EXPERIMENTAL MEASUREMENTS OF STRUCTURAL DISPLACEMENT DURING HYDROGEN VENTED DEFLAGRATIONS FOR FE MODEL VALIDATION

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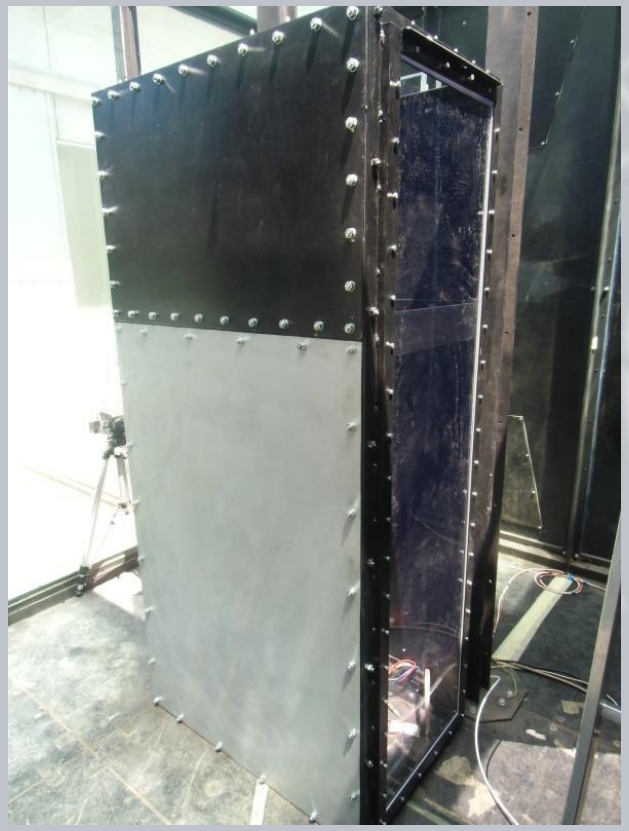
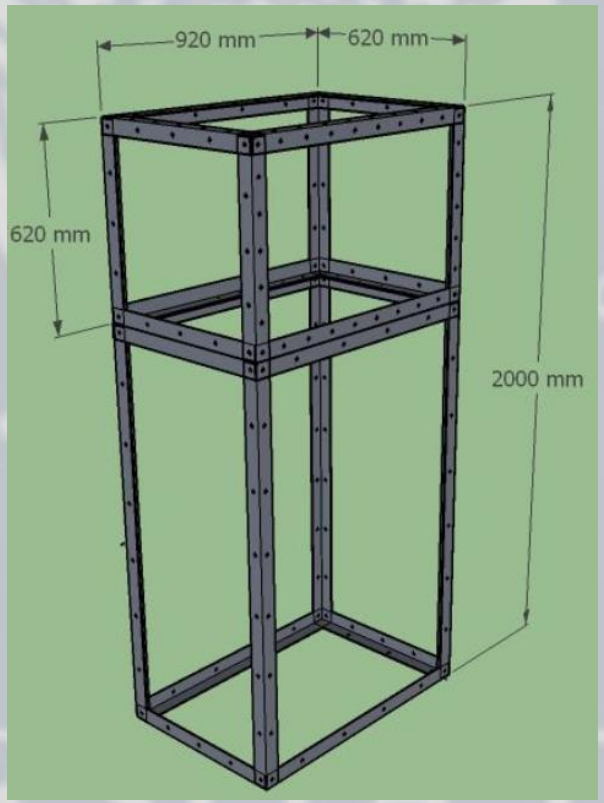
Presentation overview:

- Small Scale Enclosure
- Experimental measurements
- FE model
- Comparison between data and FE model
- Conclusions

Small Scale Enclosure



Investigation of vented hydrogen explosions in installations such as gas cabinets, cylinder enclosures, dispensers and backup power systems

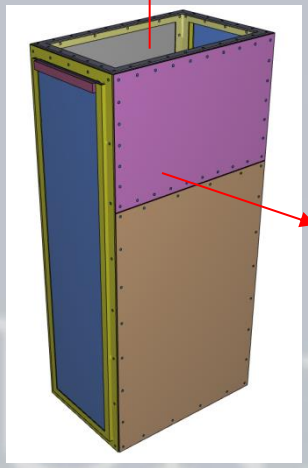


ID109, *Homogeneous hydrogen deflagrations in small scale enclosure. Experimental results*.
M. Schiavetti, T. Pini, M. Carcassi

Variables under investigation

- **Hydrogen concentration**: between 10%vol. and 18%vol.
- **Vent location**: on the top and on the upper front wall
- **Vent type**: plastic sheets in different configurations and three different types of FIKE explosion panel
- **Ignition location**: 0.5 m, 1 m and 1.5 m from the floor along the centreline of the enclosure
- **Internal congestion**: empty enclosure, 1 bottle and 3 bottles placed inside

Top vent



Front vent

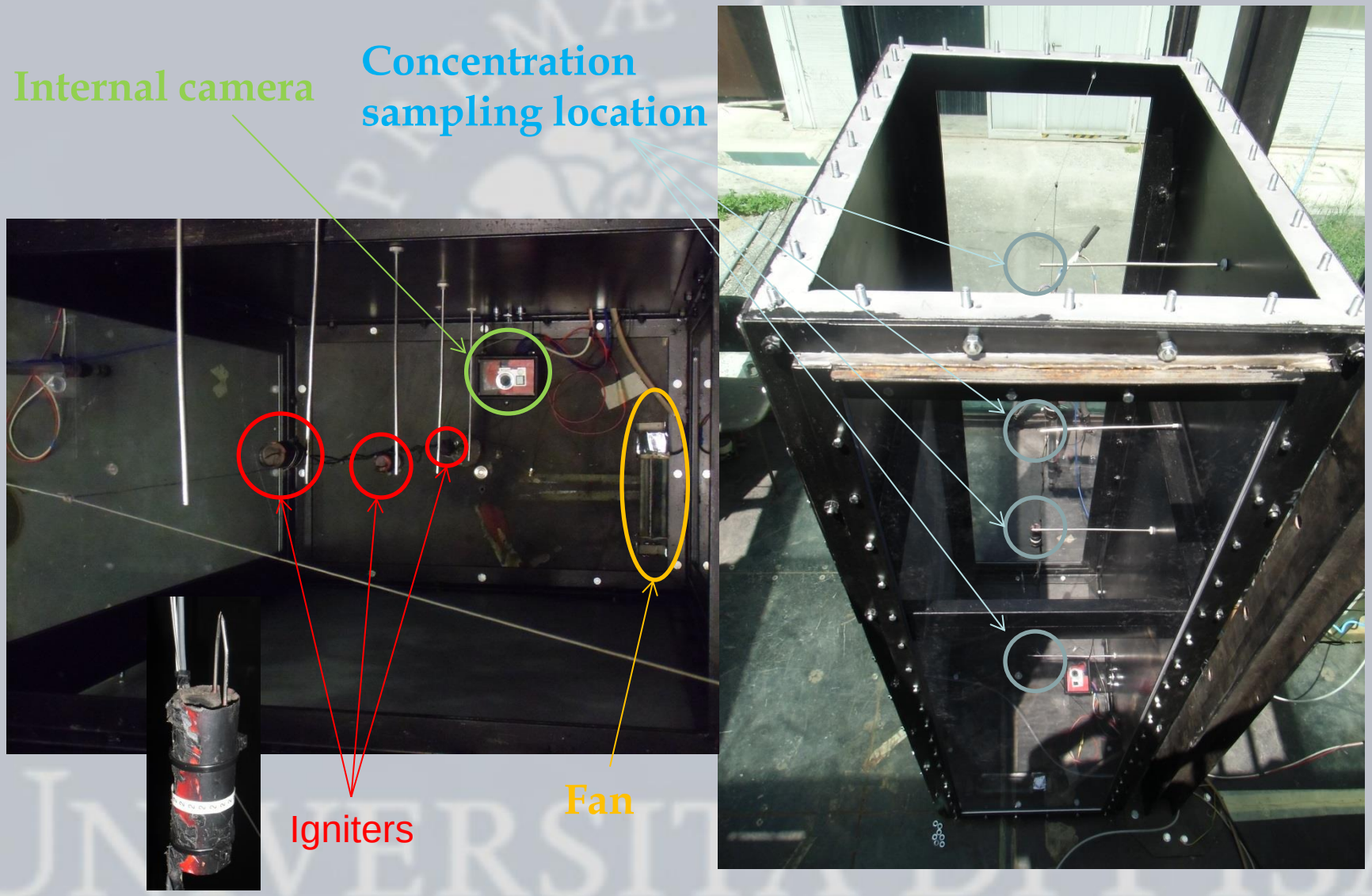
Vent Area:
0.43 m^2

3 Plastic sheets

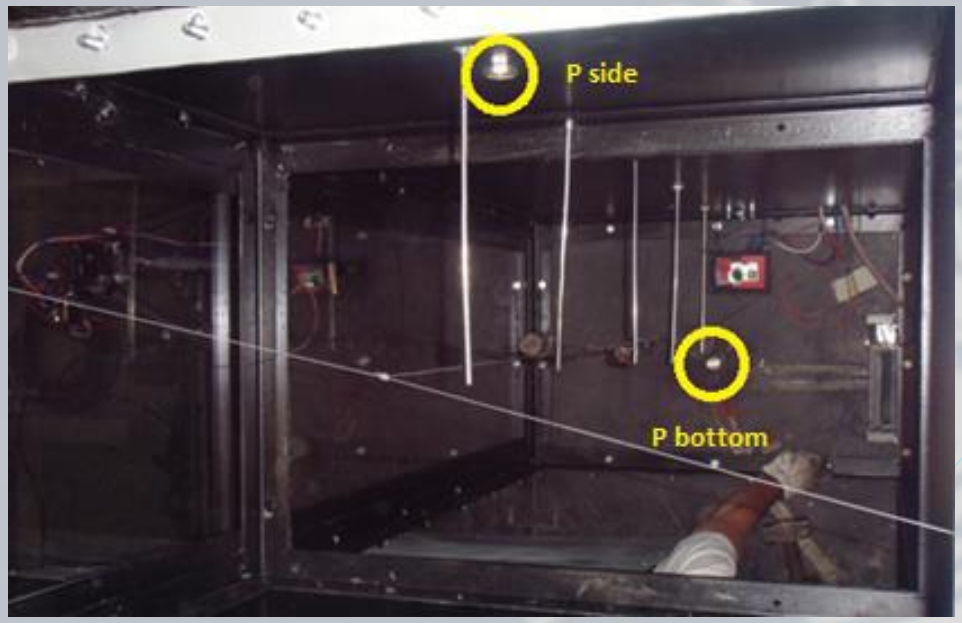
3 FIKE vents type

Bottles dimensions:
- volume 50 liters
- height 1.68 m
- diameter 0.23 m

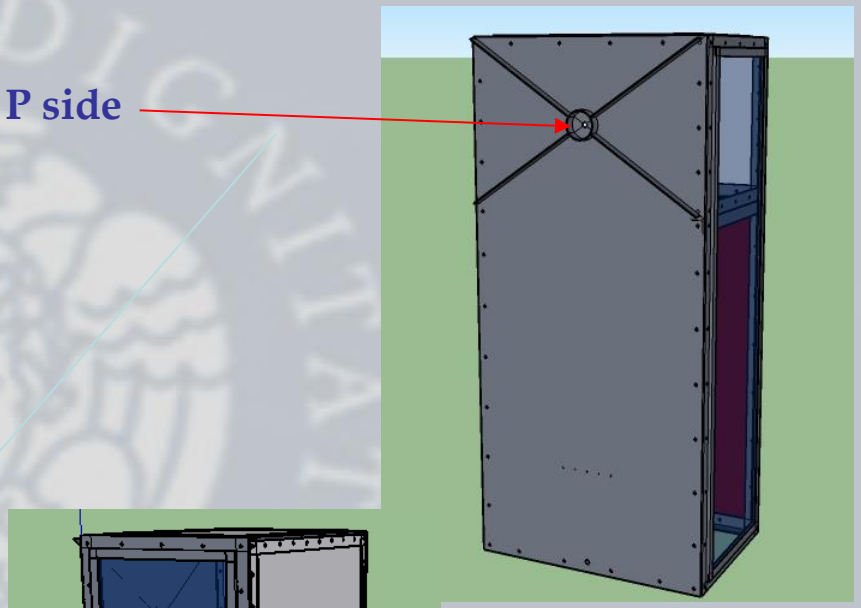
Small Scale Enclosure

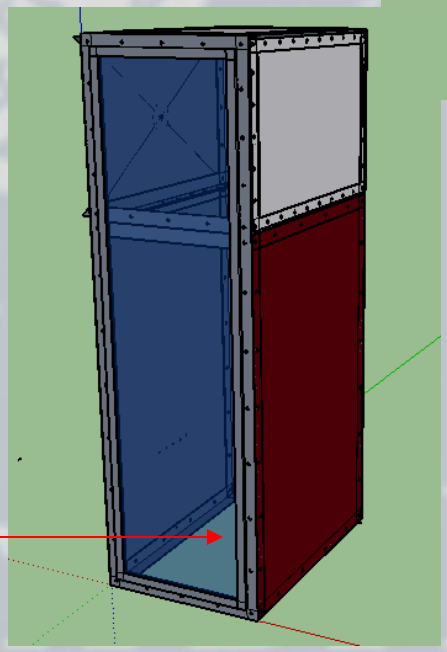


Small Scale Enclosure – Pressure transducers



Kistler piezo resistive
Transducers
Adquisition frequency: 5 kHz

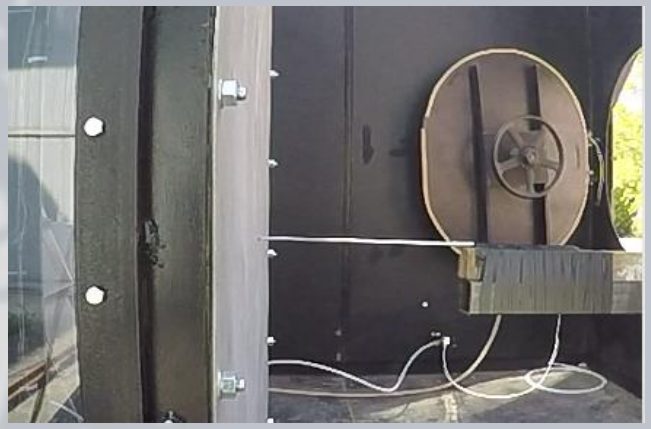




Displacement measurements methods

Antenna

- Simplicity
- Poor accuracy
- No displacement- time histories recording



Keyence Laser Sensor IL-S025

- Displacement- time histories recording
- 5 kHz acquisition
- 1 μm repeatability

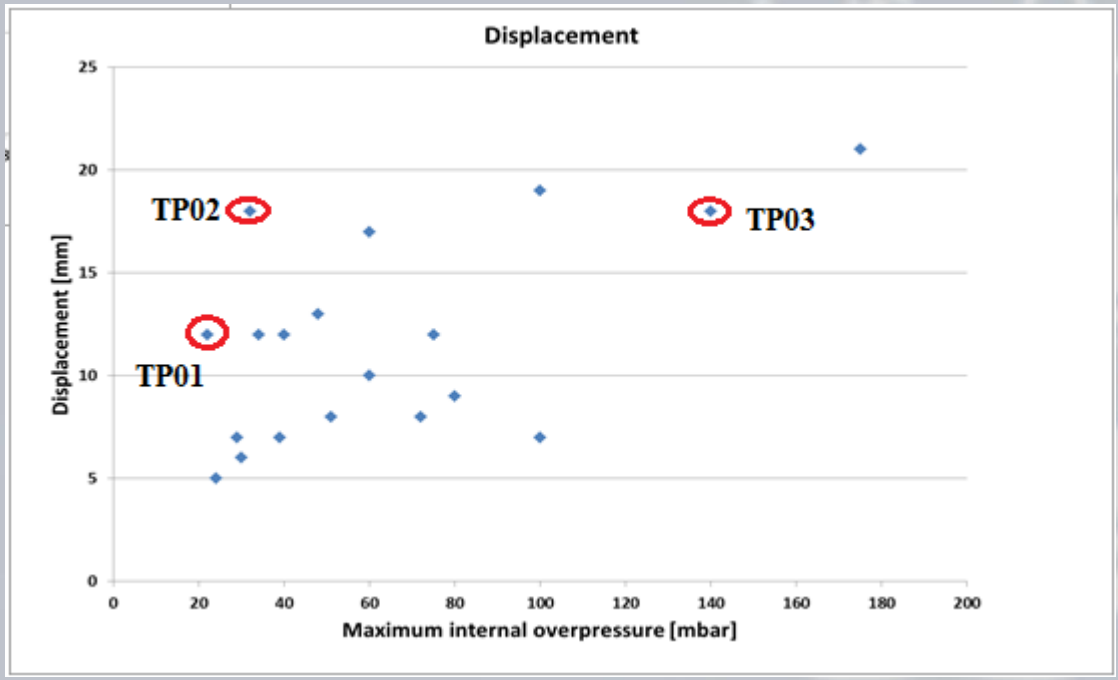
Displacement measurement test plates and positions

Measurement method	Test plate	Plate thickness [mm]	Sensor location	TEST # (interval)
Antenna	Lower	2	Plate centre	TP1-TP20
Laser	Lower	5	Plate centre	TP21-TP29 TP65-TP70
			91.3 cm from floor	TP30-TP33
			115.45 cm from floor	TP34-TP36 TP45-TP52
	Upper	5	Plate centre	TP37-TP44 TP53-TP64 TP71-TP76

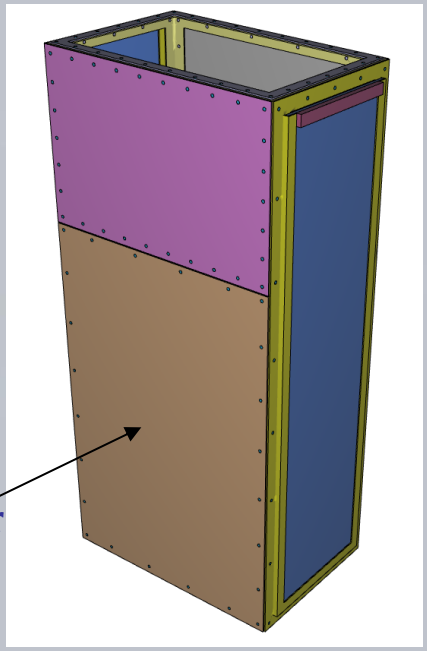
Displacement measurements experimental matrix:

- 2 thicknesses used (2 mm and 5 mm)
- 4 sensor locations

Data Analysis - Mechanical measurement



Test plate thickness: 2 mm



Measurement location:
69 cm from floor (centre)

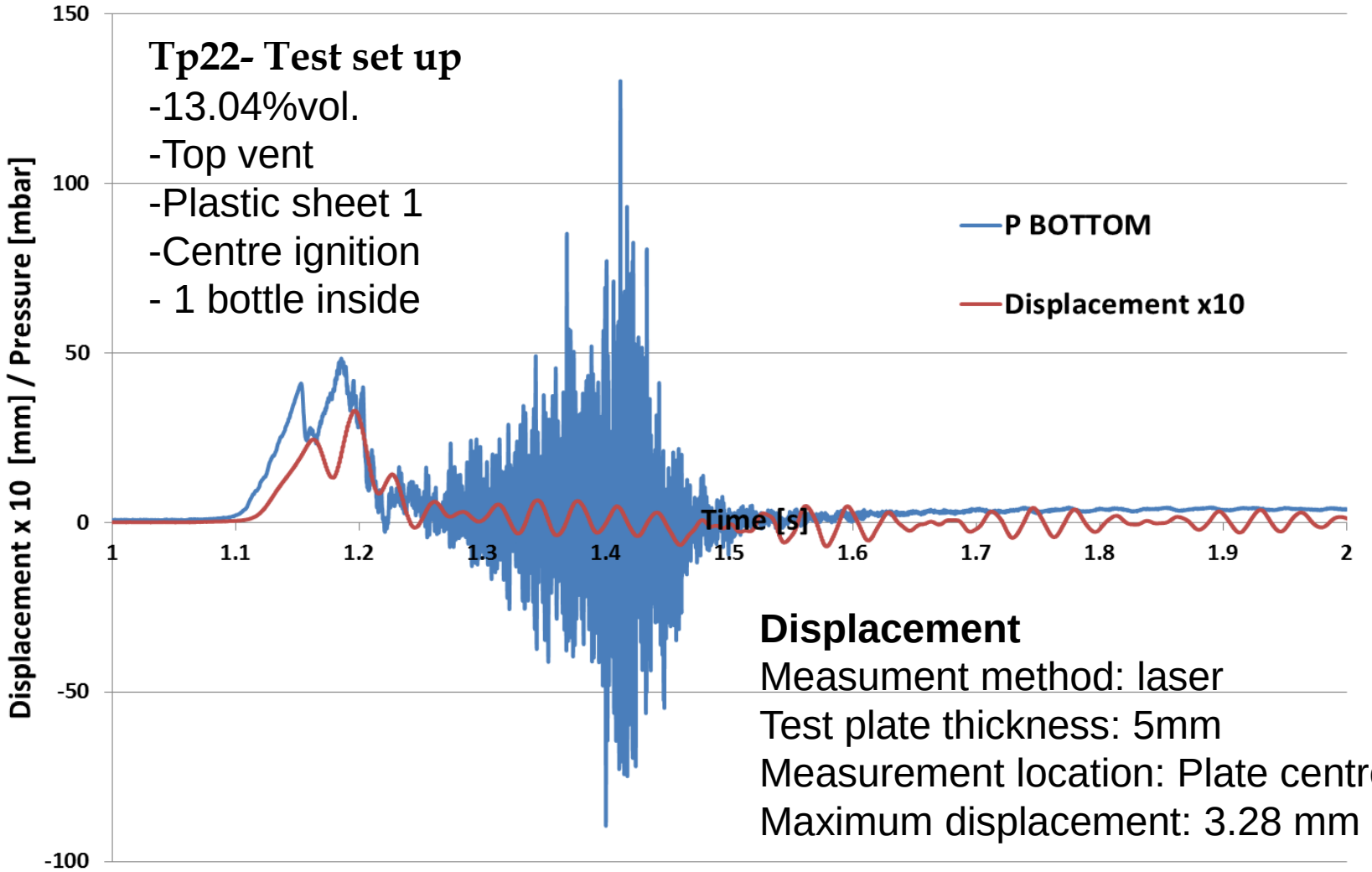
Problems found after preliminary measurements:

- 2 mm thick plate undergoes **plastic deformation** at very low overpressures
- Plastic deformation affects the displacement measurements of the following tests

Solutions taken to provide more reliable data:

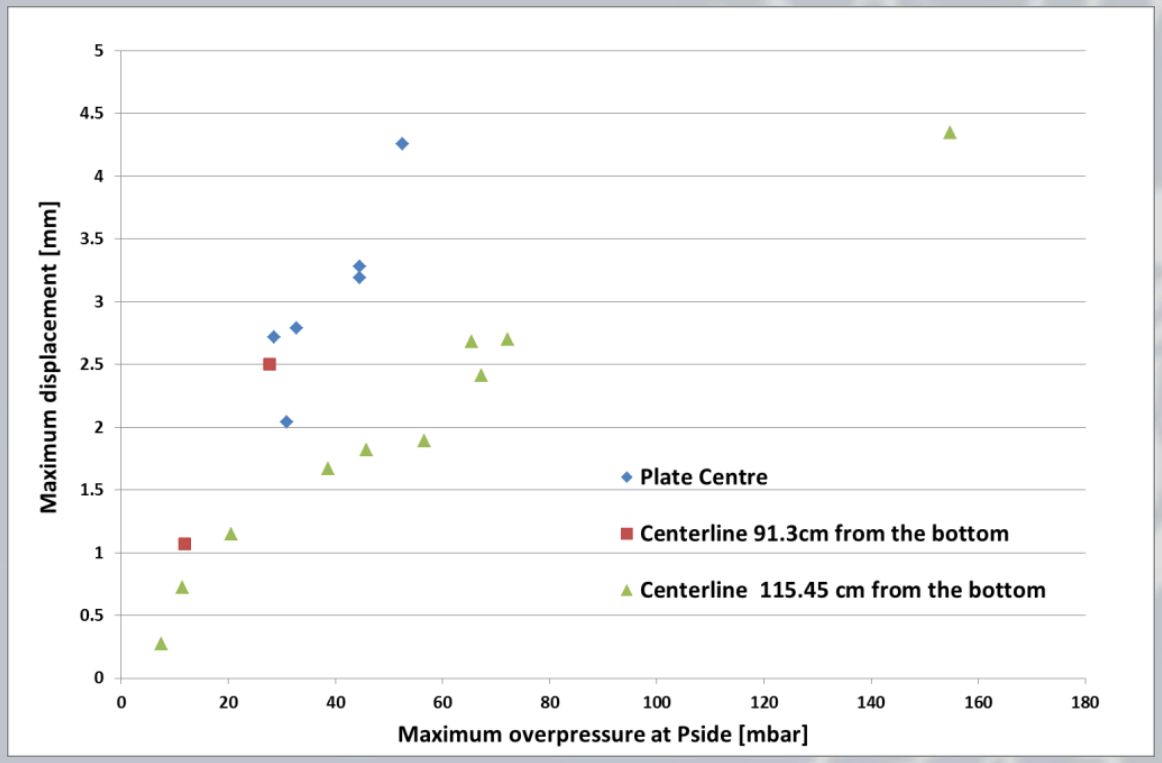
- **2 mm thick plate was substituted with 5 mm** thick plate which shows an elastic response to the applied internal pressure
- The displacement measurement was performed using a **laser sensor**

Data Analysis – Laser measurement



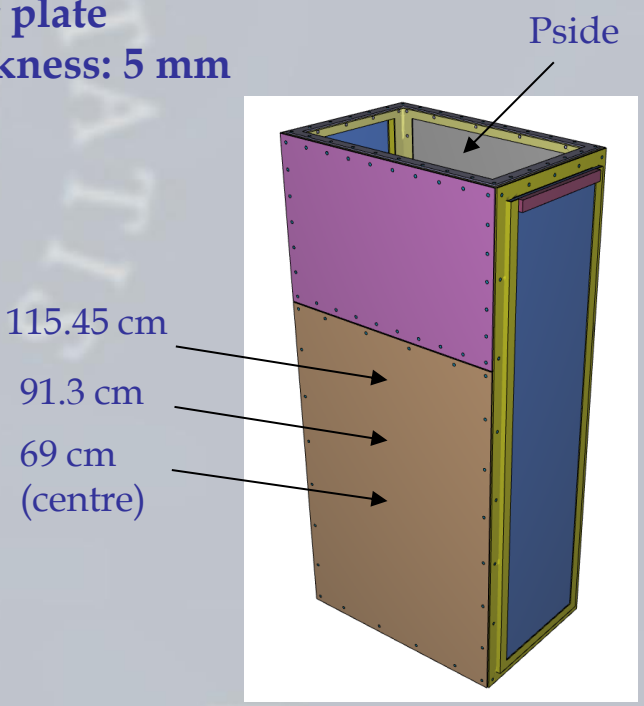
Displacement
Measument method: laser
Test plate thickness: 5mm
Measurement location: Plate centre
Maximum displacement: 3.28 mm

Data Analysis – Laser measurement



The laser was moved upward along the centerline to avoid sensor saturation at high overpressure.

Test plate thickness: 5 mm

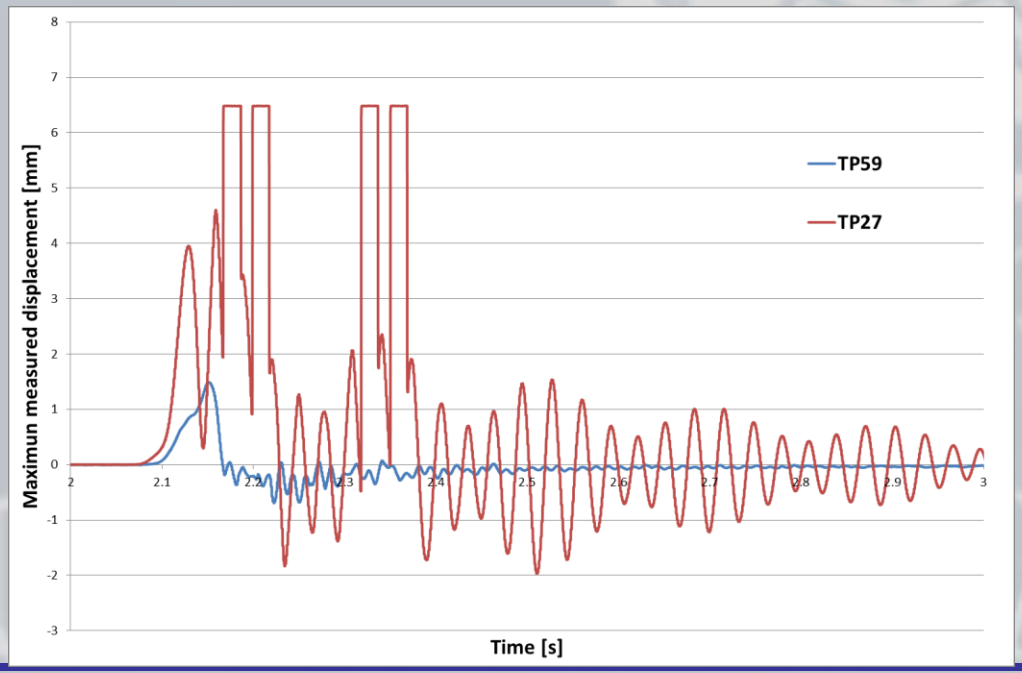


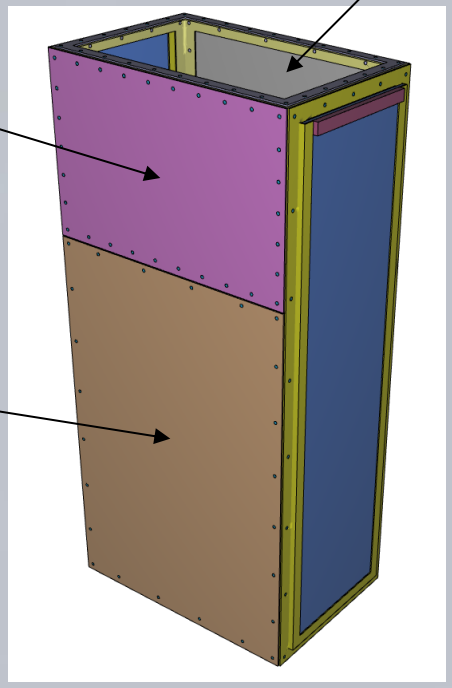
The results are quite scattered along a theoretical straight line. Due to extremely dynamic nature of the deflagration the overpressure measured in the two locations (Pside, Pbottom) are not always representative of the overpressure applied to the lower front plate

Data analysis

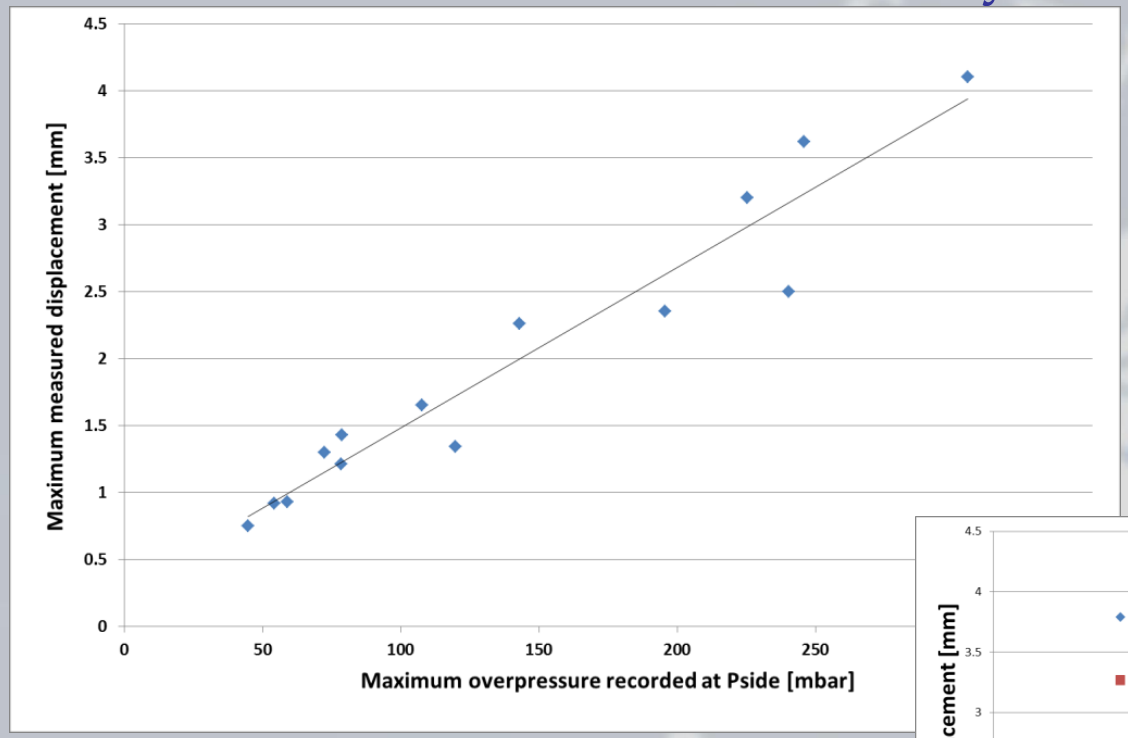
Test	TP27
Obstacle configuration	1 bottle
Ignition location	Bottom Ignition (#2)
Vent location	Top vent
Average H_2 concentration	15.97 % vol.
Plate under investigation	Lower front plate
Displacement measurement location	69 cm from the bottom (plate centre)

Test	TP59
Obstacle configuration	1 bottle
Ignition location	Bottom Ignition (#2)
Vent location	Top vent
Average H_2 concentration	15.9 % vol.
Plate under investigation	Upper front plate
Displacement measurement location	31 cm from top (plate centre)



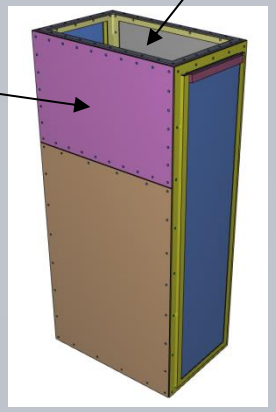


Data analysis



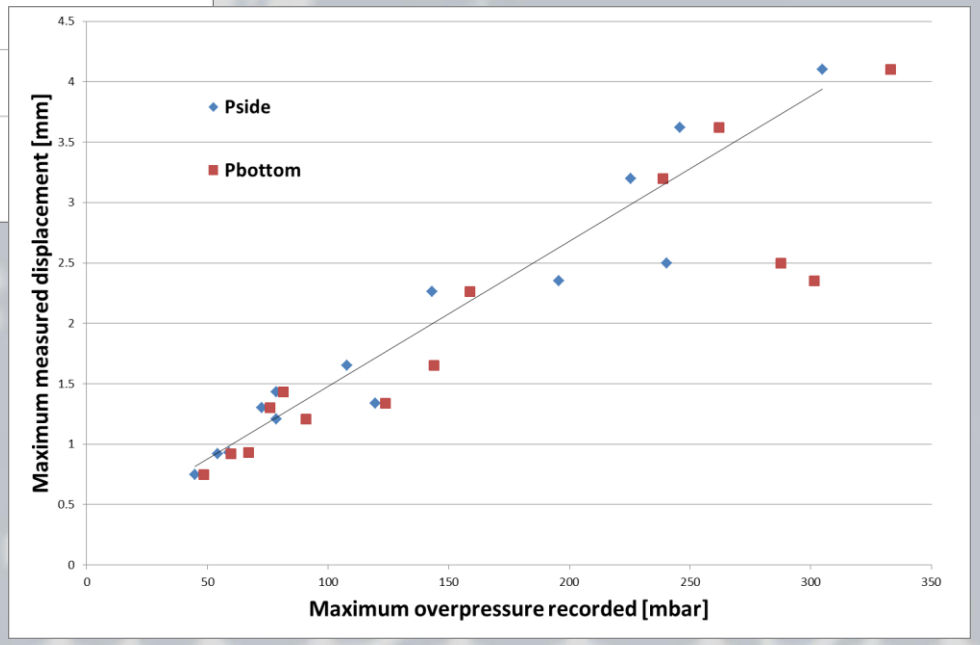
Pside

31 cm
from top
(centre)



Laser measurement

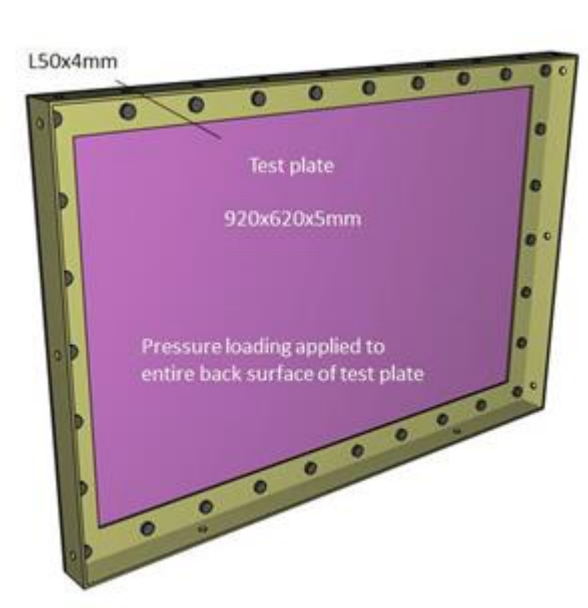
Test plate thickness: 5 mm

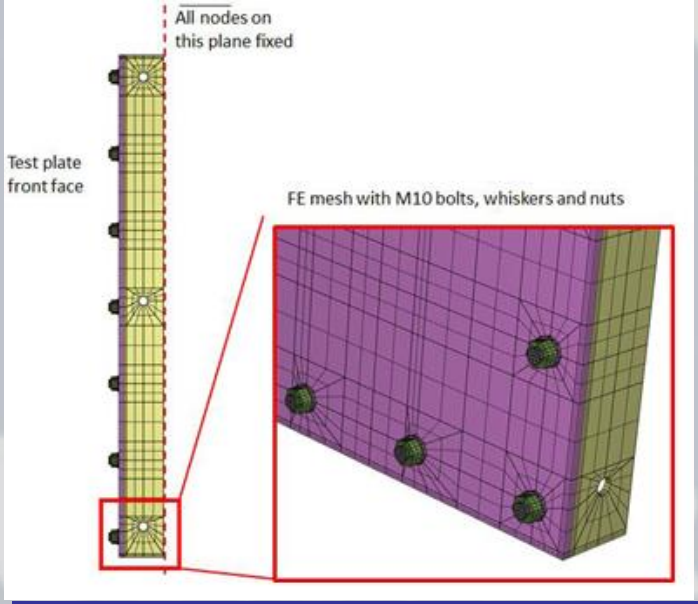


Taking the measurement on upper plate the difference between applied overpressure on the target plate and the recorded pressure at Pside is minimized. Pside transducer is just opposite of the displacement measurement location.

Video

# Test	Avg. conc [%vol.]	Vent location	Vent type	Ignition location	Obstacle conf.	Test plate thick. [mm]	Laser location
TP55	17.8	Top	Plastic sheet 1	Bottom	3 bottles	5	Upper plate centre
TP56	14	Top	FIKE 2	Bottom	3 bottles	5	Upper plate centre
TP66	15.8	Front	Plastic sheet 1	Centre	1 bottle	5	Lower plate centre





FE model

A finite element model representing the upper was developed by using IMPETUS Afea Solver.

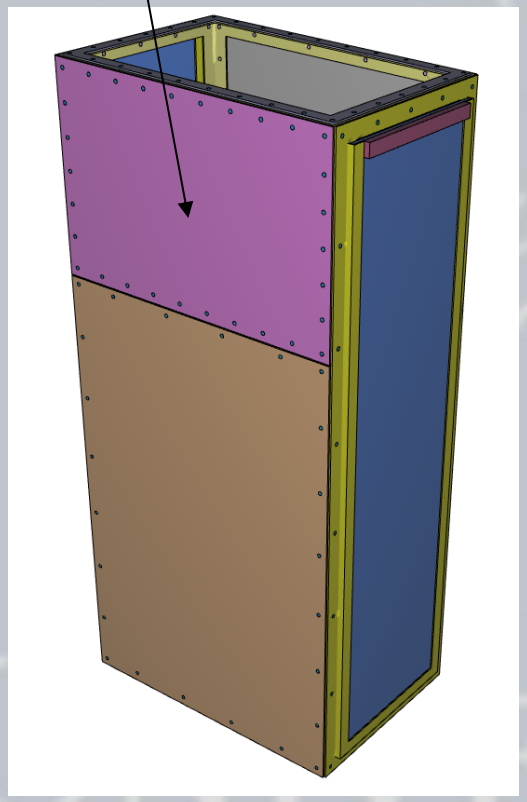
Main elements of FE model:

- main side-wall test plate (5 mm)
- main rectangular frame consisting of 4 mm thick L-profiles with outer flange dimensions 50 mm (L50x4mm)
- 30 bolts with 10 mm OD
- 30 corresponding nuts
- 30 corresponding washers
- rear end of the main frame was constrained

FE Simulation set up

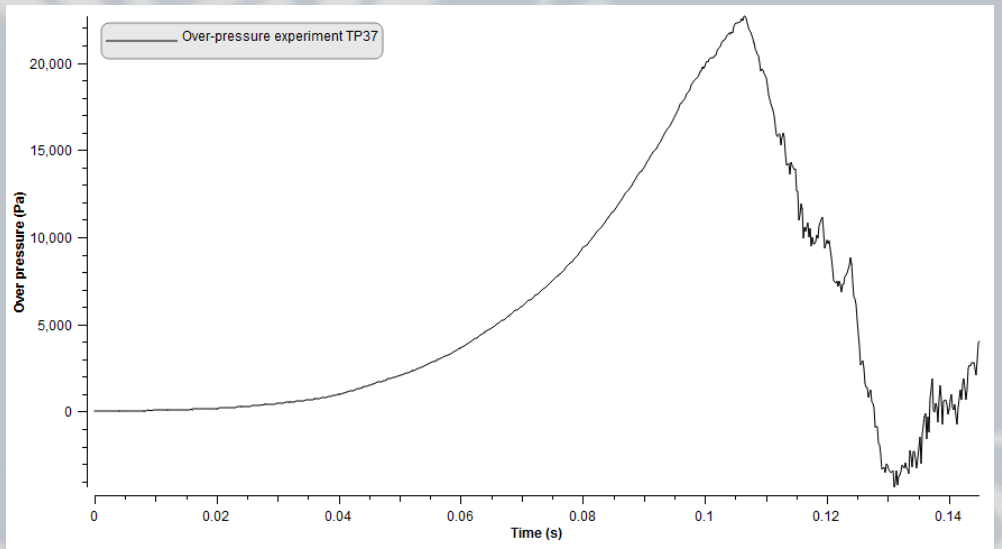
Test Id	Average H_2 Conc.	Vent location	Vent type	Ignition location	Obstacle conf.	Test plate #	Test plate thick.	Displac. Measur. method	Displac. Measur. Location
TP37	14.1%	Top vent	FIKE Vent 3	Bottom	3 bottles	(2)	5 mm	Laser	Plate centre

Displacement measurement

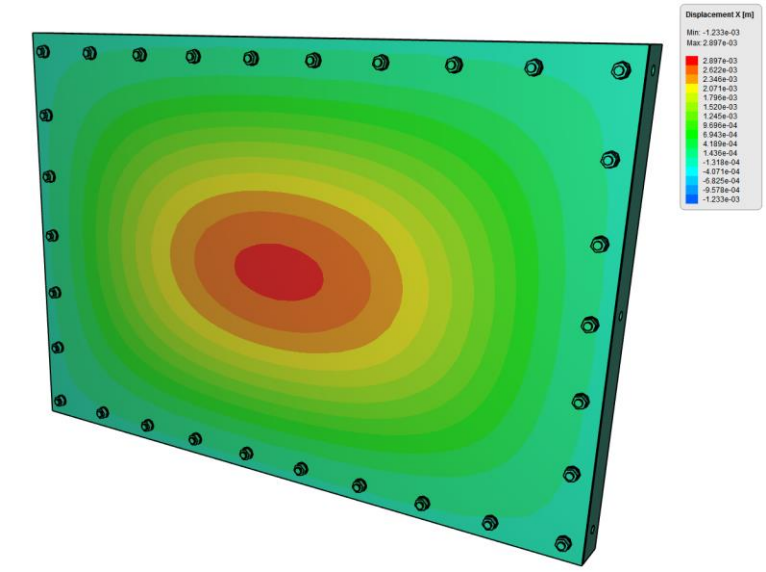


The simulation was done in two steps:

- Step 1: bolts pre-loaded to an axial stress of 200 MPa (representing the 20 Nm pre-torque).
- Step 2: TP37 pressure-time curve was imported and used to load the complete rear surface of the test plate

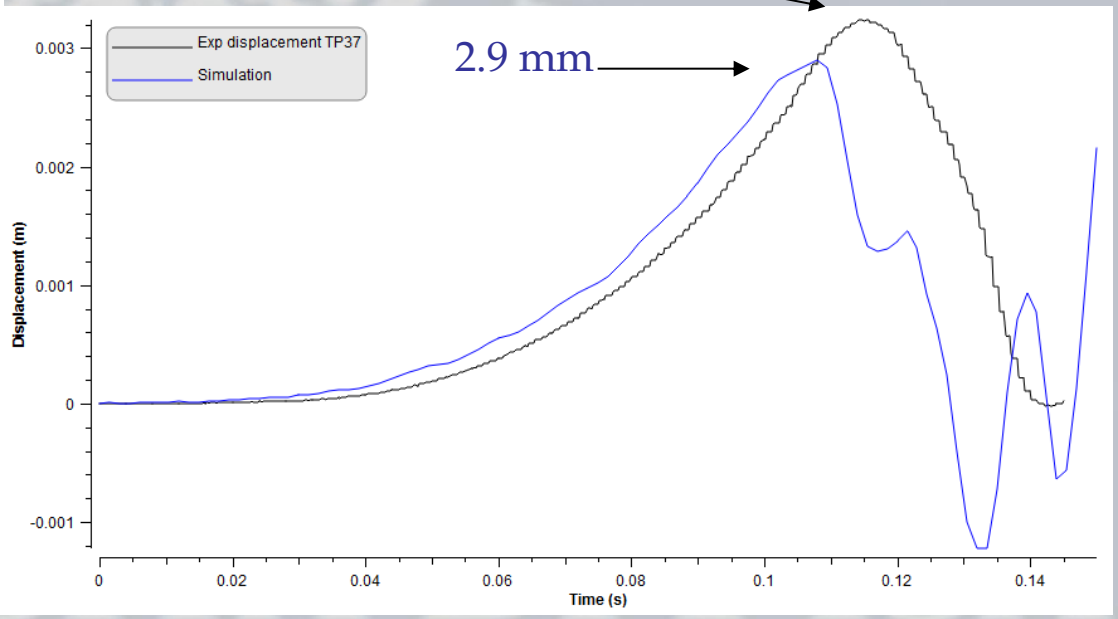


FE Simulation results



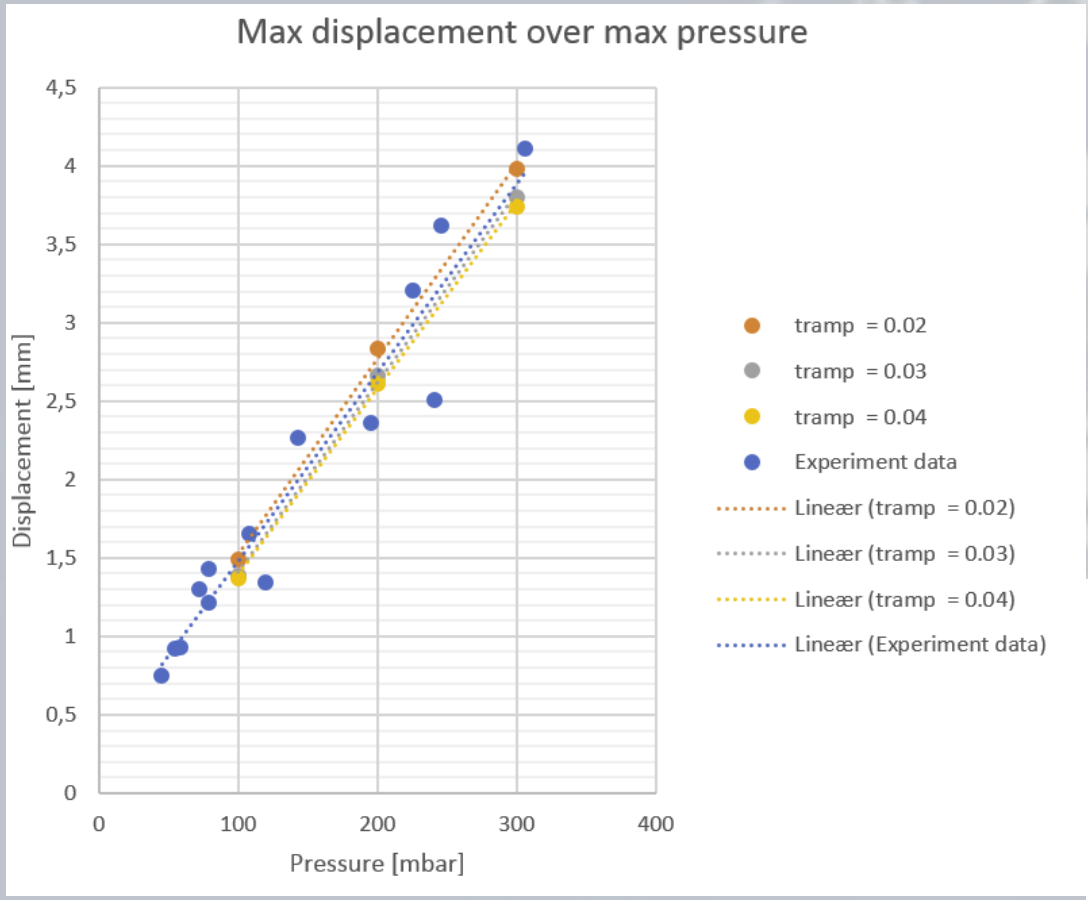
Plof the displacement field of the test plate at time t=0.102 s.

The displacement-time curve of the centre of the test plate was extracted and compared to experiment



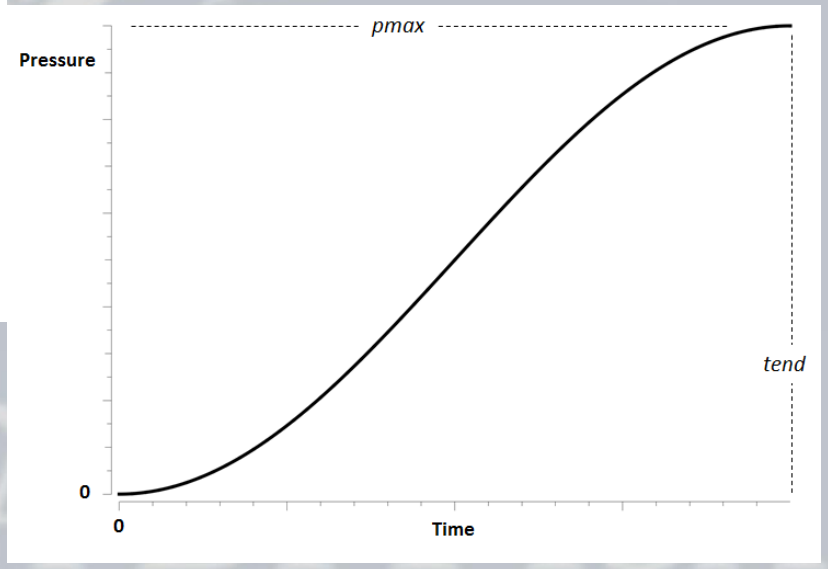
Simulation vs experiment: Displacement-time curve

FE Simulation results



Pressure ramps were simulated by using a combination of p_{max} and t_{end} to characterize the smooth ramp up below

p_{max} [100,200,300] [mbar]
t_{end} [0.02, 0.03, 0.04] [s]



Conclusions

Experimental measurements

- 5 mm thick plate is necessary to avoid metal plasticization that can affect the following measures;
- the measurement location has to be representative of pressure with respect to pressure transducer in order to ensure that the dynamic behavior of deflagration does not affect the results.

Validation of numerical model

The mesh density, element type and boundary conditions appears to represent this experimental test set-up well. (For larger pressure loads involving possible plasticity and material failure it would have been necessary to use more representative material models and possibly a finer mesh). Furthermore the pressure signal is not sampled directly at the location of the displacement measurement introducing an error whenever the dynamic of the deflagration causes spatial differences inside the enclosure.

The next planned experimental campaign that UNIPI ,with help of IMPETUS and FIKE, will provide additional data useful to validate FE model in a bigger variety of conditions and to improve his predictive capacity.

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