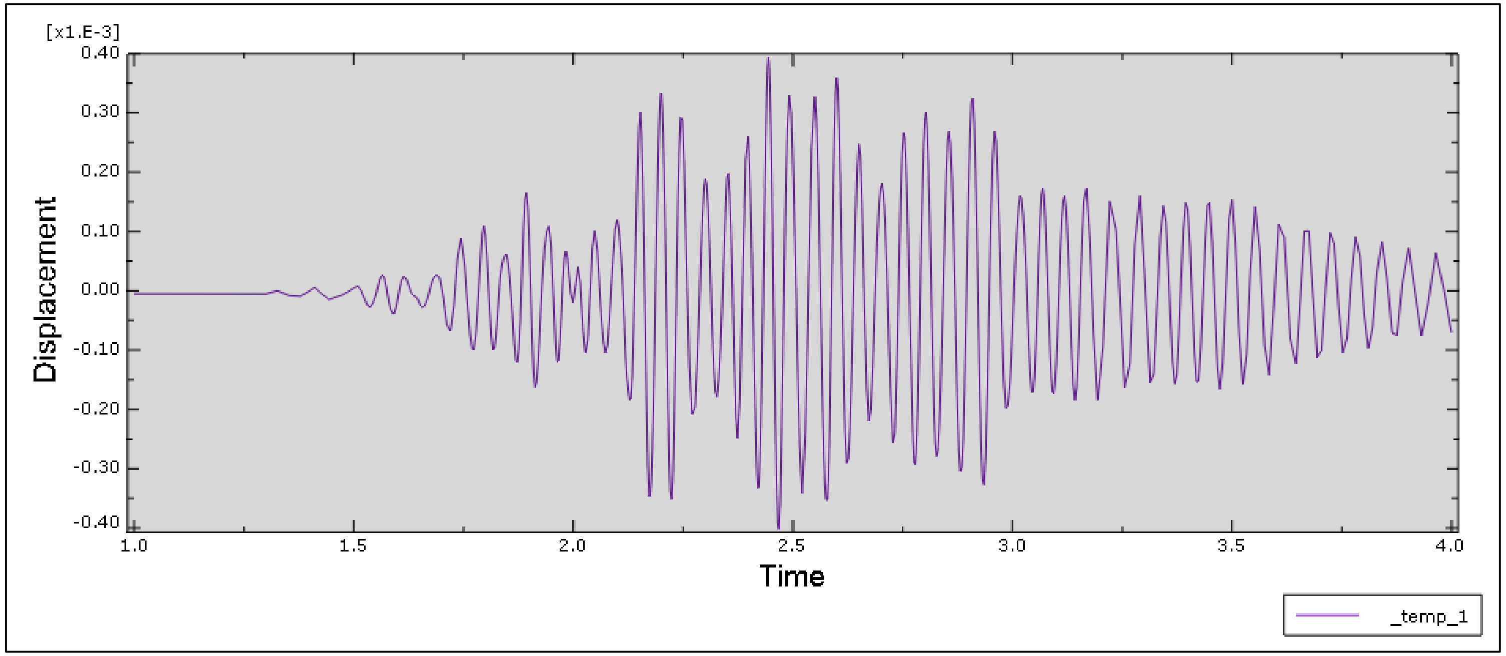


Ux,top displacement
Ux,max ~ 0.8 mm

Ux,bot displacement
Ux,max ~ 0.6 mm

1° analysis: dynamic implicit
Blast in X,Y,Z direction

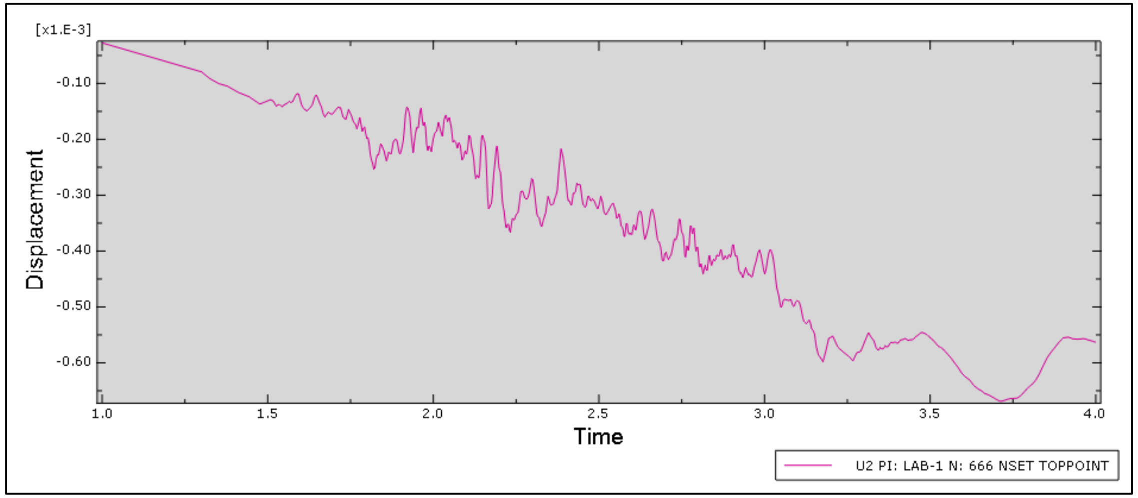
- Uz displacement time history (transverse)

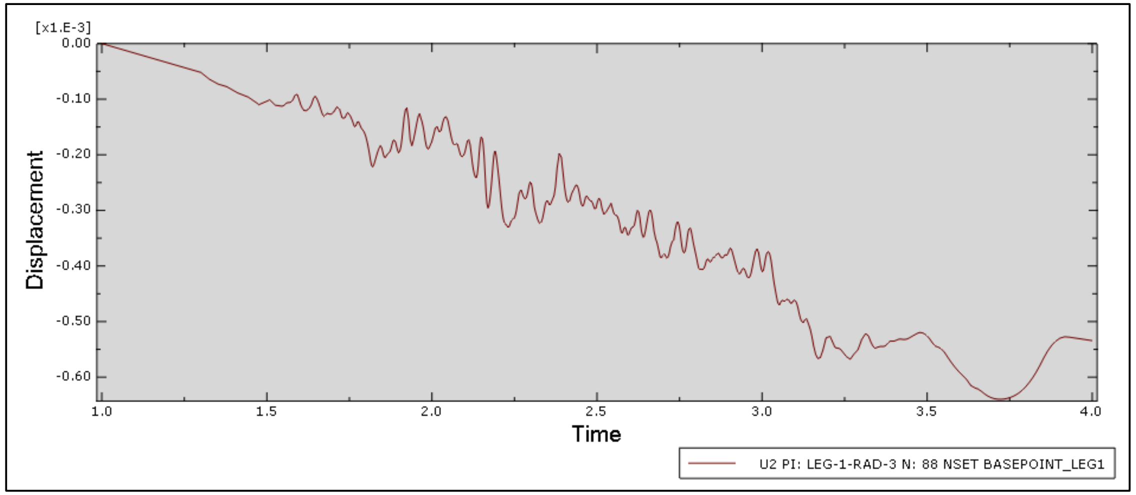


Ux relative displacement
= Ux,top(t) – Ux,bot(t); Ux,max ~ 0.4 mm

1° analysis: dynamic implicit
Blast in X,Y,Z direction

- Uy displacement time history (vertical)



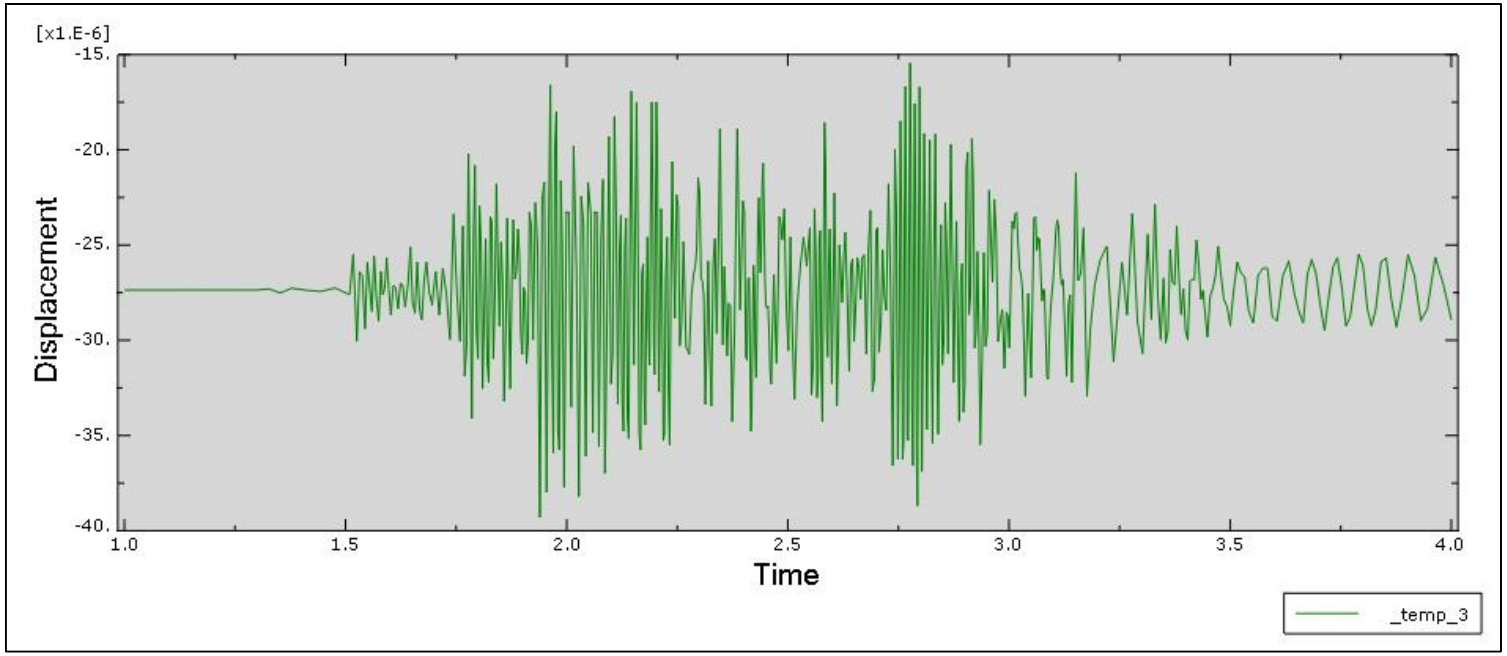


Ux,top displacement
Ux,max ~ 0.75 mm

Ux,bot displacement
Ux,max ~ 0.7 mm

1° analysis: dynamic implicit
Blast in X,Y,Z direction

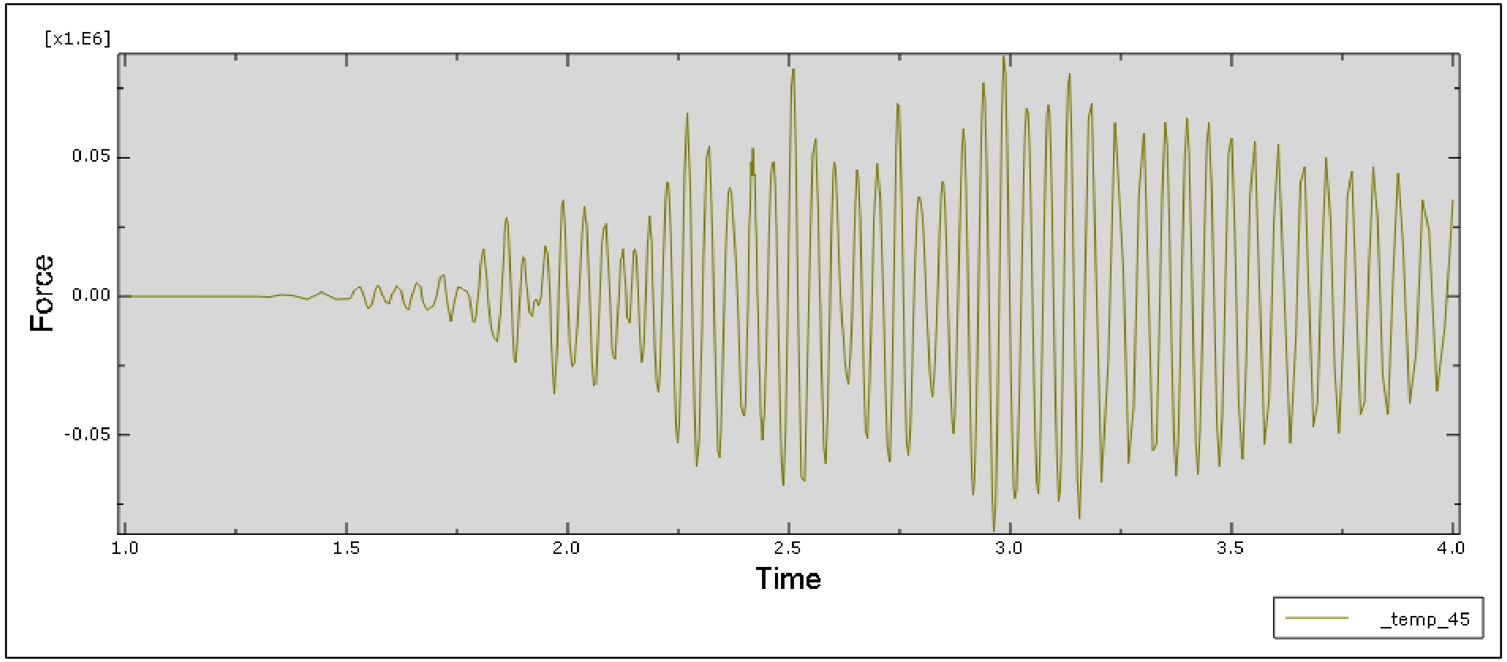
- Uy displacement time history (vertical)



Ux relative displacement
= Ux,top(t) – Ux,bot(t); Ux,max ~ 0.25 mm

1° analysis: dynamic implicit
Blast in X,Y,Z direction

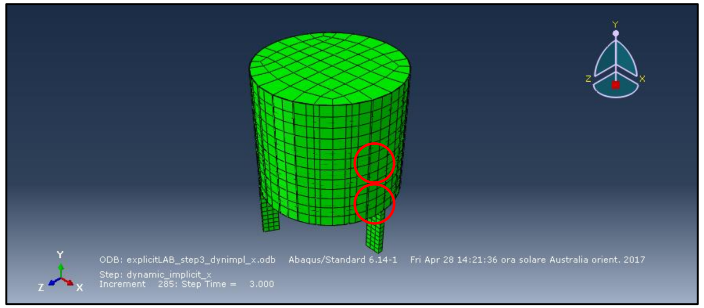
- Vx total base shear time history

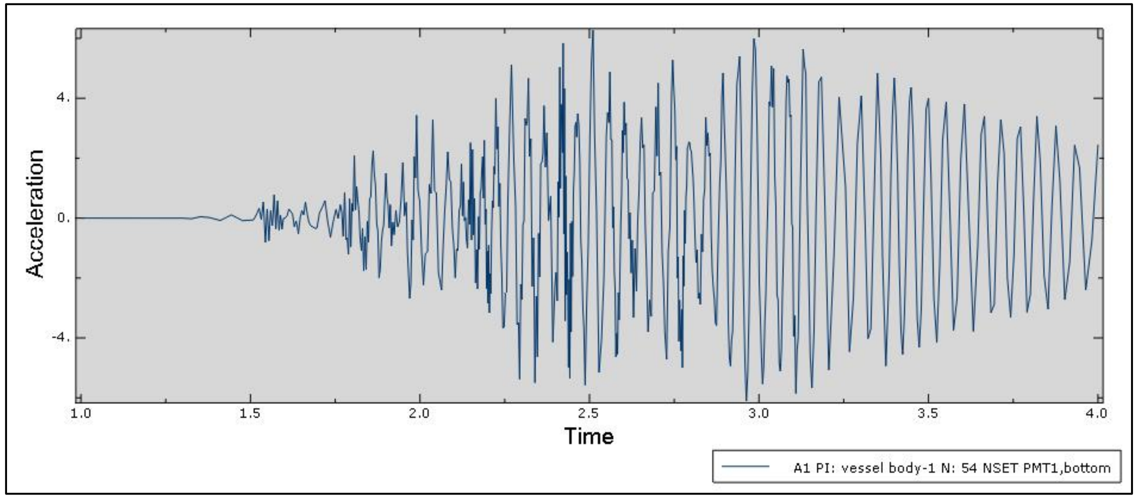


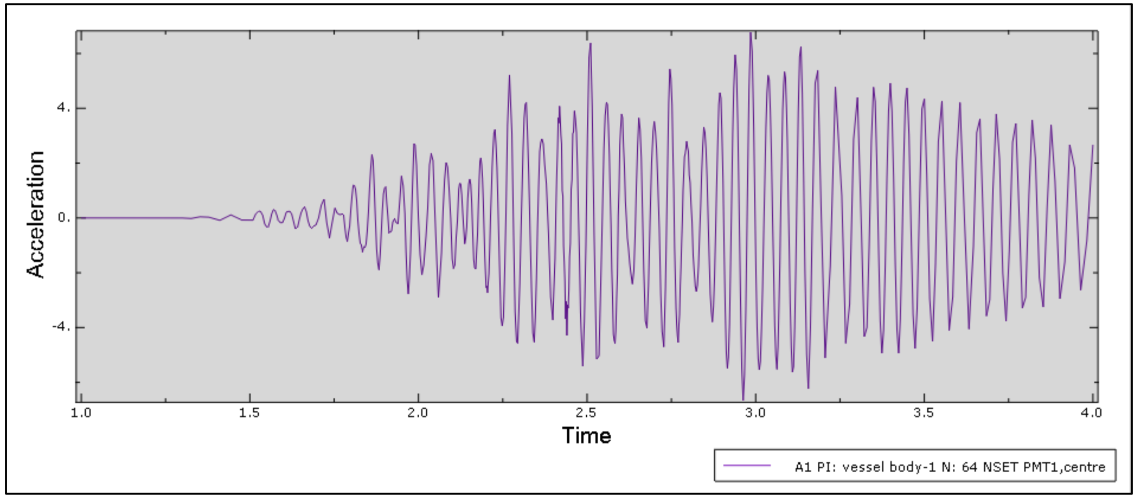
Vx – base shear
Vx,max ~ 85 kN

1° analysis: Dynamic Implicit Blast in X,Y,Z direction

- PMT along X, ACCELERATION in x direction





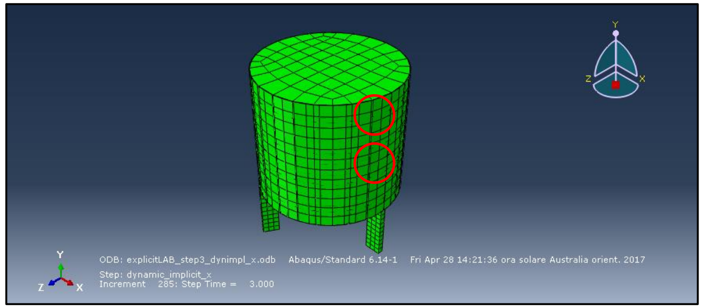


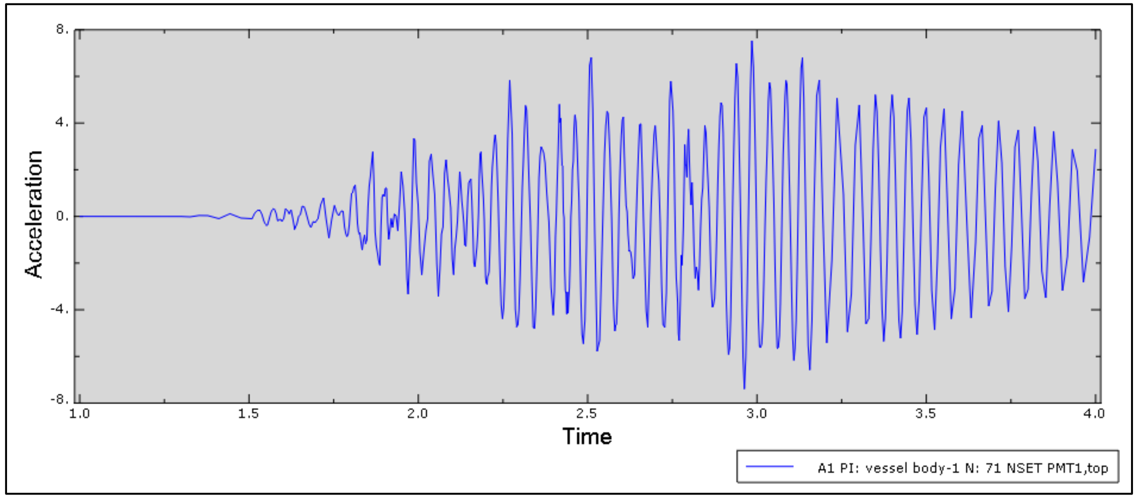
BOTTOM
a_{max} ~ 0.6 g

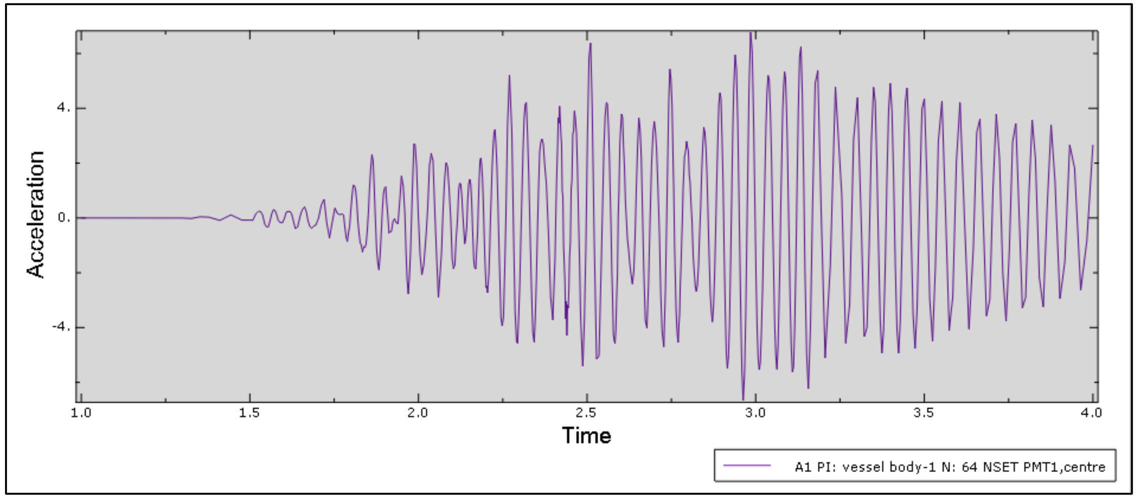
CENTRE
a_{max} ~ 0.65 g

1° analysis: Dynamic Implicit Blast in X,Y,Z direction

- PMT along X, ACCELERATION in x direction





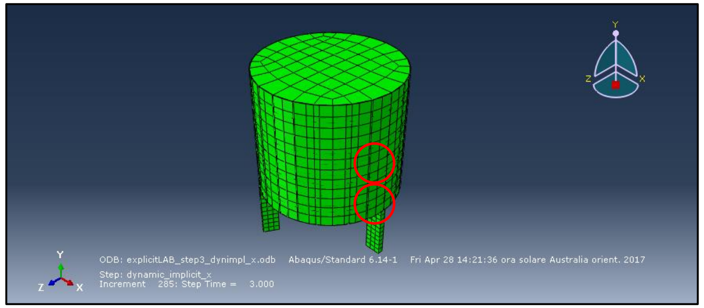


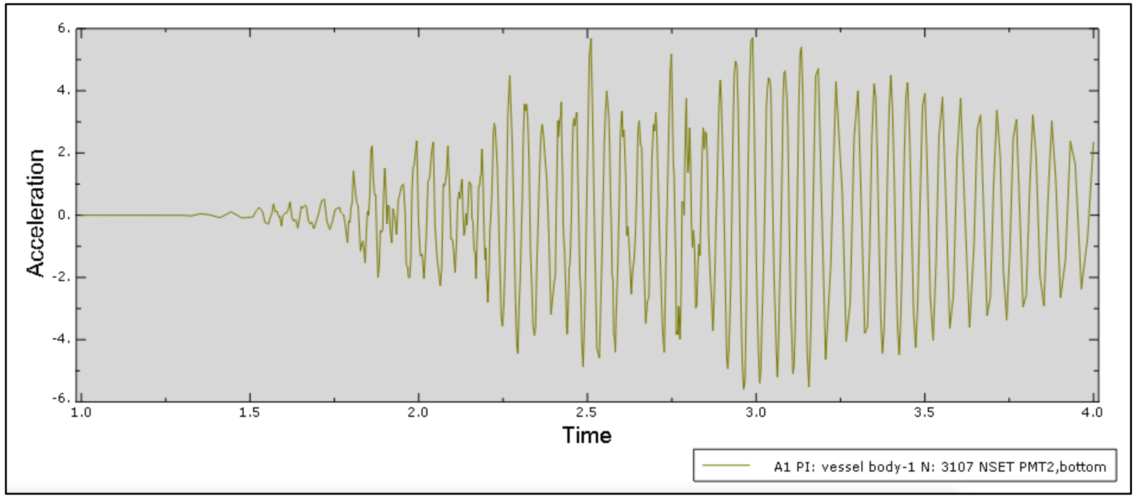
TOP
a_{max} ~ 0.8 g

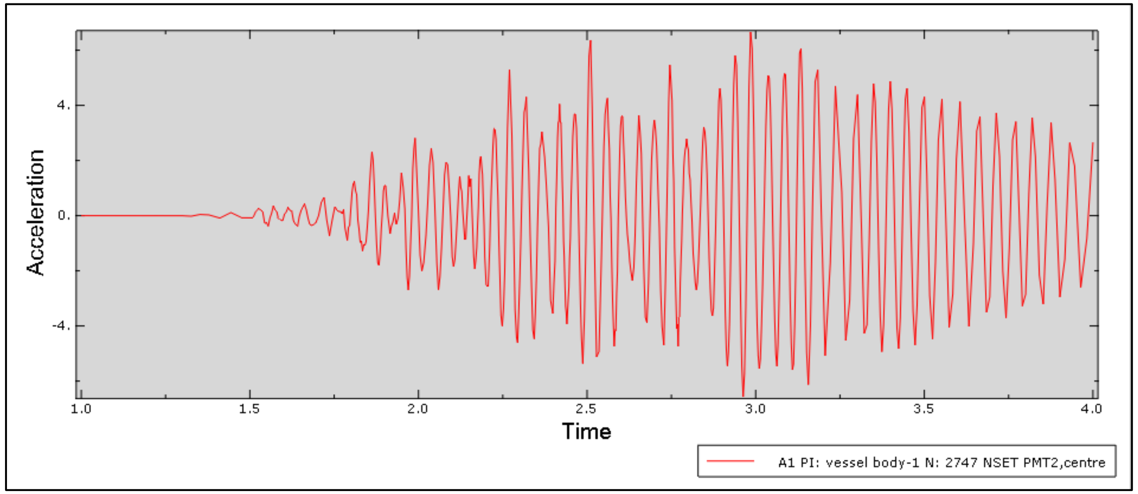
CENTRE
a_{max} ~ 0.65 g

1° analysis: Dynamic Implicit Blast in X,Y,Z direction

- PMT along Z, ACCELERATION in x direction





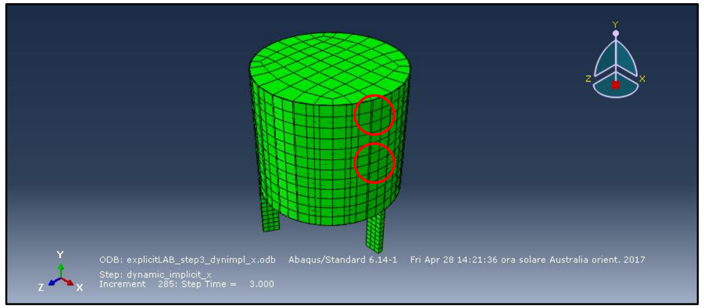


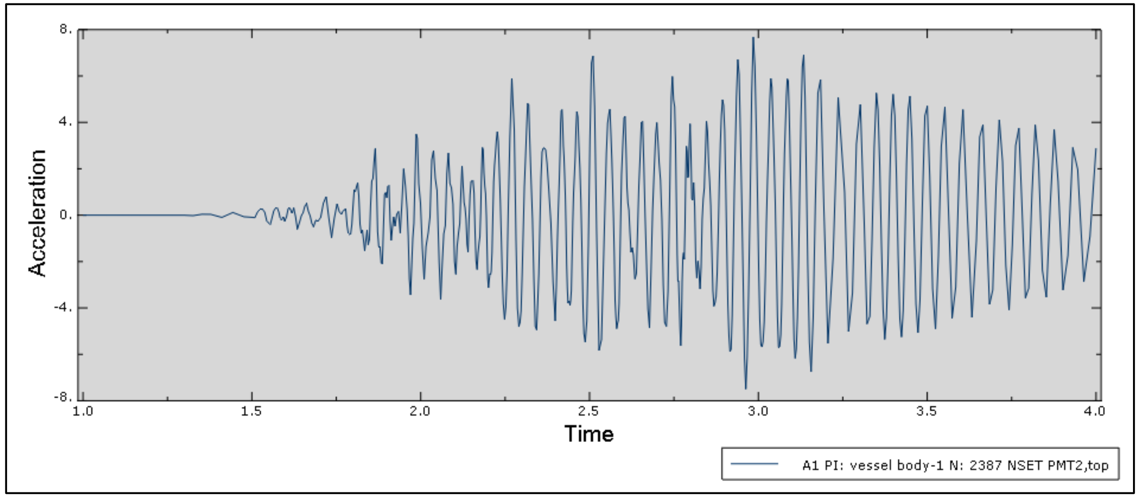
BOTTOM
a_{max} ~ 0.6 g

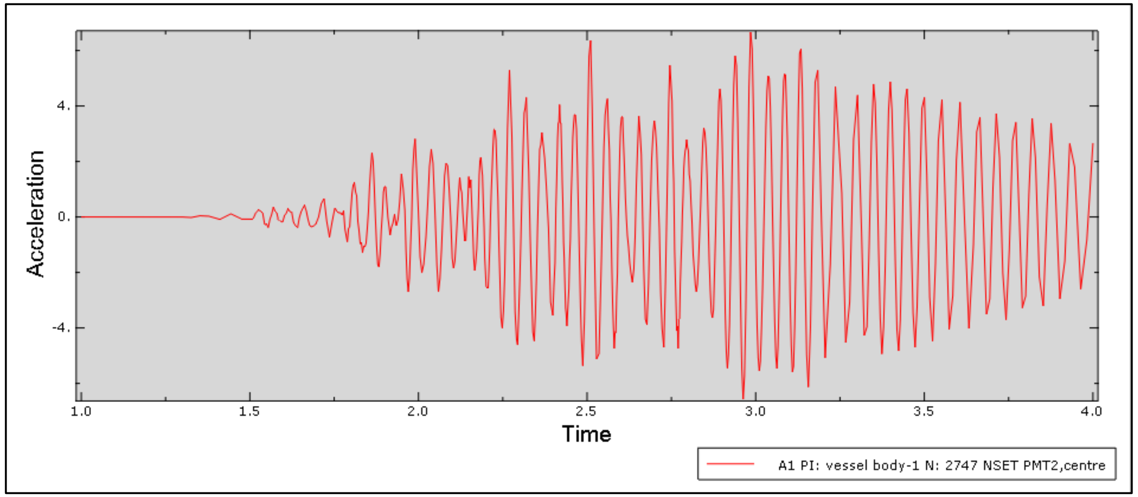
CENTRE
a_{max} ~ 0.65 g

1° analysis: Dynamic Implicit
Blast in X,Y,Z direction

- PMT along Z, ACCELERATION in x direction







TOP
a_{max} ~ 0.8 g

CENTRE
a_{max} ~ 0.65 g

Results – Part 2
Simplified vessel model
Isolated model

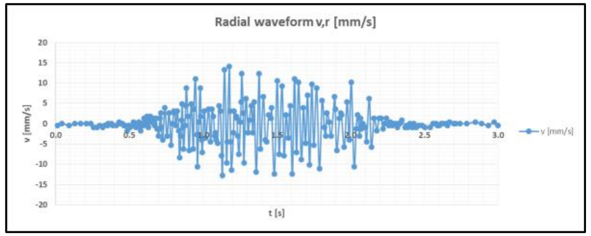
Tiziano Baroncelli

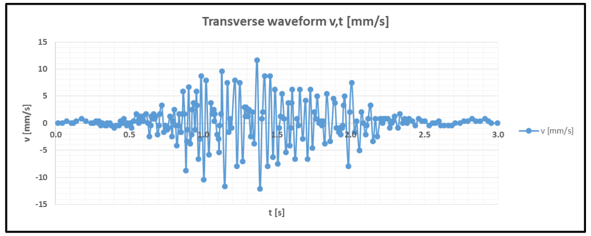
Structural Engineer

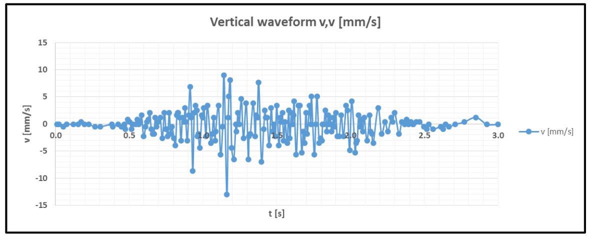
UoM

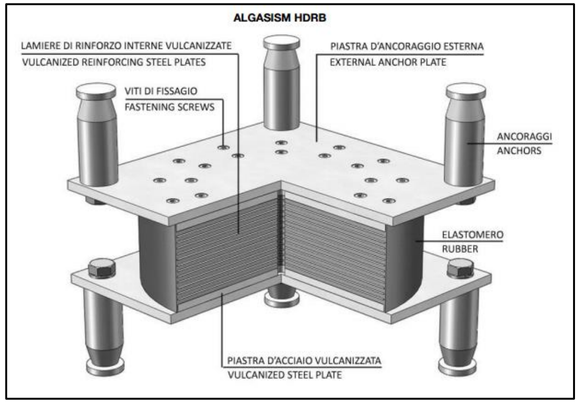
Concept: model vibration isolation through discrete (1D) connectors – elastic behaviour

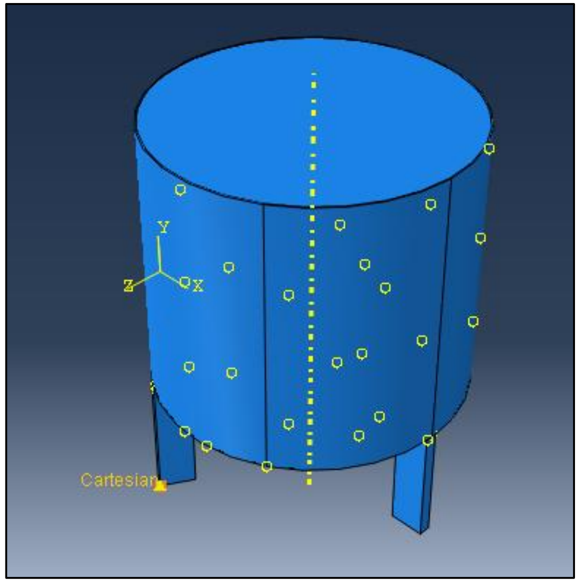
INPUT



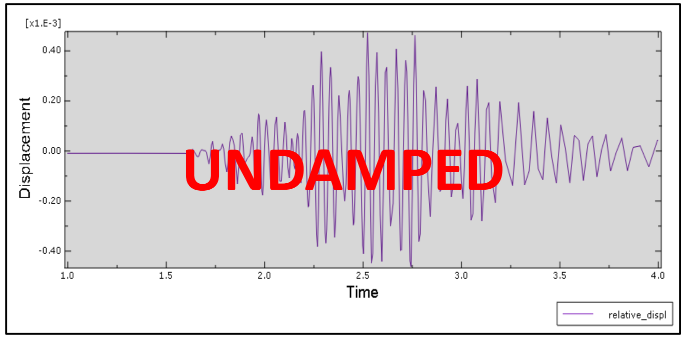




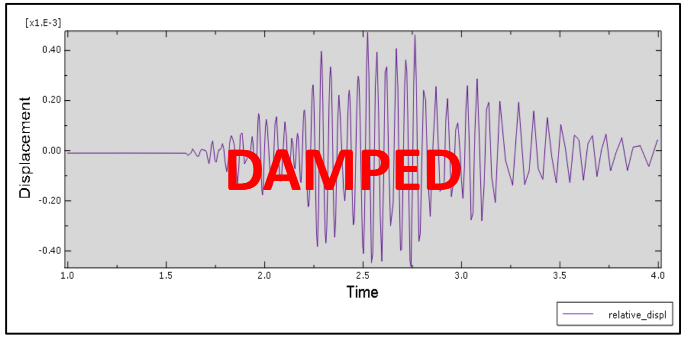




OUTPUT



VS



Analysis with High Damping Rubber Bearings (HDRB) – HDS (soft bearings)

Legenda | *Legend*

HDS (High Damping Soft)
G=0,4N/mm2 – ξ=10%.
HDN (High Damping Normal)
G=0,8N/mm2 – ξ=10%
HDH (High Damping Hard)
G=1,4N/mm2 – ξ=16%

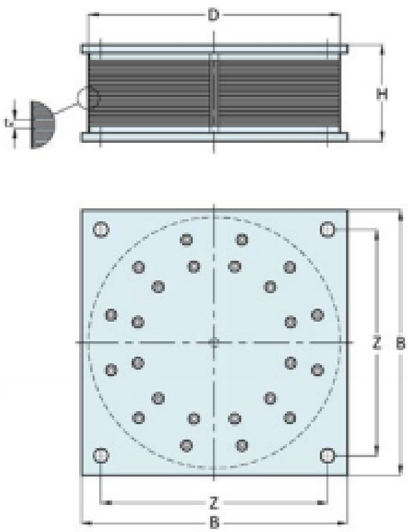
Dati tecnici | *Technical Data*

V_{max} Carico verticale massimo allo SLU con spostamento nullo
Max vertical load at ULS (Ultimate Limit State) with zero displacement
V_{sism} Carico verticale in condizione sismica
Vertical load under seismic conditions
K_r Rigidezza orizzontale
Horizontal stiffness
S_{max} Spostamento di progetto
Design displacement
ξ Smorzamento viscoso della gomma
Viscous damping of the rubber

Dati geometrici | *Geometrical Data*

D Diametro elastomero
Diameter of the elastomer
H Altezza totale isolatore
Overall height of the isolator
t_e Spessore elastomero
Thickness of the elastomer
B Dimensione d'ingombro dell'isolatore (nelle due direzioni)
Overall dimensions (space requirement) of the isolator (in two directions)
Z Interasse degli ancoraggi (nelle due direzioni)
Distance between centers of anchorages (in two directions)

B = D + 50
Z = 0,75 x B



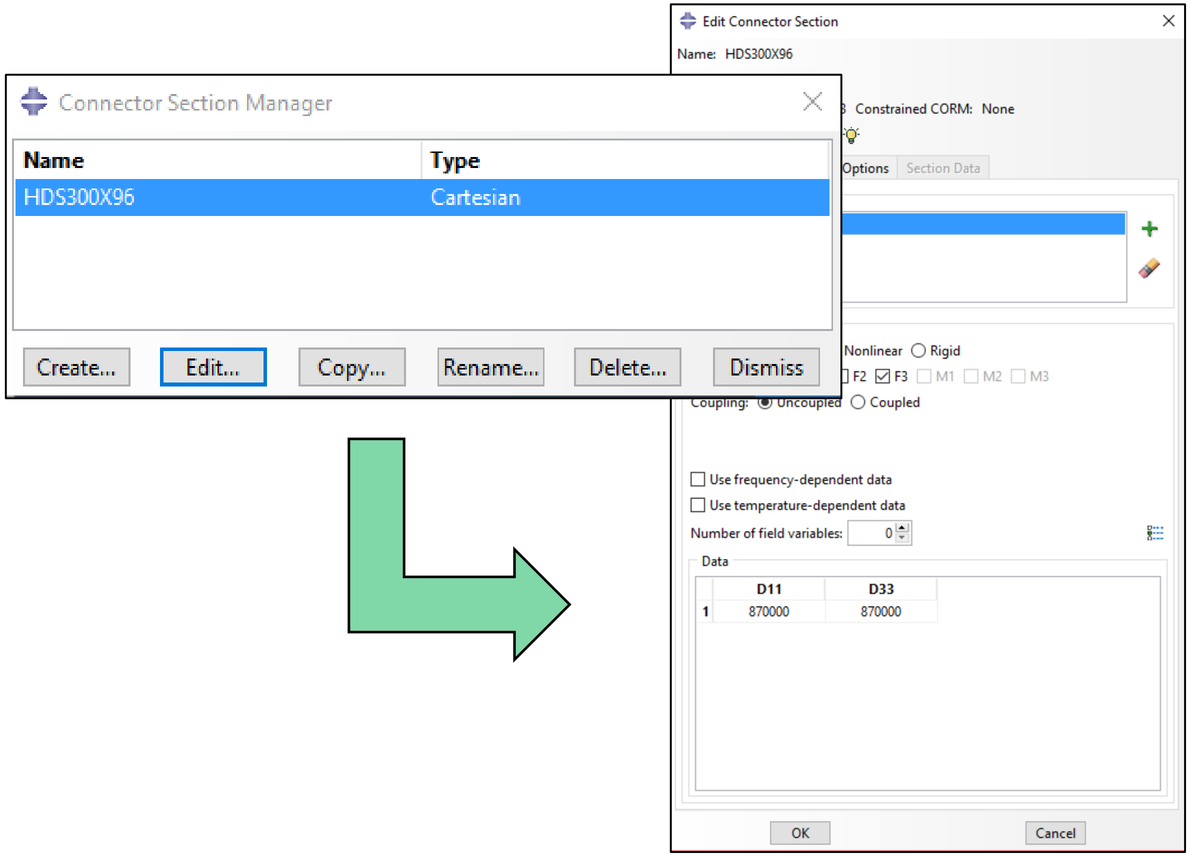
HDS	Vmax [kN]	Vsism [kN]	Kr [kN/mm]	HDN	Vmax [kN]	Vsism [kN]	Kr [kN/mm]	HDH	Vmax [kN]	Vsism [kN]	Kr [kN/mm]	H [mm]	te [mm]	Smax [mm]
Diametro elastomero / Elastomer diameter D = 300mm														
HDS300X48	800	650	0,59	HDN300X48	1650	1400	1,18	HDH300X48	2900	2500	2,06	132	48	100
HDS300X54	800	600	0,52	HDN300X54	1700	1200	1,05	HDH300X54	3050	2100	1,83	140	54	110
HDS300X60	800	520	0,47	HDN300X60	1750	1000	0,94	HDH300X60	3100	1800	1,65	148	60	120
HDS300X66	750	430	0,43	HDN300X66	1550	850	0,86	HDH300X66	2750	1500	1,50	156	66	140
HDS300X72	700	370	0,39	HDN300X72	1400	750	0,79	HDH300X72	2500	1300	1,37	164	72	150
HDS300X78	650	330	0,36	HDN300X78	1300	650	0,72	HDH300X78	2250	1150	1,27	172	78	160
HDS300X84	550	290	0,34	HDN300X84	1150	550	0,67	HDH300X84	1050	1000	1,18	180	84	170
HDS300X90	550	250	0,31	HDN300X90	1100	500	0,63	HDH300X90	1900	900	1,10	188	90	180
HDS300X96	500	210	0,29	HDN300X96	1000	400	0,59	HDH300X96	1750	750	1,03	196	96	200

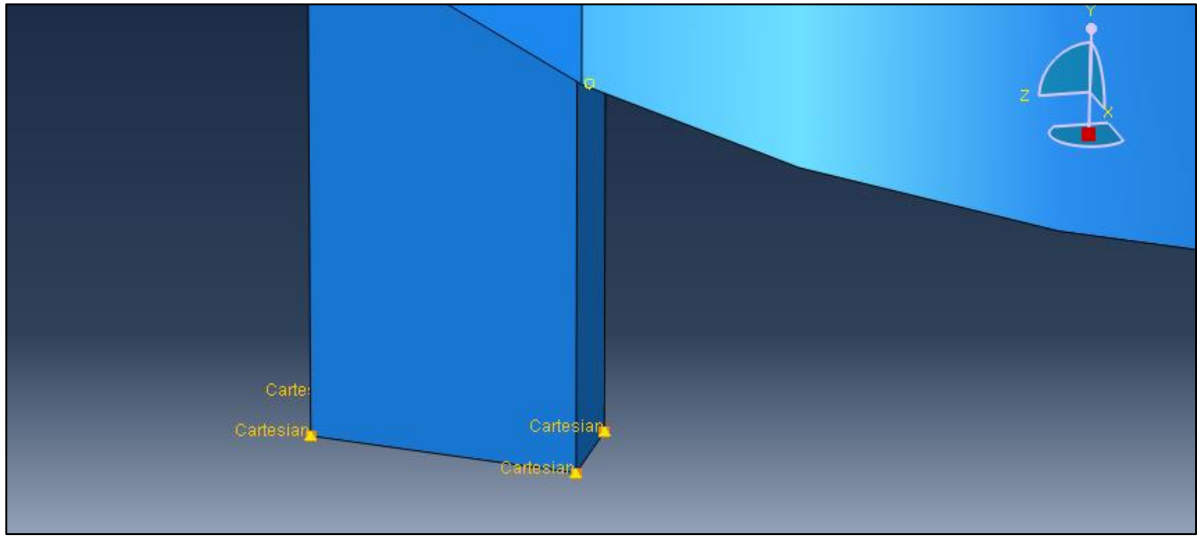
- Typical frequencies for blast waves: 10-50 Hz
- Natural vibrational frequency: 2.6 Hz
- We impose T1 = vibration period of 1° mode = 1 s (f=1 Hz)
- Even with the smallest available HDS damper we obtain:

T1 = 2πω ~ 0.85 s, f = 1.17 Hz

Analysis with High Damping Rubber Bearings (HDRB) – HDS (soft bearings)

- Equivalent horizontal stiffness: Kr = 0.29 kN/mm
- Minimum number of isolators = 3 -> Kr,tot = 0.87 kN/mm





- Application of linear connectors to column base to simulate HDS isolators

2° analysis: Modal Eigenvalue Analysis

- From the theory of harmonic oscillators: what we expect is

$$T_1^* = 2\pi\omega = 2\pi\sqrt{m/K_{H,tot}} \cong 1.17\ s$$

Which is the oscillation period of the first vibration mode of the structure.

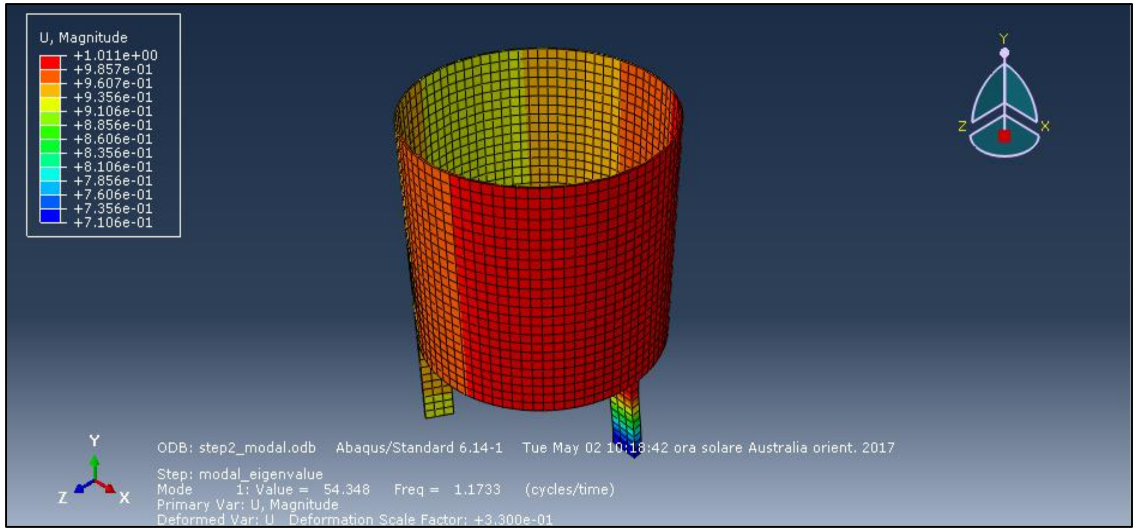
- The corresponding fundamental frequency is:

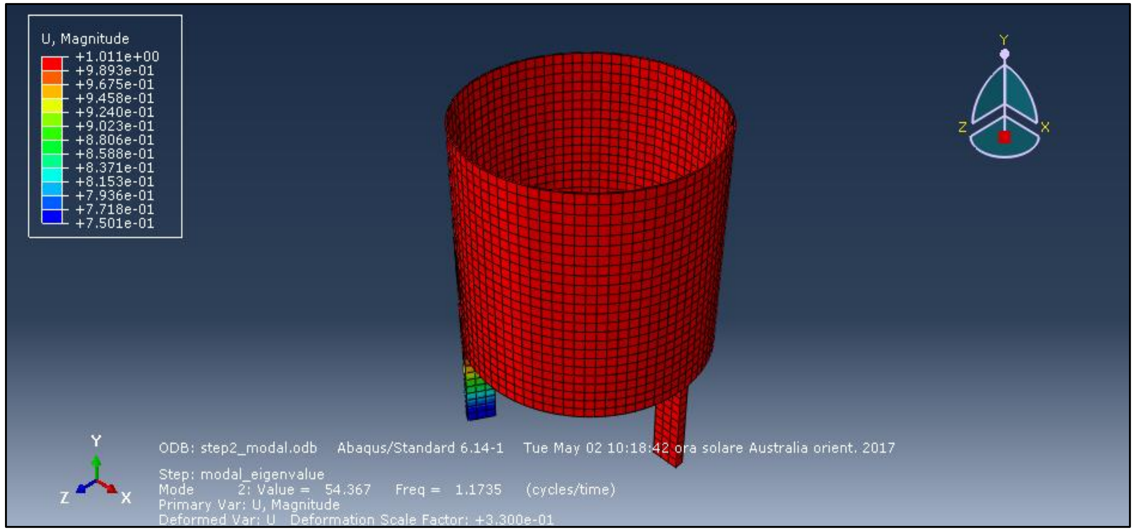
$$f_1^* = \frac{1}{T_1^*} = 1.162\ Hz$$

2° analysis: Modal Eigenvalue Analysis

- Results of modal-eigenvalue analysis: exactly what we expect:

Mode 1 = Mode 2 (translational along X,Z directions)



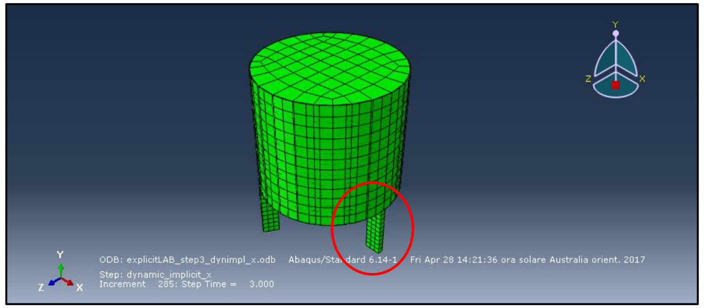


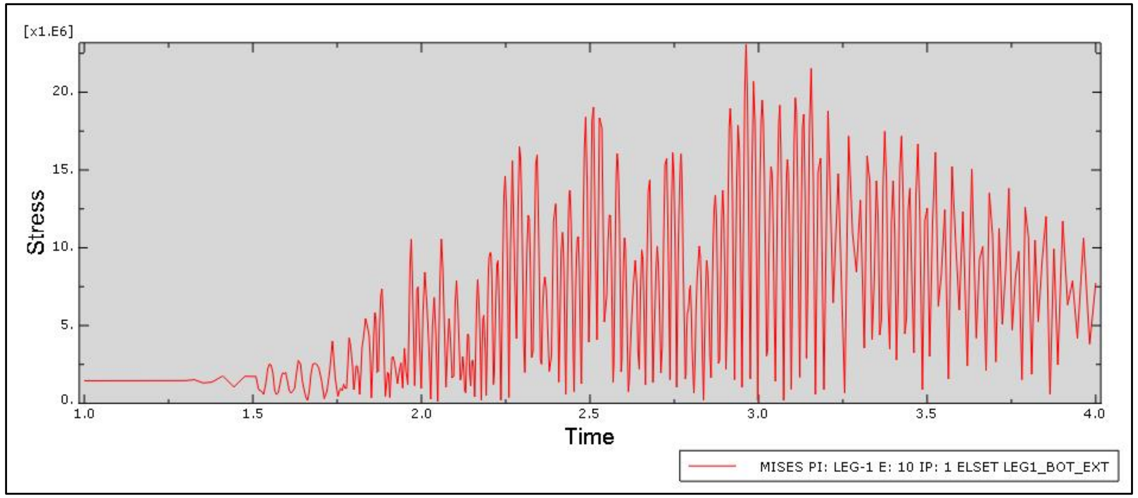
Vibrational mode 1 – Tranlsational
f = 1.17 Hz, eigenvalue = 54.4

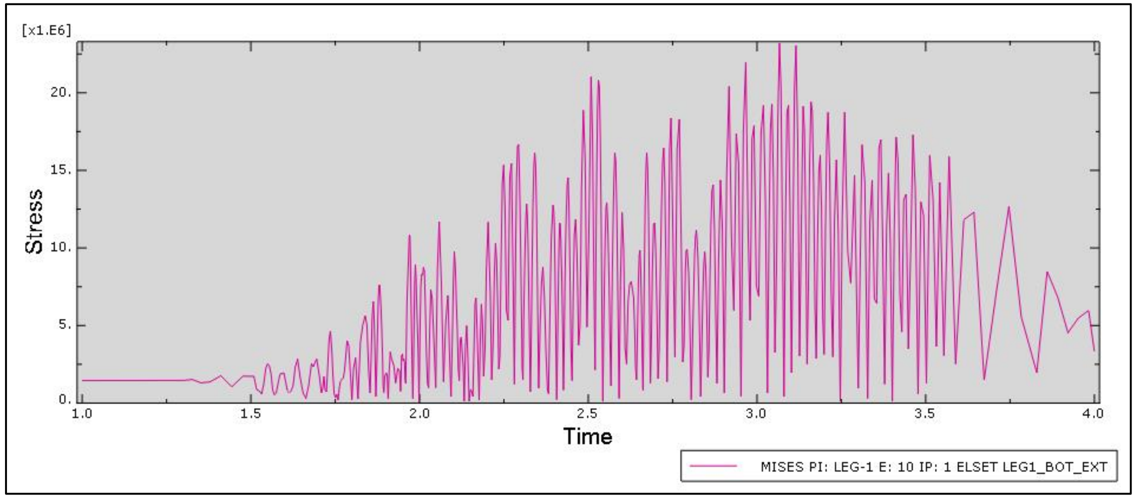
Vibrational mode 2 – Flexural
f = 1.17 Hz, eigenvalue = 54.4

2° analysis: dynamic implicit
Blast in X,Y,Z directions -damped

- Support system stress history: comparison leg1







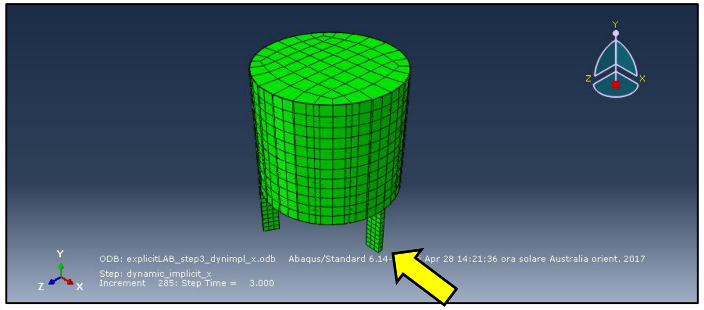
UNDAMPED
$\sigma_{max,V.M.}$ ~ 27 Mpa

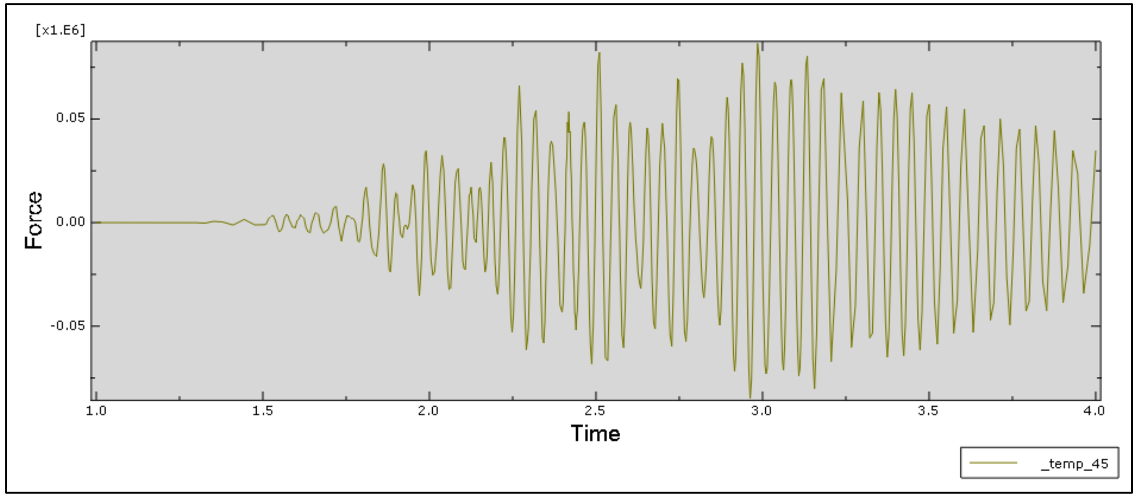
=

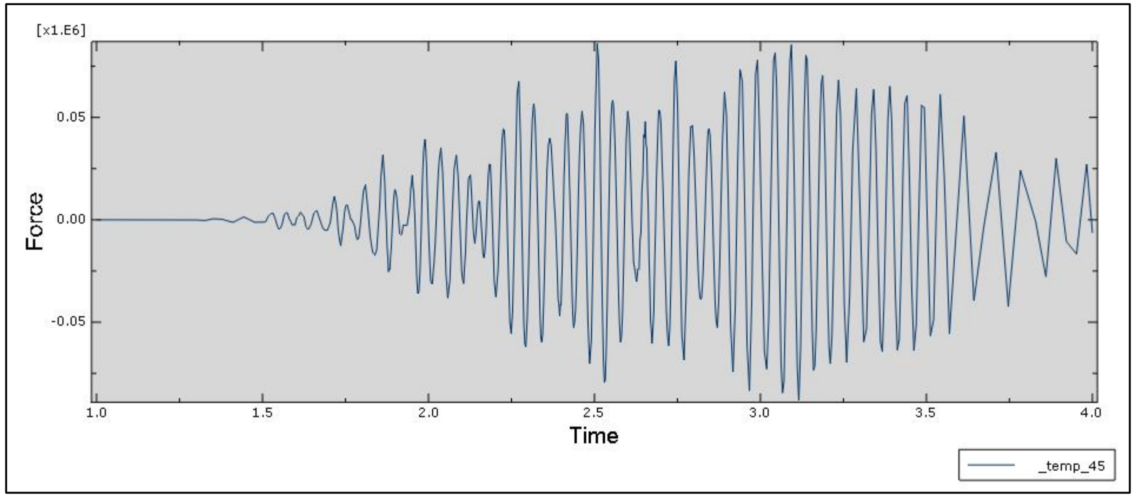
DAMPED
$\sigma_{max,V.M.}$ ~ 27 Mpa

2° analysis: dynamic implicit
Blast in X,Y,Z directions -damped

- Total base shear Vx (X dir.) - comparison







UNDAMPED
Vx,max ~ 85 kN

=

DAMPED
$\sigma_{max,V.M.}$ ~ 85 Mpa

Conclusions:

The results seem to be identical:

This is probably due to the fact that the BC are imposed (over time) in the same part of the model as the isolators: so the structure is forced to move in the same way.

Explicit modelling of a platform will follow – should solve the issue.

Model will be cross checked to ensure consistency;

Different isolators will be modelled to check structural response.

Following steps: refining the model

GENERAL MODELLING:

- Apply these simulations to possible shielding structure: qualitative assessment of shielding behaviour under horizontal actions.

SPECIFIC MODELLING:

- Response spectrum analysis VS dynamic implicit
- Take into account the non-linear behaviour of elastomeric bearings;
- Model different types of isolators – different ranges of frequency;
- Real geometry of the vessel (if possible: computational cost!);