

VALIDATE SIMULATION TECHNIQUES OF A MOBILE EXPLOSIVE CONTAINMENT VESSEL

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ABSTRACT – A Mobile Explosive Containment Vessel (MECV) is a chamber for protection against effects caused by explosions and is used to safely secure, contain, transport, store or test explosive materials. The MECV has been tested for an 8 kg TNT equivalent and strain levels at several positions were measured. These test data was used for comparison and validation of two simulation techniques and if necessary improve the simulation models.

The detailed geometry was simplified and volume meshed with nearly one million hexa elements in ANSA using several functions for structured mesh. The simulations were performed with the nonlinear dynamic finite element software LS-DYNA. The first well-applied technique using an axisymmetric model for the explosive blast load and then a script to map the blast load to a 3D structure simulation showed after some small modifications good agreement to the test. The second much more time-consuming technique with the blast load and the structure in the same analysis using fluid-structure interaction lead to significant lower strain levels compared to the test. A more detailed parameter study was performed to improve the simulation results.

As conclusion we now have two validated simulation techniques and procedures to make realistic explosive simulations of containment vessels.

TECHNICAL PAPER –

1. INTRODUCTION

The objective with this project is to validate two previously used simulation techniques against real tests of a Mobile Explosive Containment Vessel and if necessary improve the simulation techniques. This paper will give some additional focus on the creation of the structured volume finite element model.

2. MOBILE EXPLOSIVE CONTAINMENT VESSEL (MECV)

The project is carried out for Dynasafe Protection Systems AB in Sweden which is a company that offers a wide variety of products in explosion protection and bomb disposal technologies. A Mobile Explosive Containment Vessel (MECV) is a chamber for protection against effects caused by explosions and is used to safely secure, contain, transport, store or test explosive materials. The MECV has been tested for an 8 kg TNT equivalent and strain levels at several positions were measured [1]. A typical MECV and the test setup are shown in Figure 1.

The MECV have an outer length of 1 500 mm, an outer diameter of 1 300 mm, a wall thickness of 30 mm and weight about 2 800 kg. It consists of a vessel, a cover and a locking ring. The chamber is opened or closed by rotating the locking ring 15° and sliding the cover end.



Figure 1 – A typical MECV to the left and the test setup to the right.

3. SOFTWARE

The analyses are performed with the nonlinear dynamic finite element software LS-DYNA R6.0.0 [2]. The model was built for a previous project a few years ago with ANSA v13.1.2 [3]. The images in this paper are made with the current versions ANSA v14.1.0 [4] and μ ETA v14.1.0 [5].

4. FE-MODEL

From the detailed drawing the most relevant load carrying parts are identified and used for further geometry clean up, see Figure 2. This includes the vessel, the cover, the locking ring and some outer attachments. Details that are removed are pressure pipes, sealing rings and a fragment shield on the inside. The FE-model will be meshed with mainly hexa elements with a size of 6 mm in the locking mechanism and 10 mm in the rest of the chamber. This will result in about one million fully integrated volume elements which is a good compromise between simulation accuracy and simulation time.

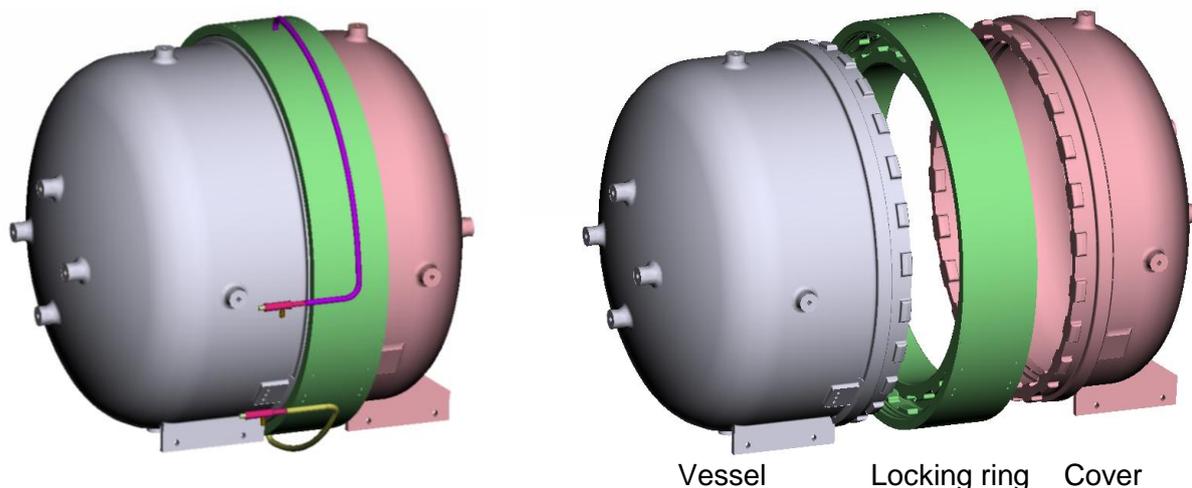


Figure 2 – The drawing to the left and the most load carrying parts to the right.

The locking mechanism consists of two flanges and a locking ring with in- and outside teeth. The teeth need to be simplified to fulfil the element requirements. A section of 15° of the flange is used due to symmetry, see Figure 3. After the geometry simplifications the flange section can be MAP meshed with four volumes, see Figure 4. The locking ring is meshed in the same way with just a half 15° section due to symmetry, see Figure 5. The section of the locking mechanism is finally mirrored and rotated to get a complete model. A cut through the meshed locking mechanism is shown in Figure 6.

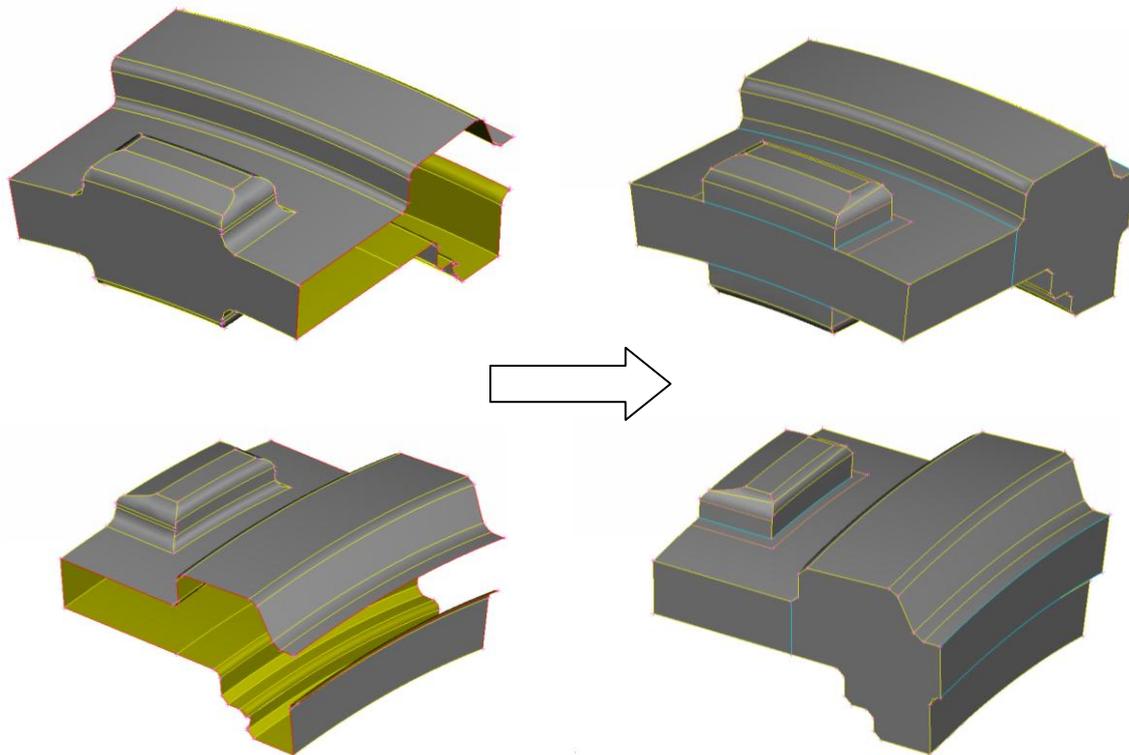


Figure 3 –The teeth at the flanges are simplified.

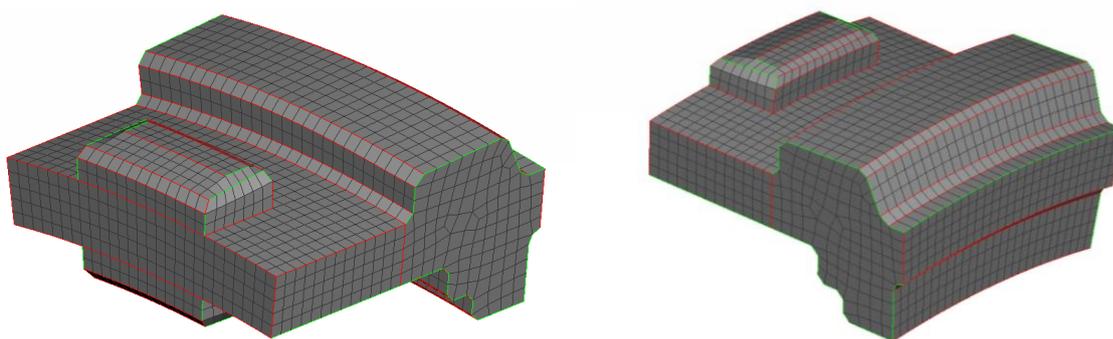


Figure 4 – A section of the teeth flanges are MAP meshed.

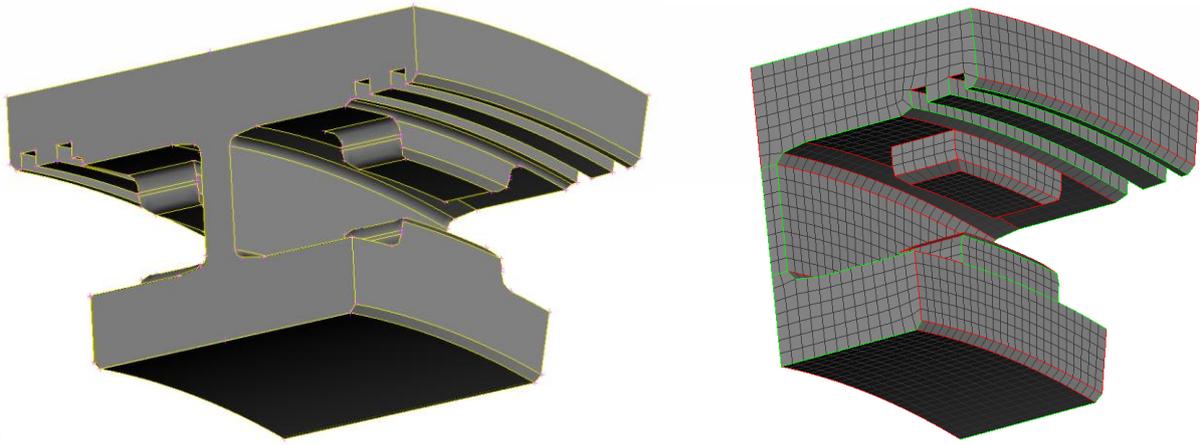


Figure 5 – A half section of the locking ring is simplified and MAP meshed.

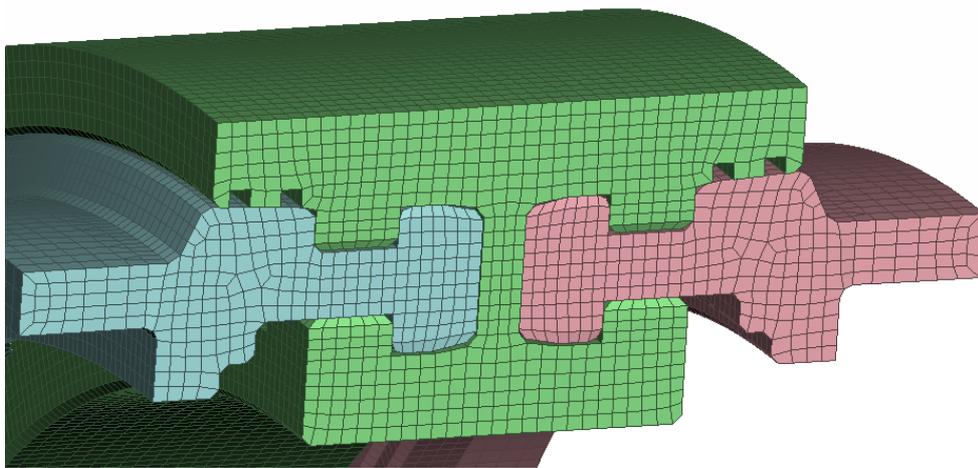


Figure 6 – Cut through the meshed locking mechanism.

Since the locking mechanism is meshed with smaller elements compared to the vessel and the cover a transition zone needs to be done, see Figure 7. The first transition close to the flange is in the circumference direction and meshed with a shell offset. The second transition is in the thickness direction and meshed with a shell rotation. The vessel and the cover is shell meshed and then offset to volume elements, see Figure 8.

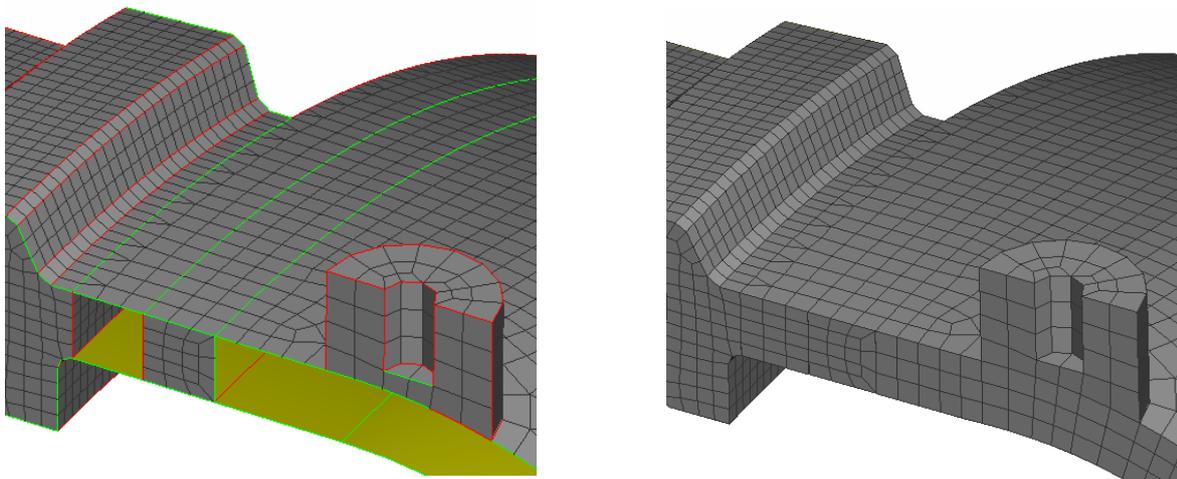


Figure 7 – The transition between the flange and the vessel is meshed by offset and rotation.

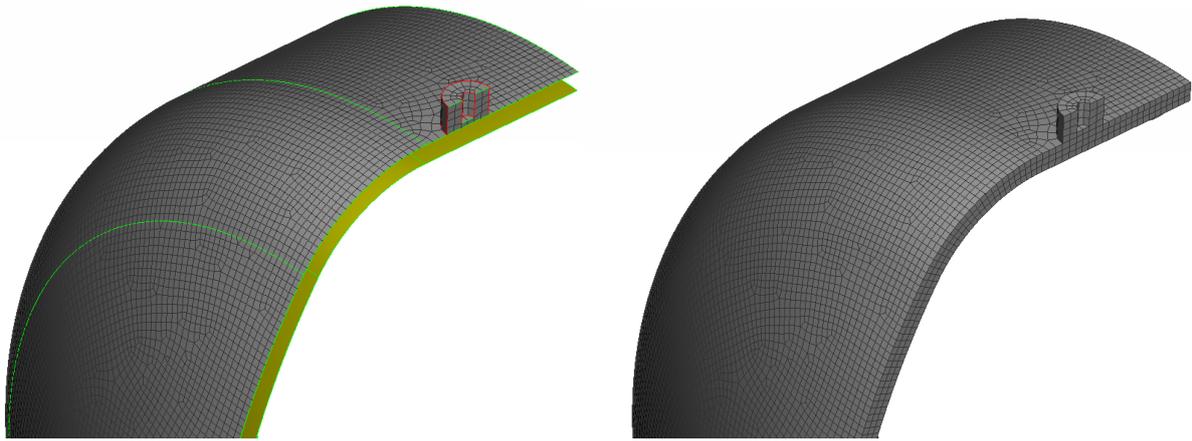


Figure 8 – The vessel and the cover are meshed by offset.

Half of the model is meshed and then mirrored to a complete 3D model, see Figures 9-10. During the project some changes were made at the outer attachments. Two additional attachments have been added at the bottom, the yellow parts in the images below. These attachments were created directly in ANSA just from photos of the test setup. The complete model consists of 800 000 volume elements with 99.6 % hexas and 0.4 % pentas.

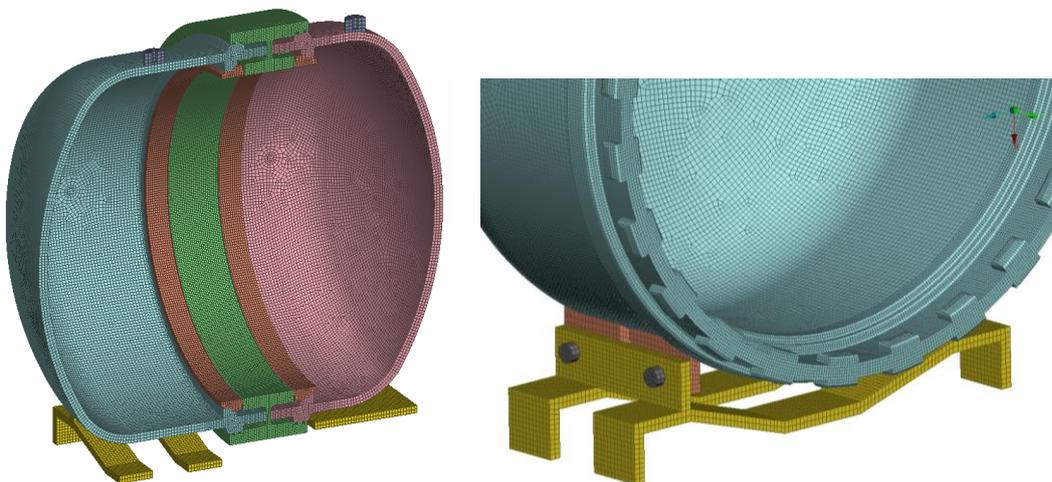


Figure 9 – The mesh of the MECV model.

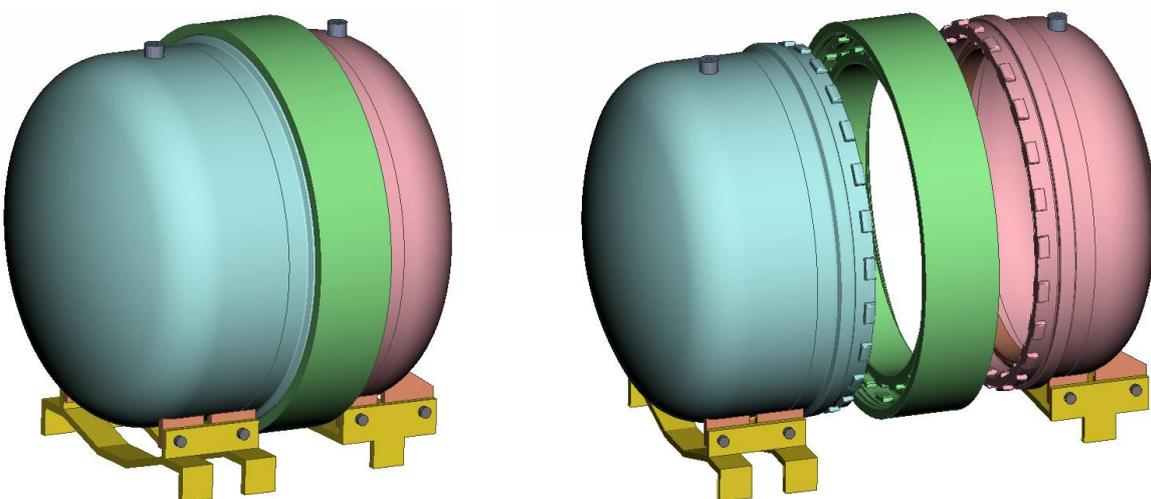


Figure 10 – The complete MECV model.

5. SIMULATION SETUP

Load case

The load case is a spherical charge of 8.0 kg TNT equivalent placed in the centre of the chamber, see Figure 11. The charge is initiated in the centre. The outer attachments are constrained at the bottom feet with a fixed boundary condition.

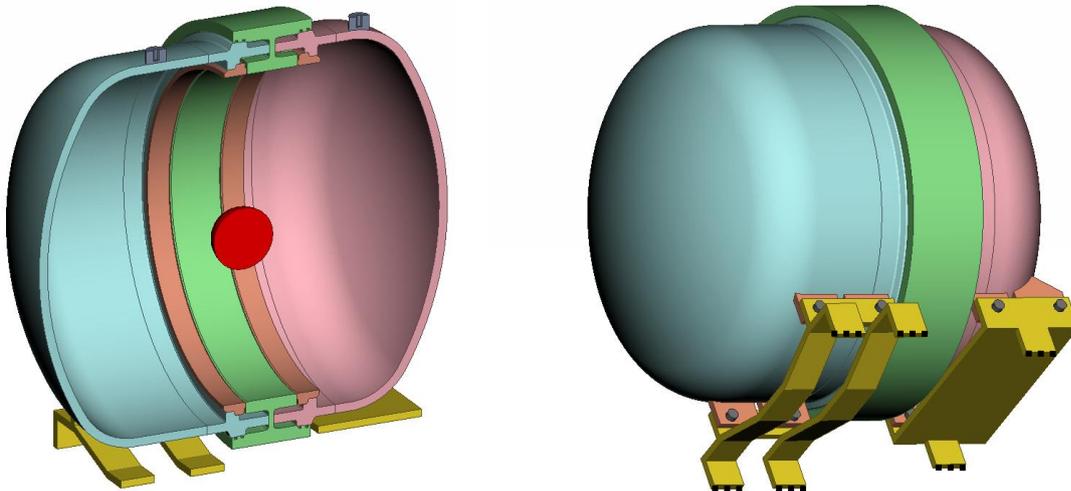


Figure 11 – The charge position to the left and the fixed boundary conditions to the right.

Material

The MECV is made of a high strength steel with a yield strength above 700 MPa. The material damping is set to 0.5-1.0 % of critical in the frequency range 100-3000 Hz. An elasto-plastic material model with linear hardening is used. The Jones-Wilkins-Lee-Baker (JWL) equation of state is used for the fluid blast load analysis to describe the high pressure regime produced by the detonation. The air is modelled as an ideal gas.

Strain measurement

Shell elements are used as strain gauges to capture the strain on the surface of the structure. The strain measurements are done in a similar way as the test [1] with respect to gauge location, sampling frequency and signal filter. The four strain gauges are placed as illustrated in Figure 12.

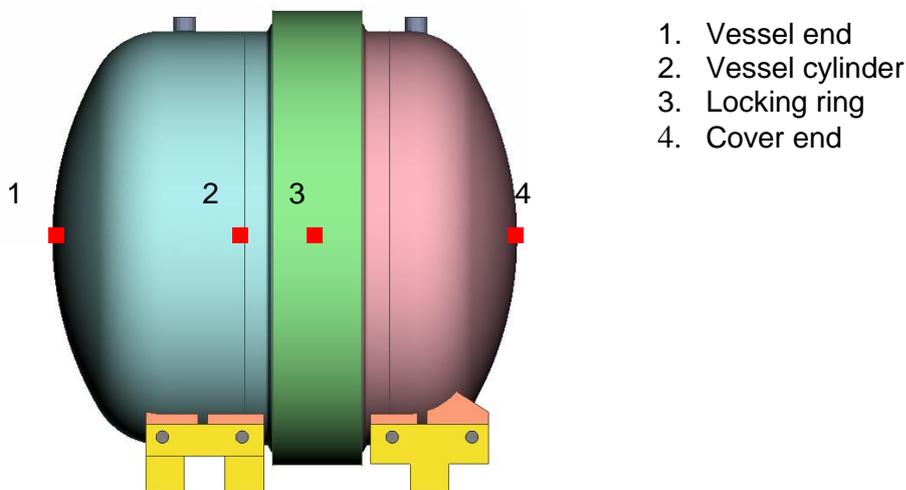


Figure 12 – Location of the strain gauges.

6. BLAST LOAD TECHNIQUE

Axisymmetric mapped to 3D

The explosive blast load is done in a separate axisymmetric fluid simulation using Multi Material Arbitrary Lagrangian Eulerian (MMALE). This includes air and explosive interaction and blast wave reflections. The fluid element length is 5 mm and the model consists of 31 000 elements. The inside of the chamber is modeled and the boundaries are fixed, see the red line in Figure 13. The pressure is recorded at the fixed boundary and then a script is used to map the blast load to the 3D solid structure simulation.

Fluid-structure coupling in 3D

The explosive blast load is done directly in the structure simulation using 3D MMALE with a fluid-structure coupling. This includes air and explosive interaction, blast wave reflections and fluid-structure interaction. The fluid element length is 15 mm and the model consists of a block with 760 000 hexa elements, see Figure 13.

Table 1. Advantages and disadvantages with the two techniques

Axisymmetric mapped to 3D	Fluid-structure coupling in 3D
<ul style="list-style-type: none"> + Fine resolution of the blast load + One blast load simulation can be used for many structure simulations + The safety factor can be changed in the mapping step + Fast simulation time - No fluid-structure interaction - Small numerical errors at the fluid symmetry line 	<ul style="list-style-type: none"> + Fluid-structure interaction + Can be used for non-axisymmetric geometry and/or load case - Coarse resolution of the blast load - Long simulation time - Many parameters for the fluid-structure coupling - Leakage in the fluid-structure coupling

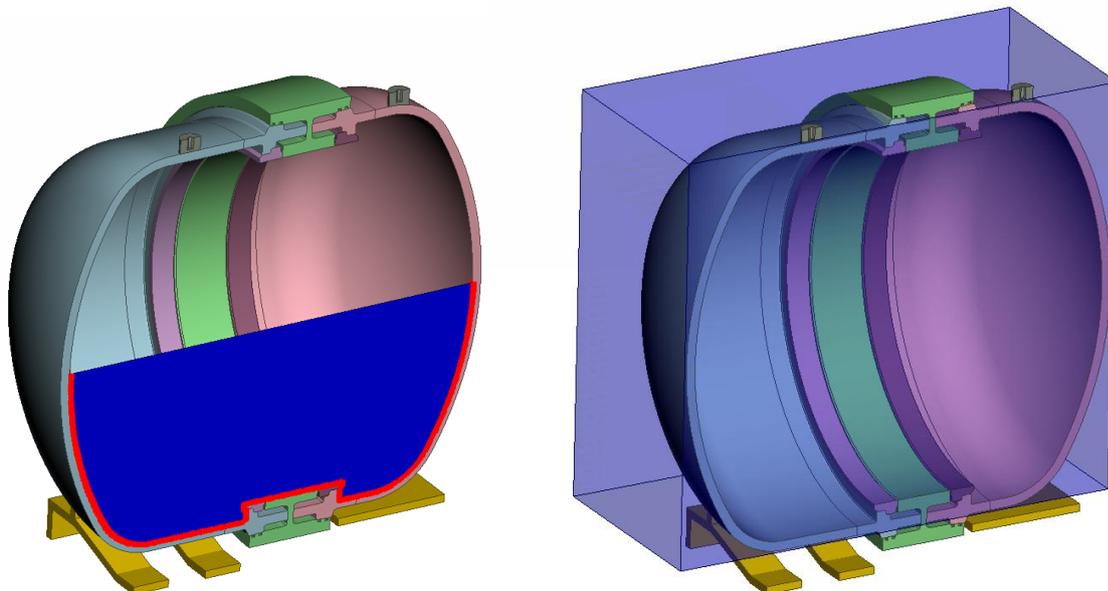


Figure 13 – Axisymmetric fluid to the left and 3D fluid to the right.

7. RESULTS

Axisymmetric mapped to 3D

This well-applied technique showed, after some small modifications in the material damping, relatively good agreement to the test. The termination time is 30 ms and some of the strain curves are compared in Figure 14. The Gauge 3 curve clearly shows that the oscillation frequency is in very good correlation between the test and the simulation. The total CPU time is about 3 hours with a 16 processor cluster.

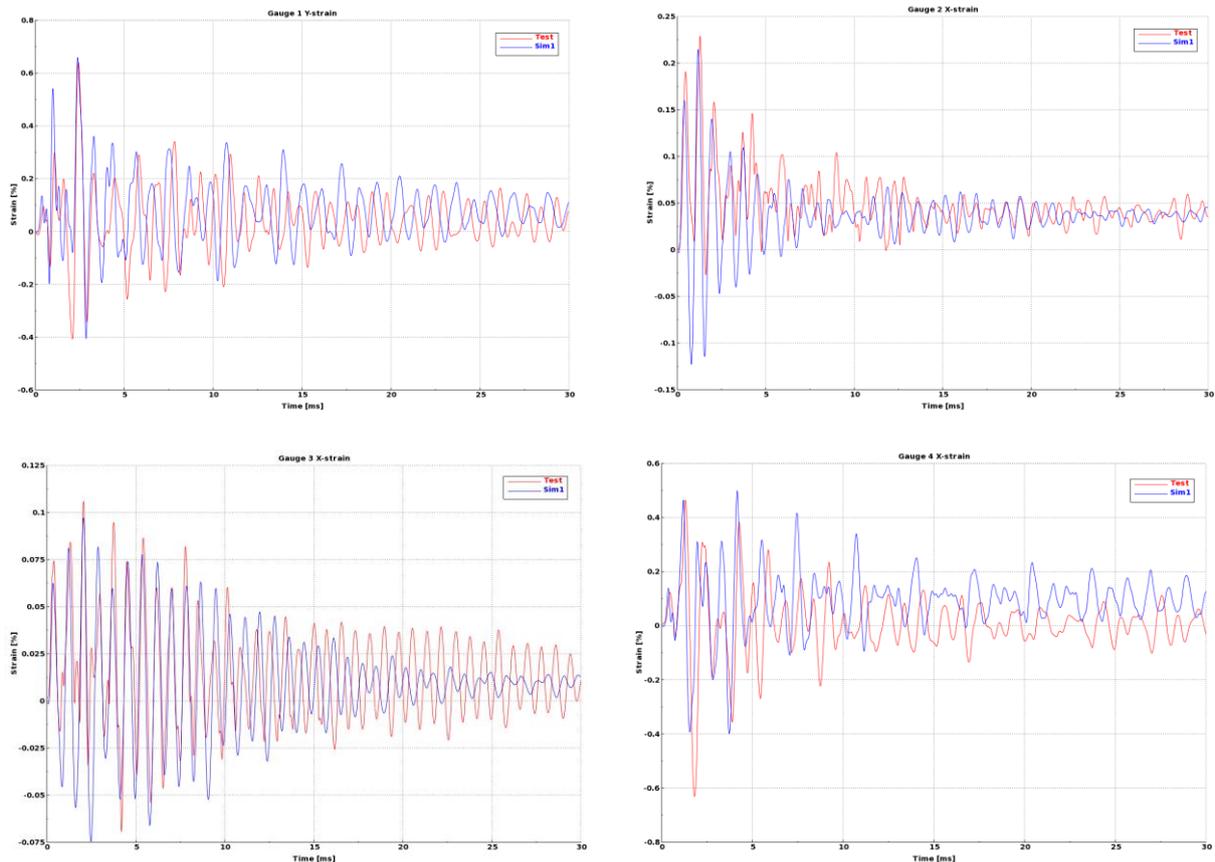


Figure 14 – Strain comparison of the test vs. simulation.

Fluid-structure coupling in 3D

The first analysis lead to significant lower strain levels compared to the test. A more detailed parameter study had to be performed to improve the simulation results. The fluid element length, the material damping and several coupling parameters were evaluated to improve the results. The final results are in relatively good agreement to the test. The termination time is 30 ms and some of the strain curves are compared in Figure 15. The influence of the fluid-structure coupling leakage gives a significant lower strain towards the end. The Gauge 3 curve shows that the oscillation frequency is in very good correlation.

The CPU time is about 24 hours with a 16 processor cluster. Two possibilities to speed up the CPU time is to either use a half model due to symmetry or remove the fluid after 5-10 ms. This will give about the same results in a substantially shorter time.

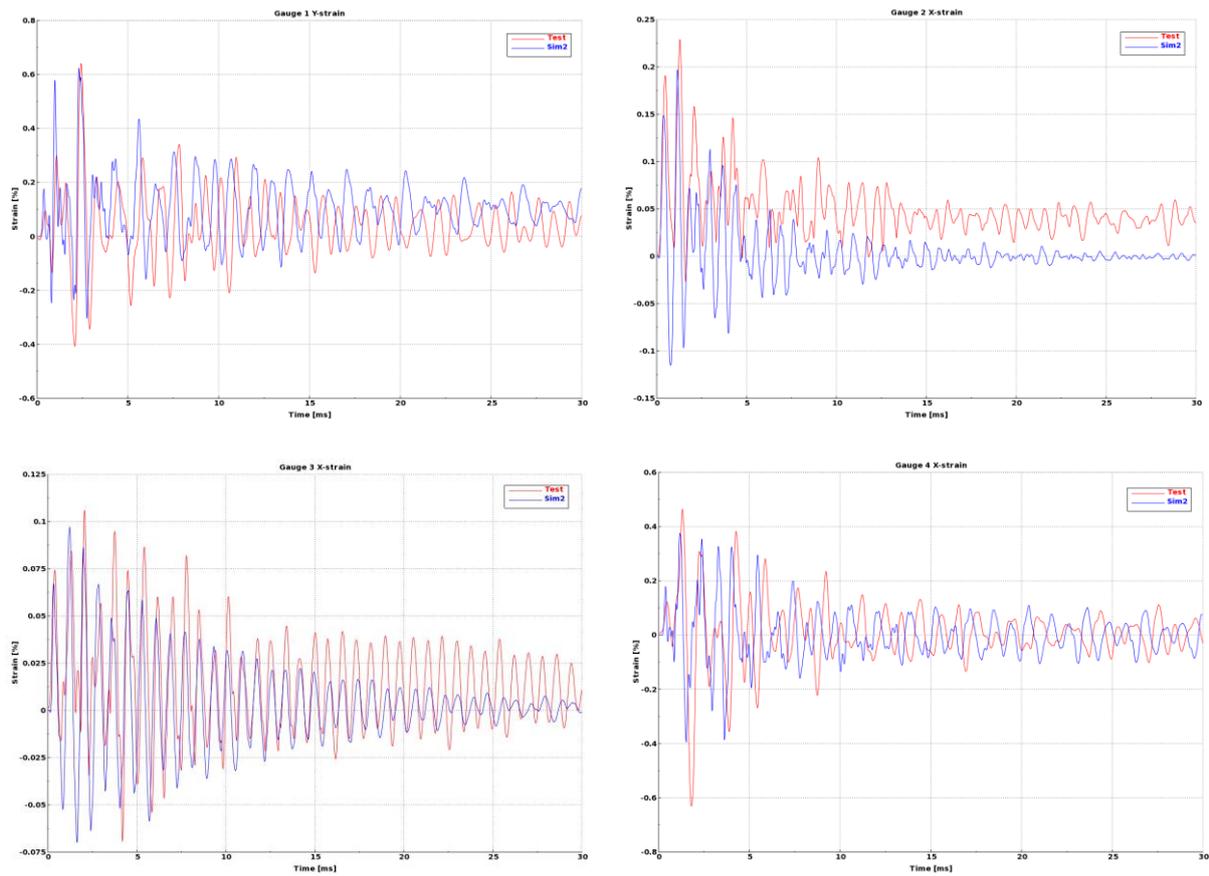


Figure 15 – Strain comparison of the test vs. simulation.

8. CONCLUSIONS

As conclusion we now have two validated simulation techniques and procedures to make realistic explosive simulations of containment vessels.

REFERENCES

- (1) MECV8L Report from test campaign 2, Nr 064428, Dynasafe AB, 2012
- (2) LS-DYNA Keyword User's Manual, Version 971, LSTC, 2012
- (3) ANSA version 13.1.2 User's Guide, BETA CAE Systems S.A., 2011
- (4) ANSA version 14.1.0 User's Guide, BETA CAE Systems S.A., 2013
- (5) μ ETA version 14.1.0 User's Guide, BETA CAE Systems S.A., 2013