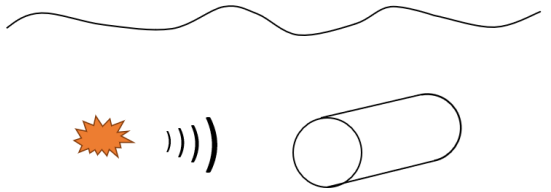


Structural responses due to underwater detonations

EBBA CARLSSON GUSTAV BLOMGREN

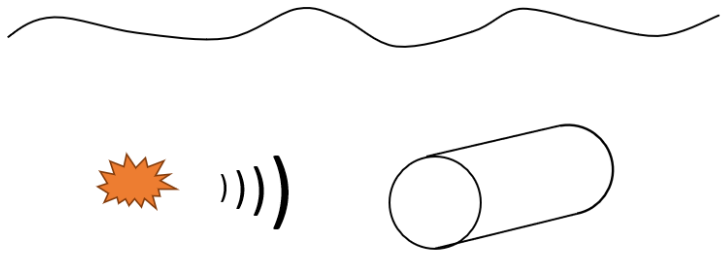
Agenda

- Project description
- Theory
- Method
  - Experiment
  - Sub-Sea Analysis (SSA)
  - Multiphysics-analysis with SSA
  - Multiphysics-analysis with full detonation
- Results & Discussion
- Conclusions
- Future work

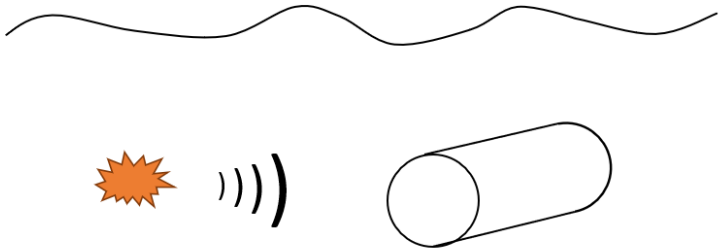
Project description

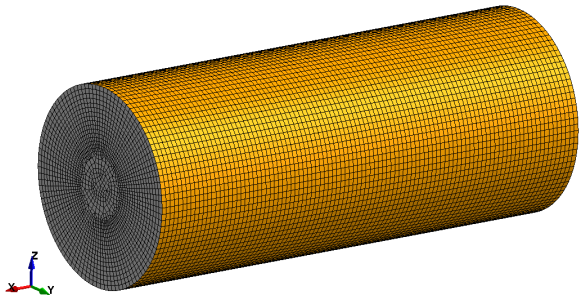
STRUCTURAL RESPONSES DUE TO UNDERWATER DETONATIONS

Project description

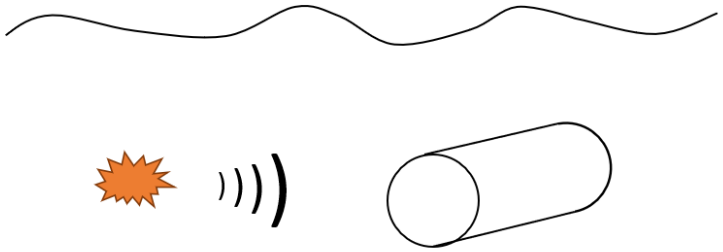


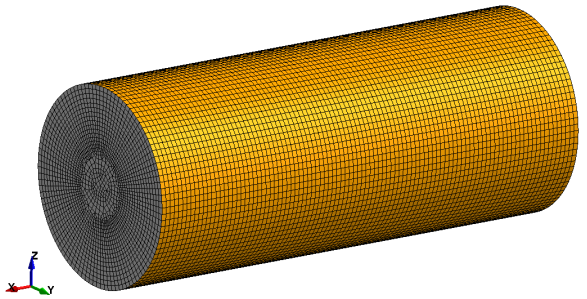
Project description

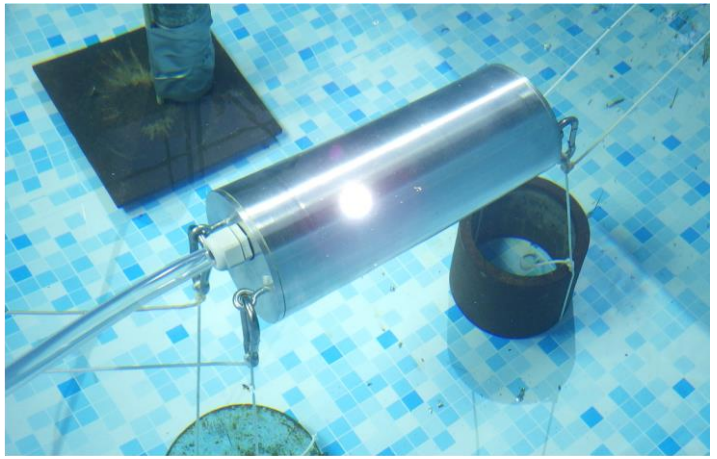




Project description







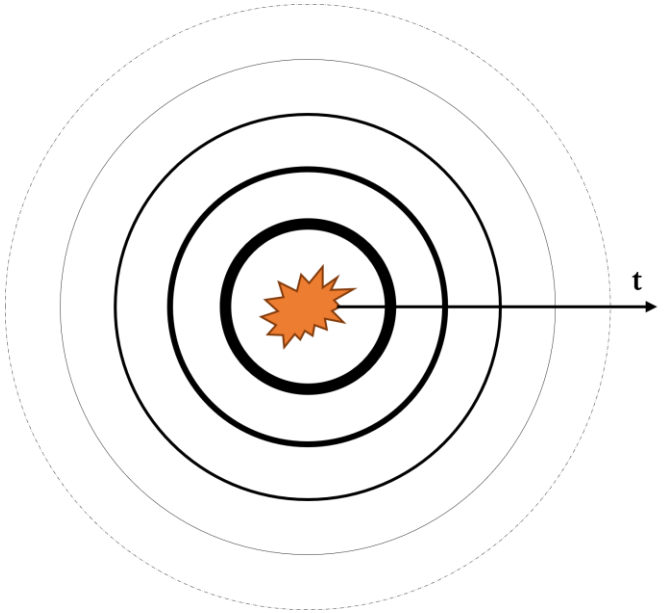
Theory

STRUCTURAL RESPONSES DUE TO UNDERWATER DETONATIONS

Theory

- Underwater detonation
  - **Shock wave**
  - Gas bubble
  - Reflections
- Structural responses
  - Plastic deformation
  - Natural frequencies
- Numerical methods
  - Modelling
  - Coupling between solid and fluid

$$P(t) = P_0 \cdot e^{-t/\theta} \quad 0 \leq t \leq \theta$$

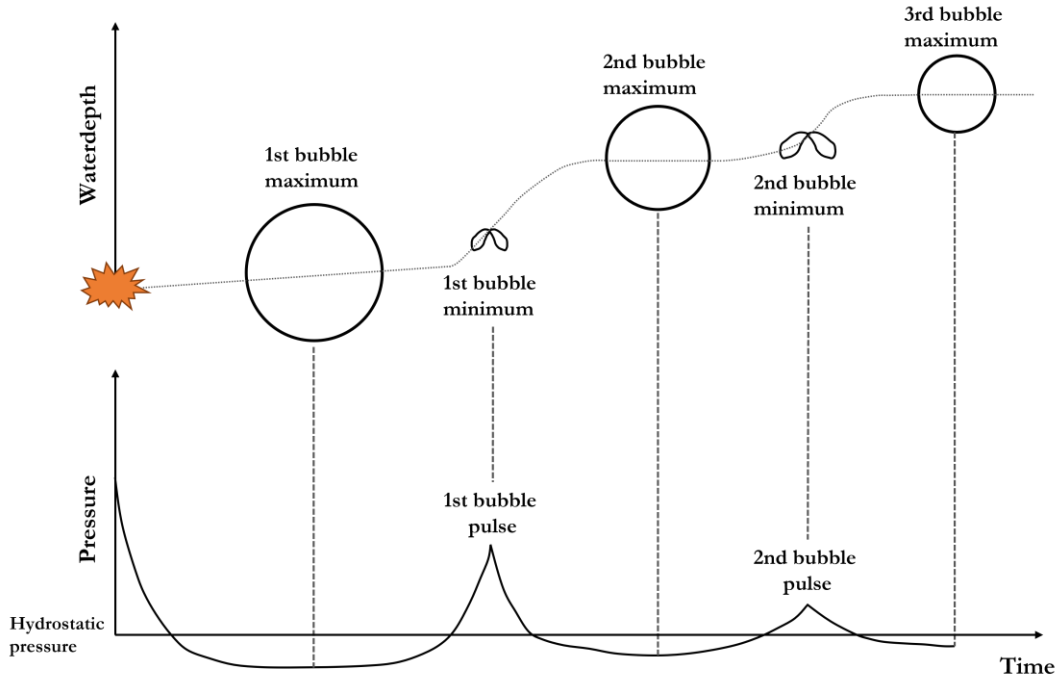


Theory

- Underwater detonation
  - Shock wave
  - **Gas bubble**
  - Reflections
- Structural responses
  - Plastic deformation
  - Natural frequencies
- Numerical methods
  - Modelling
  - Coupling between solid and fluid

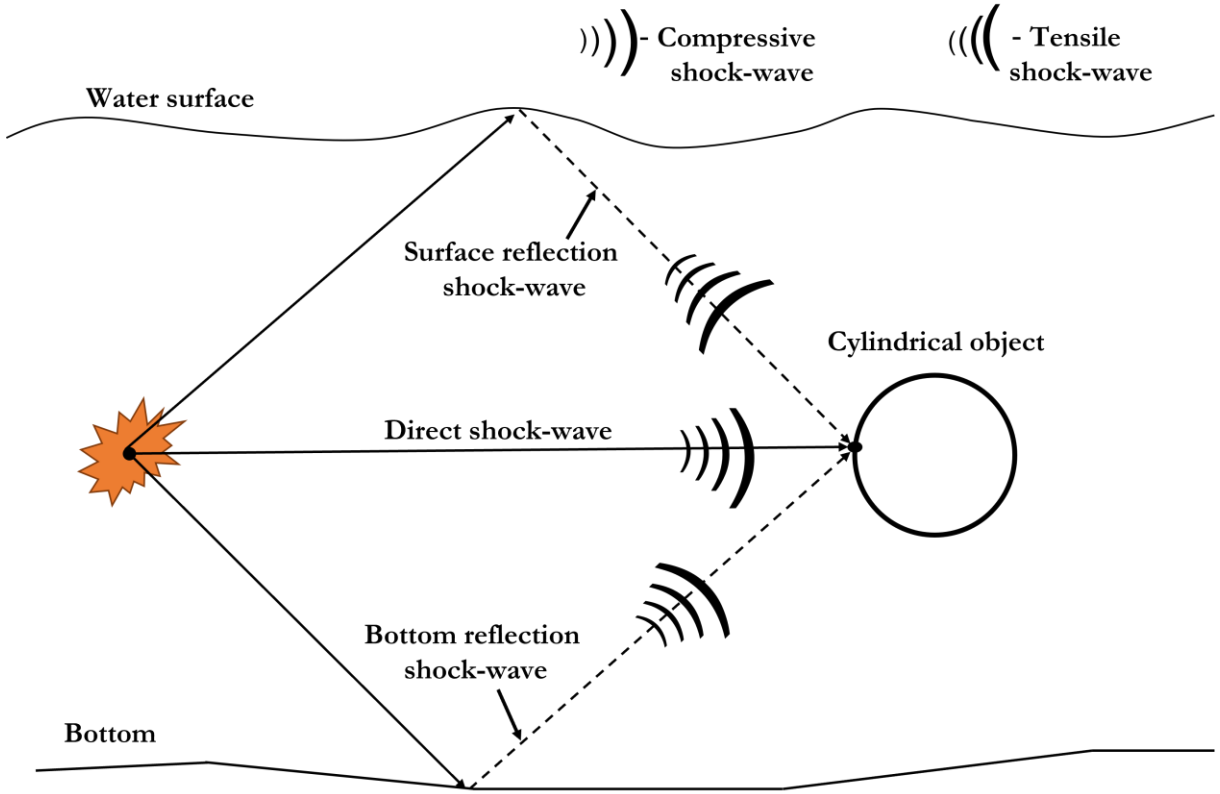
$$R_{max} = K6 \cdot (W^{1/3}/(D + 9.8))^{1/3}$$

$$T = K5 \cdot (W^{1/3}/(D + 9.8)^{5/6})$$



Theory

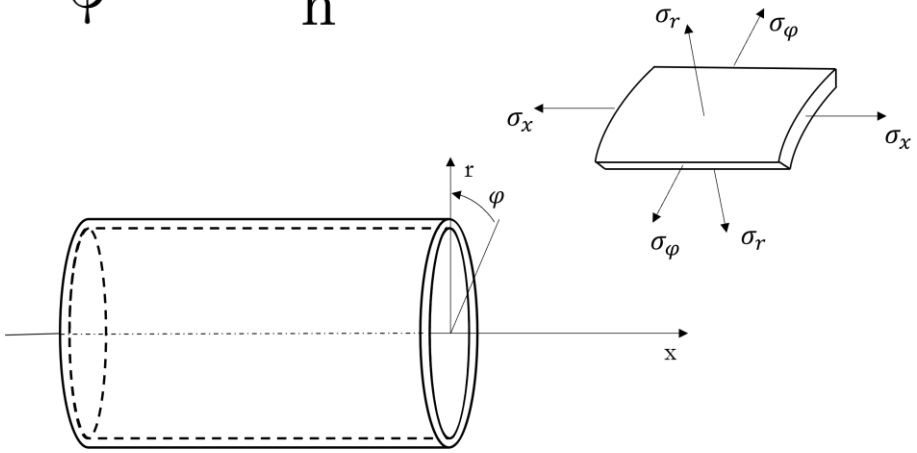
- Underwater detonation
  - Shock wave
  - Gas bubble
  - **Reflections**
- Structural responses
  - Plastic deformation
  - Natural frequencies
- Numerical methods
  - Modelling
  - Coupling between solid and fluid



Theory

- Underwater detonation
  - Shock wave
  - Gas bubble
  - Reflections
- Structural responses
  - **Plastic deformation**
  - Natural frequencies
- Numerical methods
  - Modelling
  - Coupling between solid and fluid

$$\sigma_\varphi = \frac{P\ r}{h}$$



Theory

- Underwater detonation
  - Shock wave
  - Gas bubble
  - Reflections
- Structural responses
  - Plastic deformation
  - **Natural frequencies**
- Numerical methods
  - Modelling
  - Coupling between solid and fluid

Caused by:

- Shock wave
- Bubble pulse
- Reflections
- Combinations

Theory

- Underwater detonation
  - Shock wave
  - Gas bubble
  - Reflections
- Structural responses
  - Plastic deformation
  - Natural frequencies
- Numerical methods
  - **Modelling**
  - Coupling between solid and fluid

SSA

- No modelling of water domain needed
- Based on theoretical equations

S-ALE

- Modelled water domain
- Modelled detonation
- Computationaly heavy

Theory

- Underwater detonation
  - Shock wave
  - Gas bubble
  - Reflections
- Structural responses
  - Plastic deformation
  - Natural frequencies
- Numerical methods
  - Modelling
  - **Coupling between solid and fluid**

SSA
BEM – Boundary Element Method

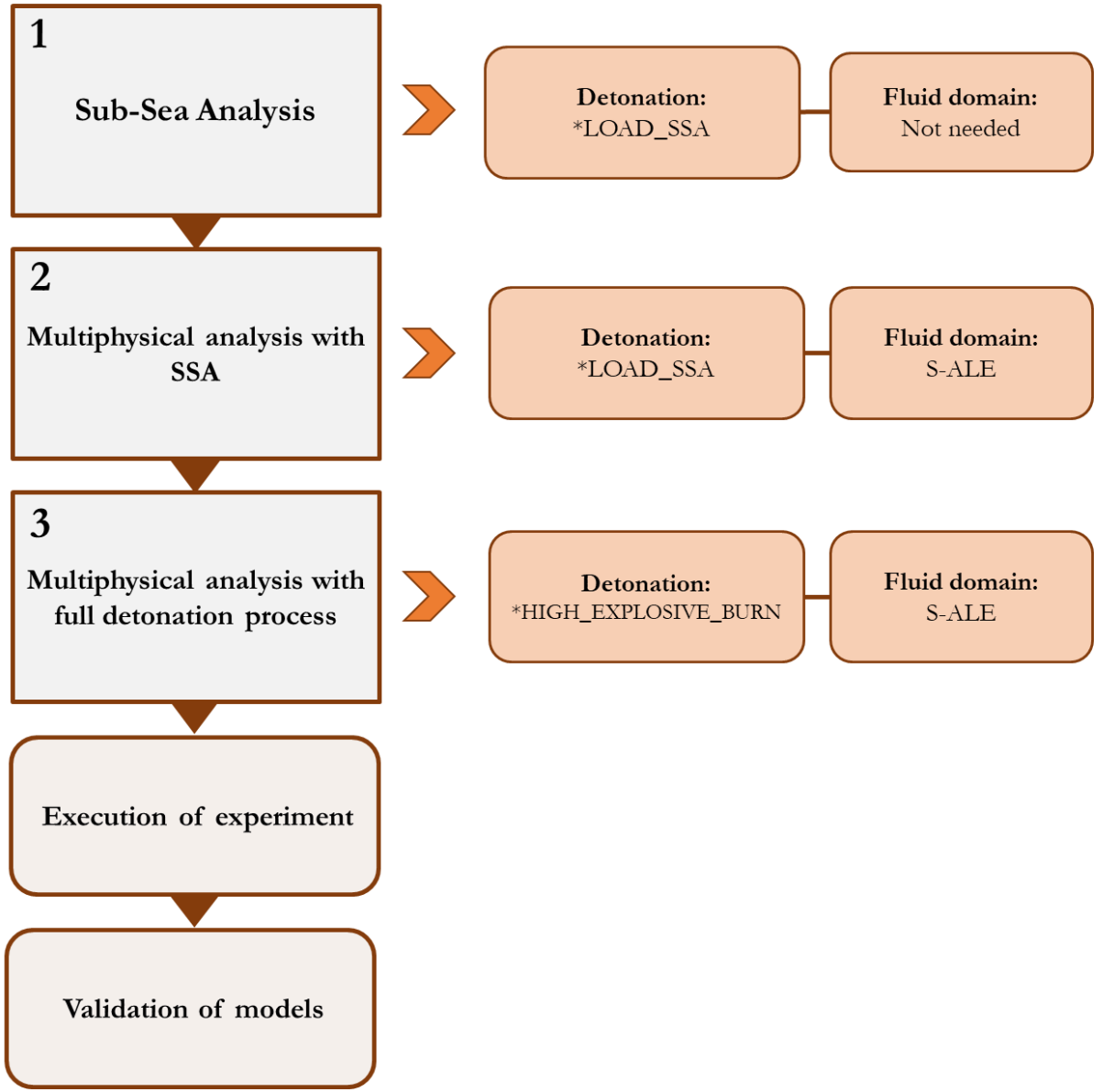
S-ALE
FSI – Fluid Structure Interaction

Method

STRUCTURAL RESPONSES DUE TO UNDERWATER DETONATIONS

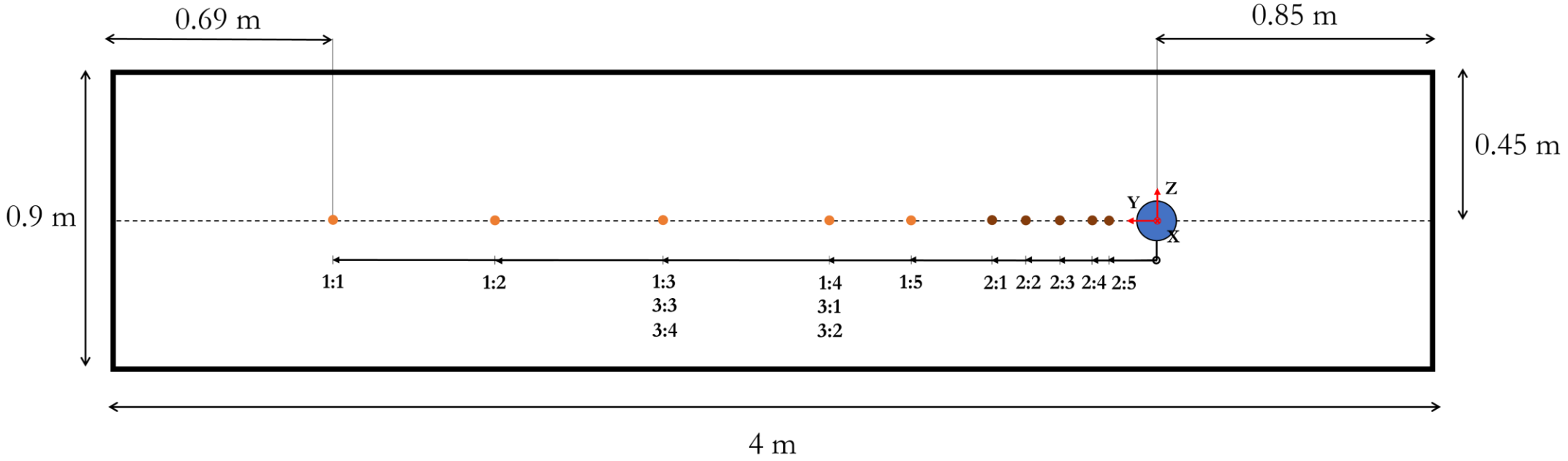
Project stages

- Modelling in LS-Dyna
- Increased complexity
- Experiments for validation



Experiments

- Three series
- Varied distance to charge
- Varied weight of charge



Experiments

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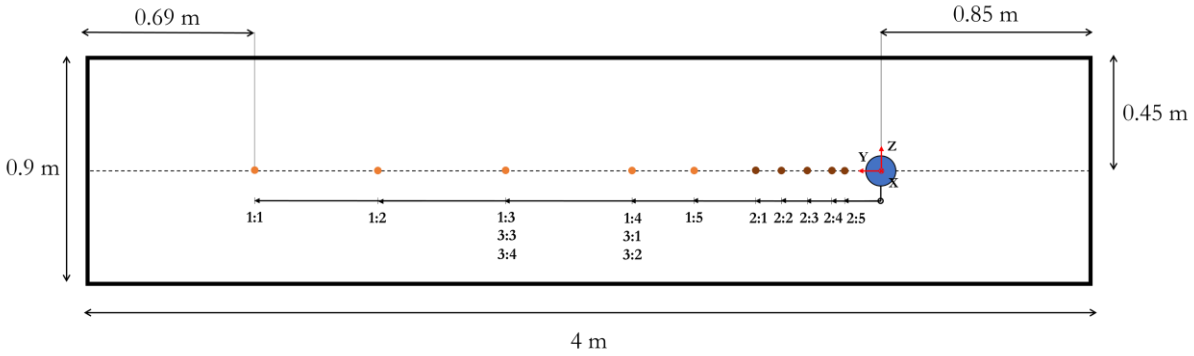
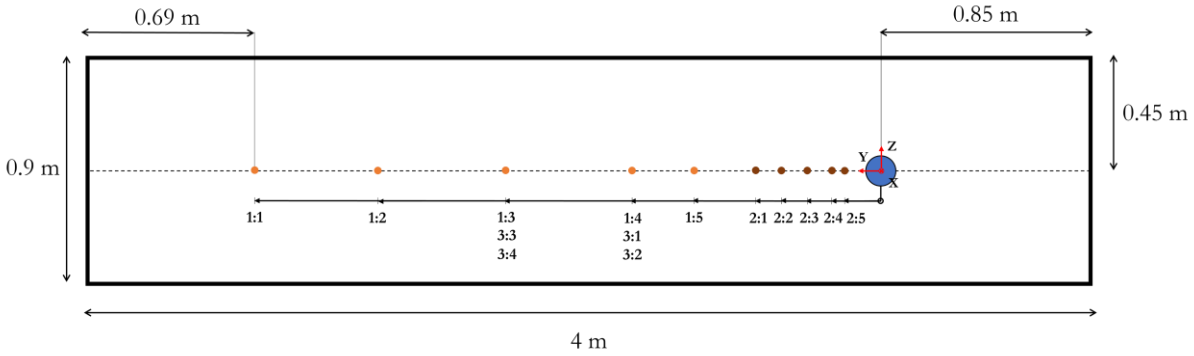


Experiment	Distance to detonation [m]	Weight for charge
1:1	2.50	w1
1:2	2.00	w1
1:3	1.50	w1
1:4	1.00	w1
1:5	0.75	w1
2:1	0.50	w1
2:2	0.40	w1
2:3	0.30	w1
2:4	0.20	w1
2:5	0.15	w1
3:1	1.00	w2
3:2	1.00	w3
3:3	1.50	w4
3:4	1.50	w5

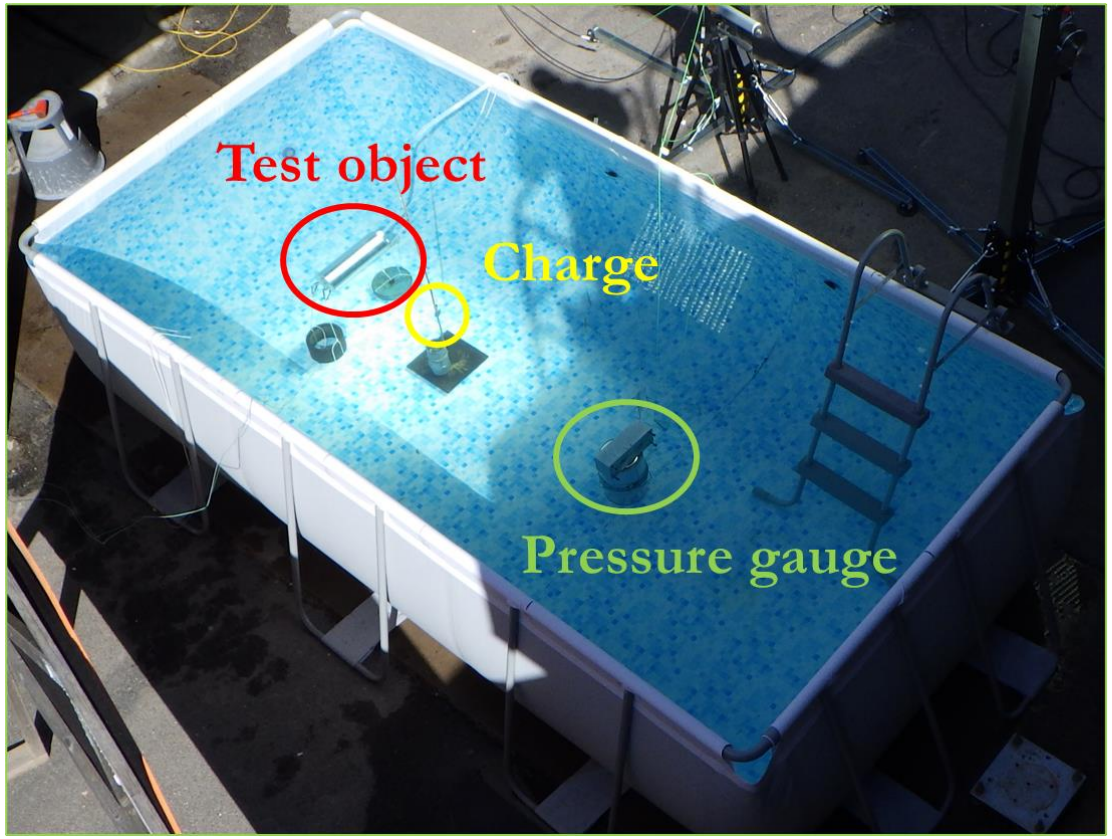
Experiments

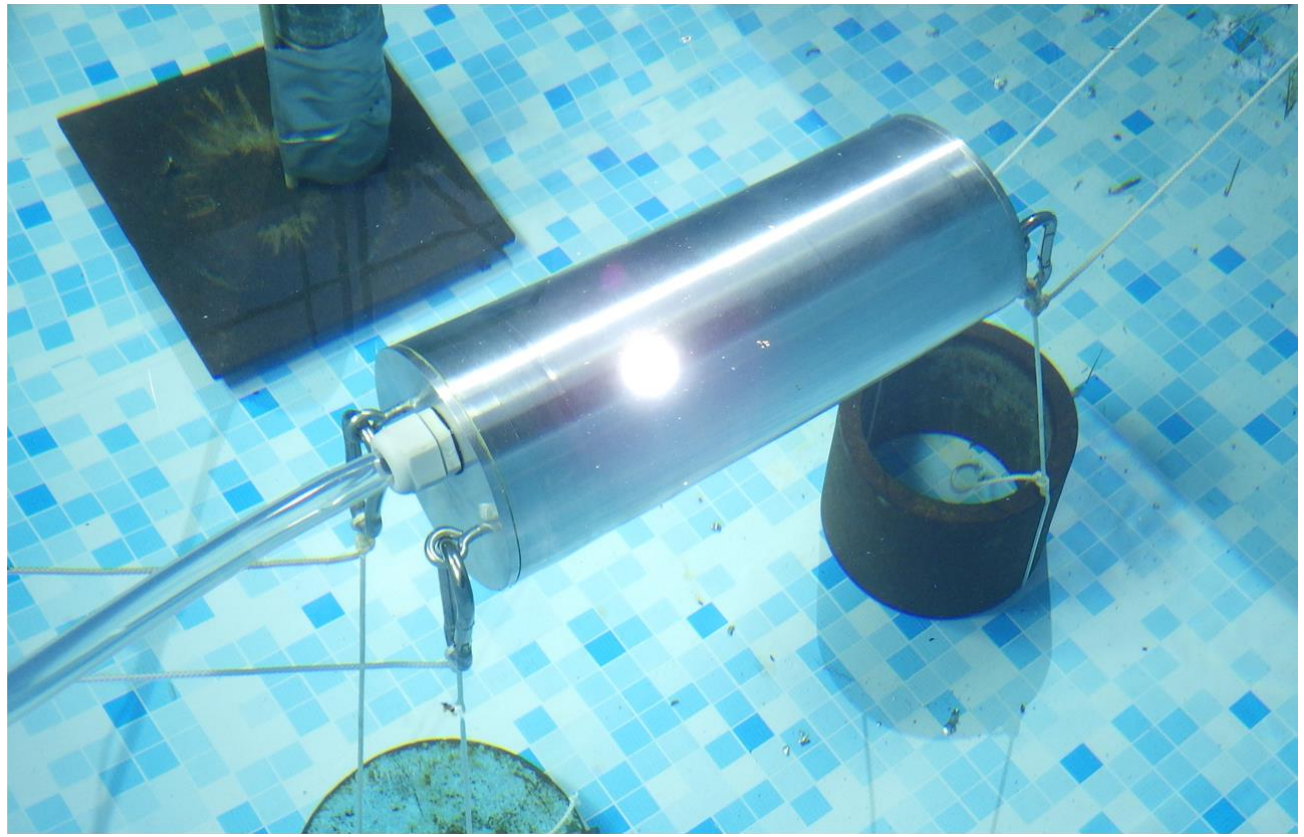
- Three series
- Varied distance to charge
- Varied weight of charge



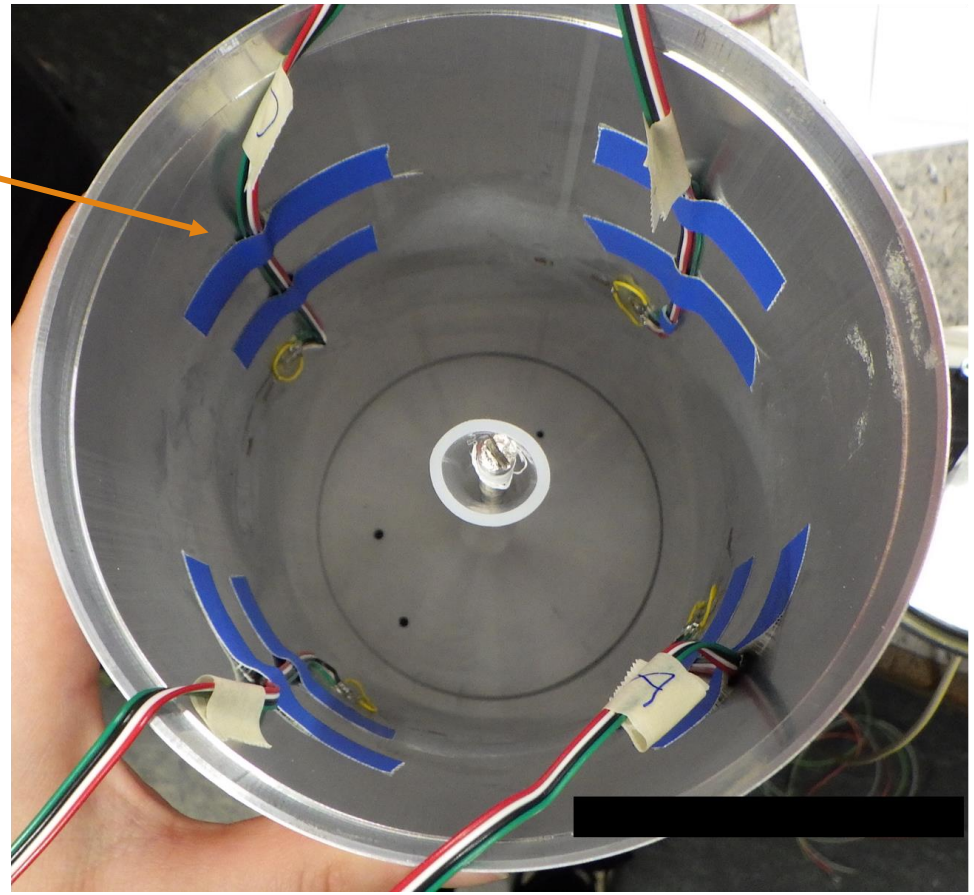
Experiment	Distance to detonation [m]	Weight for charge
1:1	2.50	w1
1:2	**2.00**	**w1**
1:3	1.50	w1
1:4	1.00	w1
1:5	**0.75**	**w1**
2:1	0.50	w1
2:2	0.40	w1
2:3	0.30	w1
2:4	0.20	w1
2:5	**0.15**	**w1**
3:1	1.00	w2
3:2	1.00	w3
3:3	**1.50**	**w4**
3:4	1.50	w5

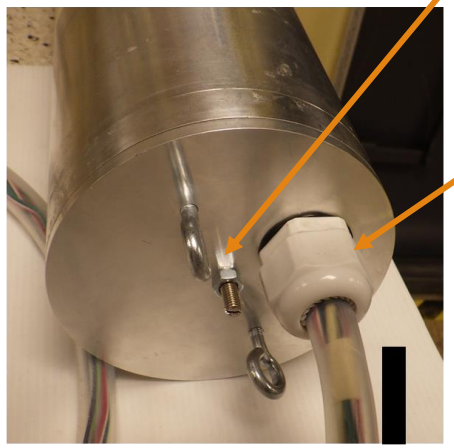
Experiments - Setup

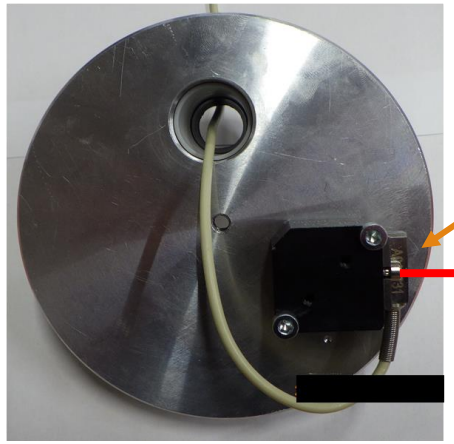




Experiment – Measuring instruments

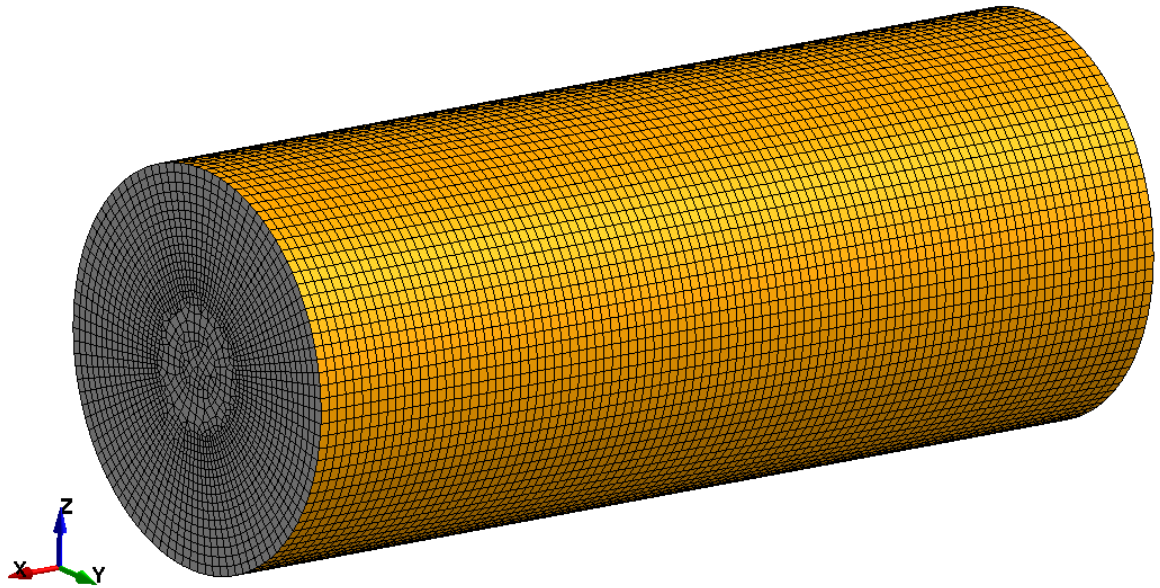






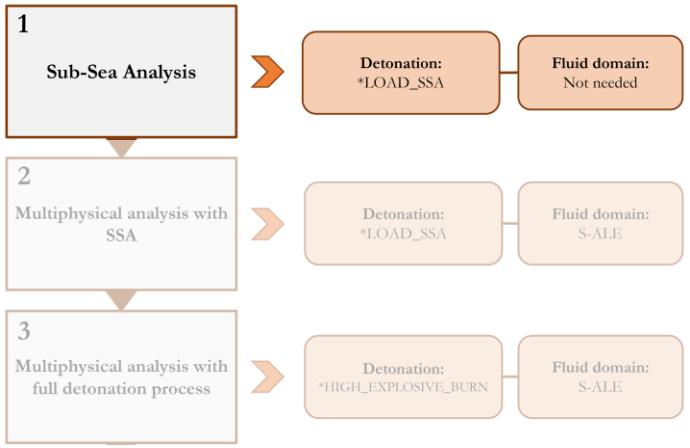
Model of test object

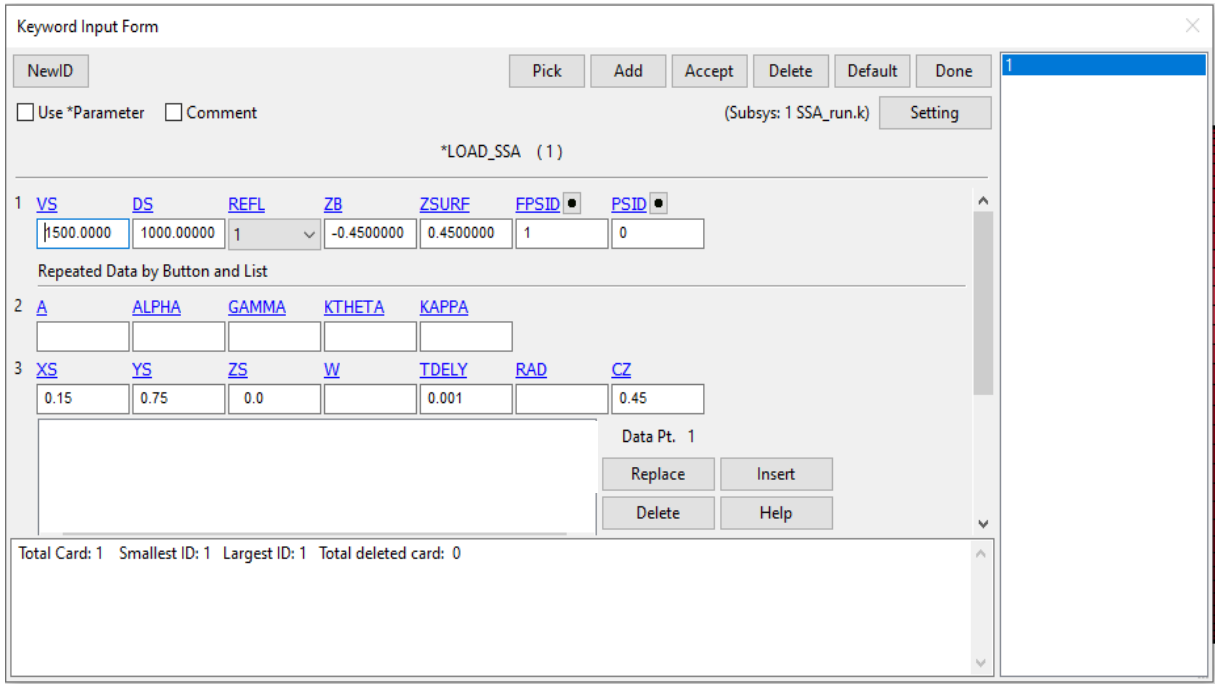
- Used for all simulation methods
- Used for all experiments
- Dimensions:
  - L = 300 mm
  - ⌀ = 120 mm
  - h = 1.5 mm
- Material
  - Alu 6060
  - Yield stress – 140 Mpa
  - Strain at failure – 11%



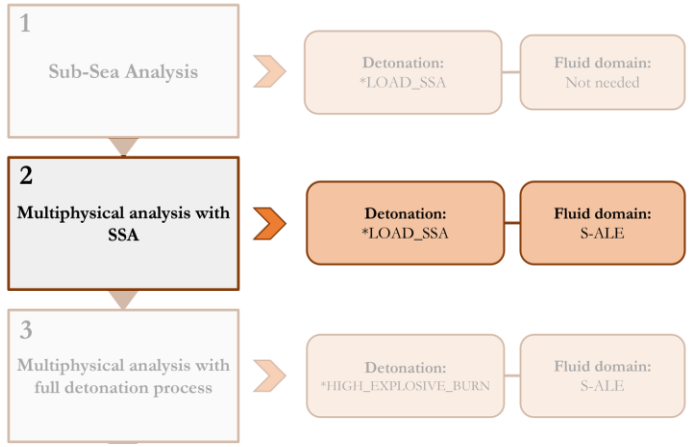
Sub-Sea Analysis (SSA)

- **Validation of analytical calculations**
- **Simulation of experients**

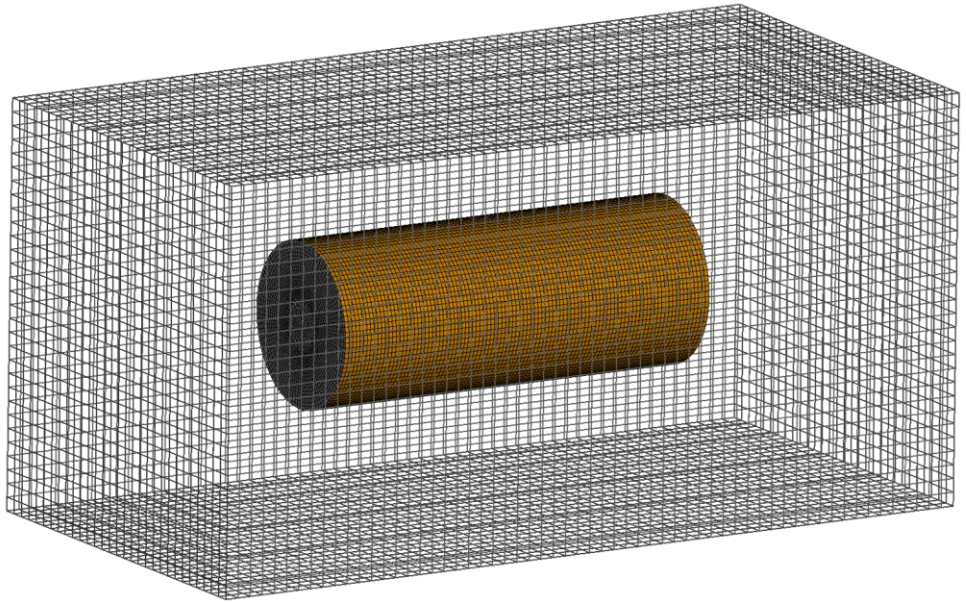




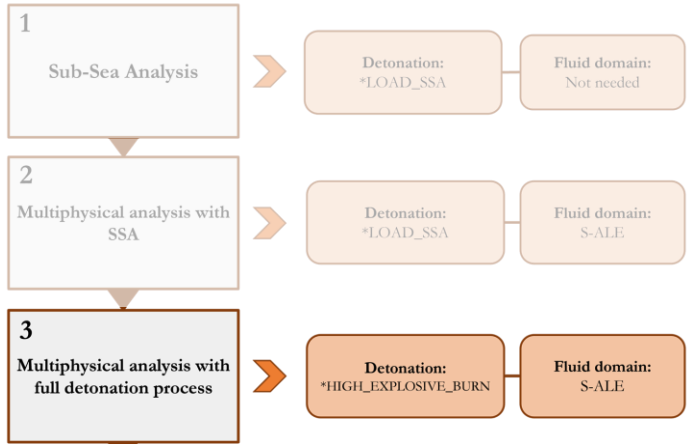
Multiphysics analysis with SSA



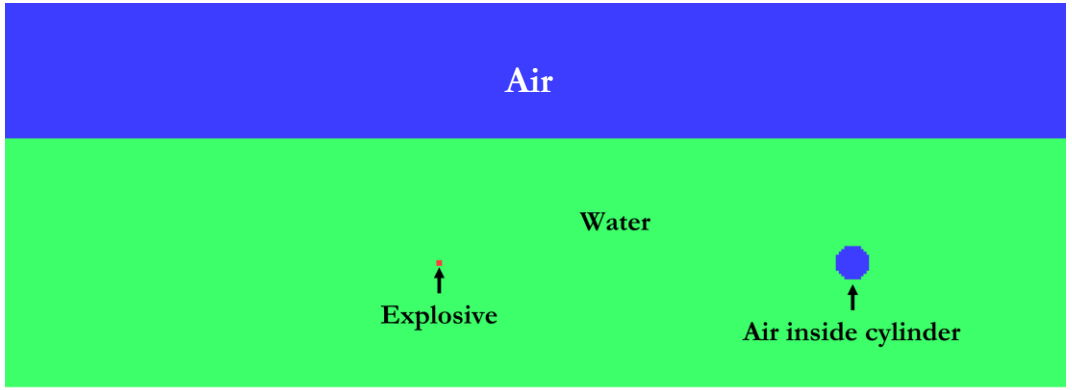
- Combination of SSA and S-ALE
- Including physics from water



Multiphysics analysis with full detonation event



- **Three materials: Explosive, Water and Air**
- Ambient BC along domain boundaries
  - Intension to let shock wave travel out of the domain
- Mesh-verification
  - Pressure in the fluid
  - Stress in the cylinder



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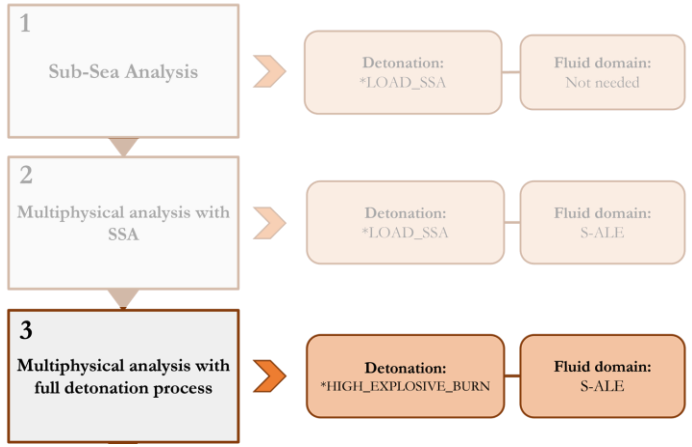

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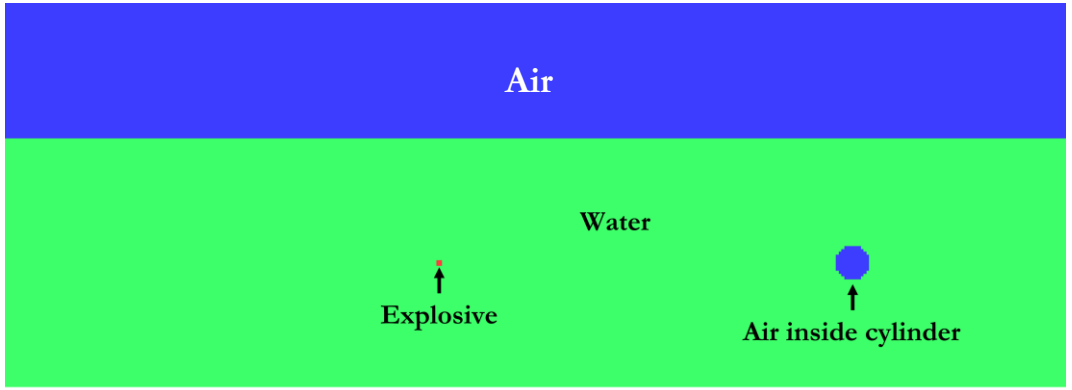
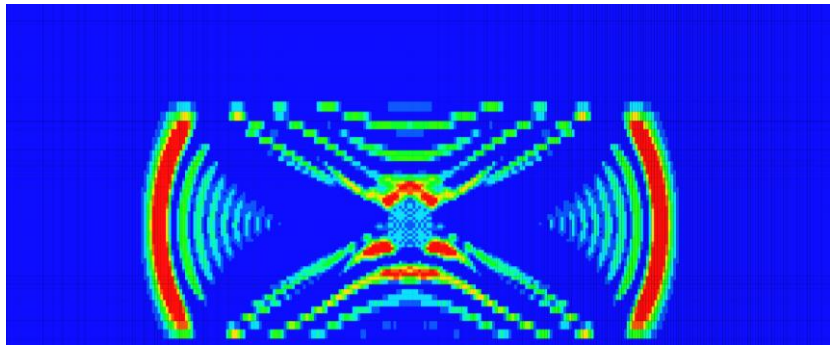
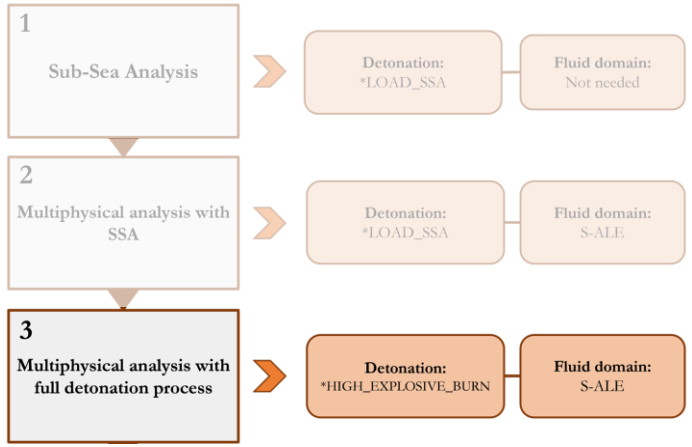




Multiphysics analysis with full detonation event



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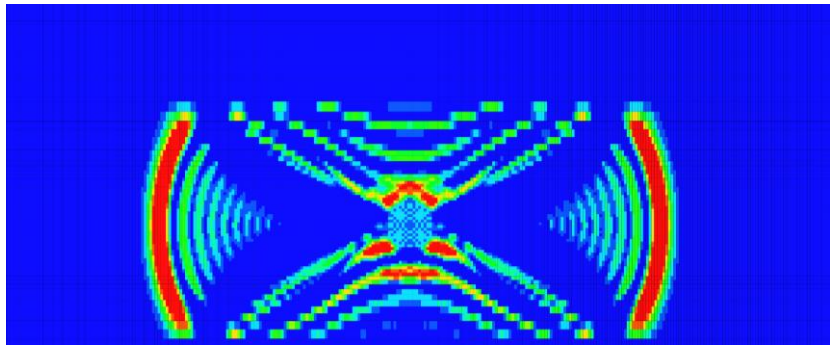
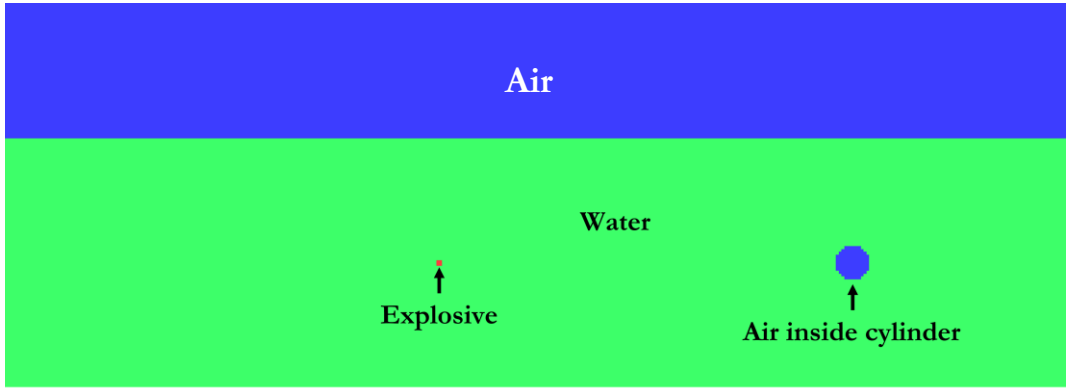
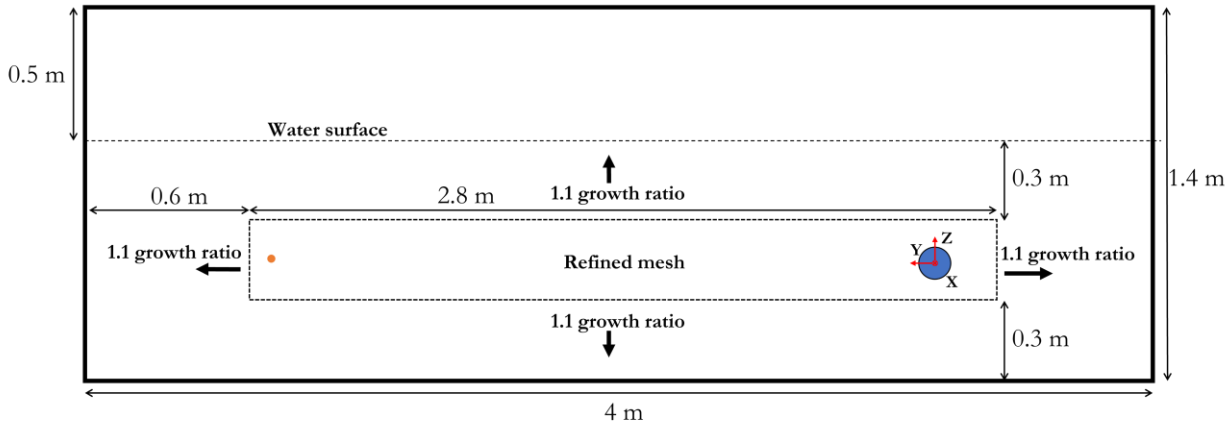
  - Intension to let shock wave travel out of the domain
- **Mesh-verification**
  - **Pressure in the fluid**
  - **Stress in the cylinder**



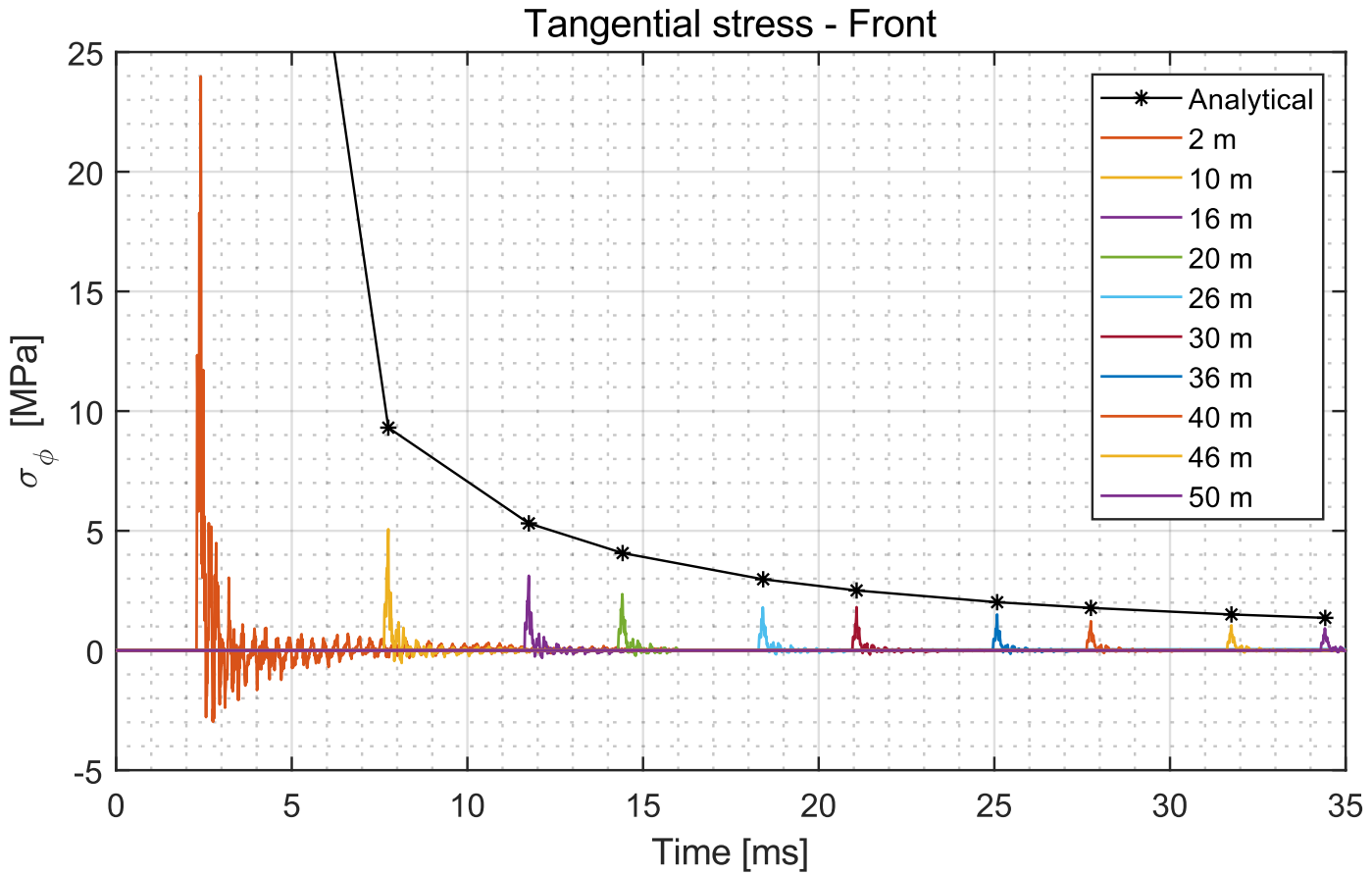




Results & Discussion

STRUCTURAL RESPONSES DUE TO UNDERWATER DETONATIONS

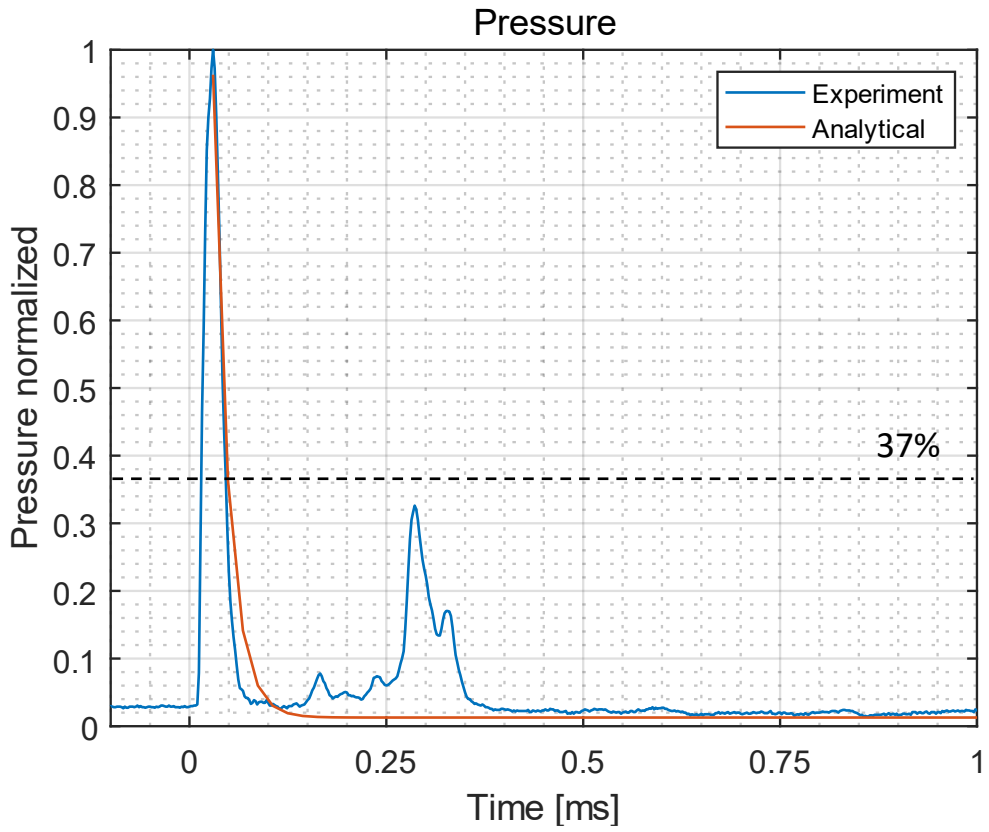
Analytical calculations vs SSA



Pressure study

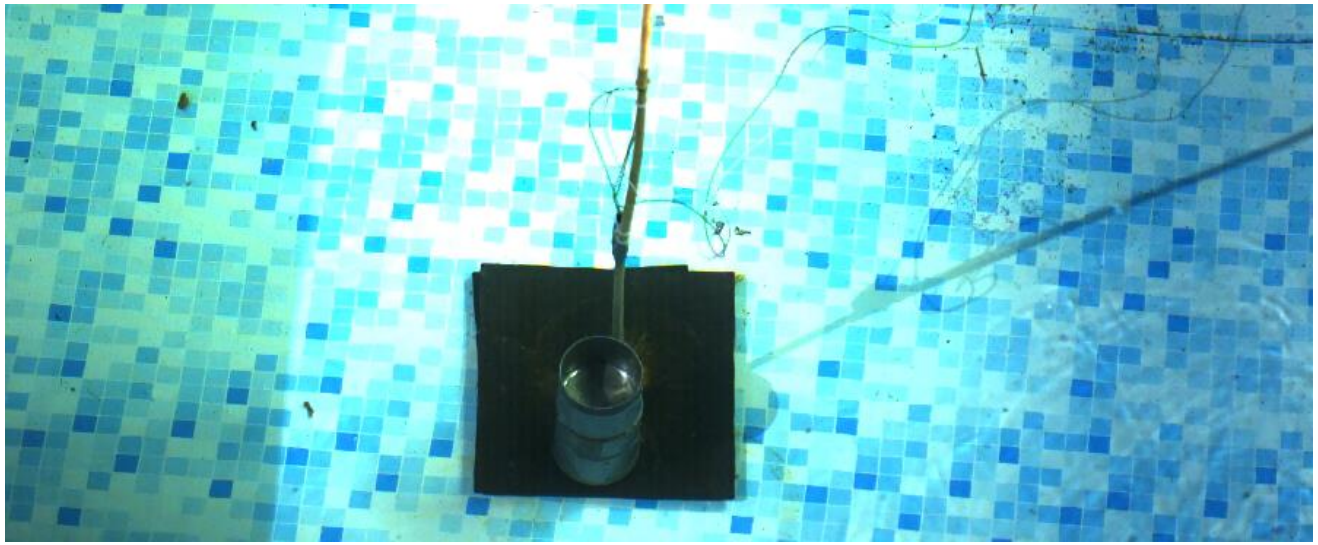
- Normalized towards experiments
- S-ALE underpredicts pressure
  - Smaller difference for larger explosive charge
- Experiments och Analytical
  - Good aggrement to approx. 30% of P_{max}

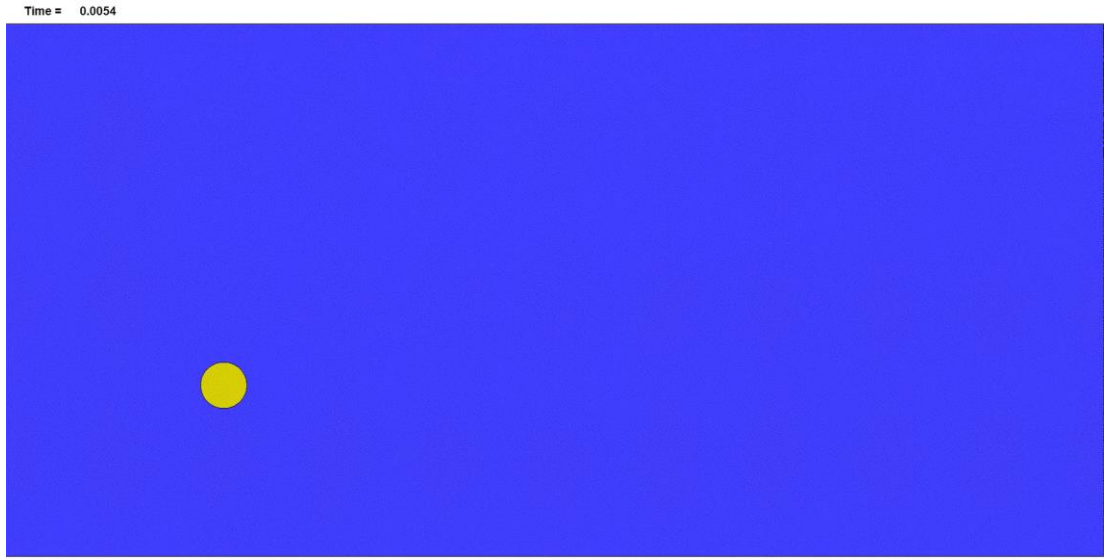
Distance [m]	Weight	Experiment	Analytical	S-ALE
2	w1	1	0,94	0,25
1,5	w4	1	0,55	0,35
1,35	w1	1	0,80	0,19
0,75	w1	1	0,99	0,13



Case 1:5 – Detonation event

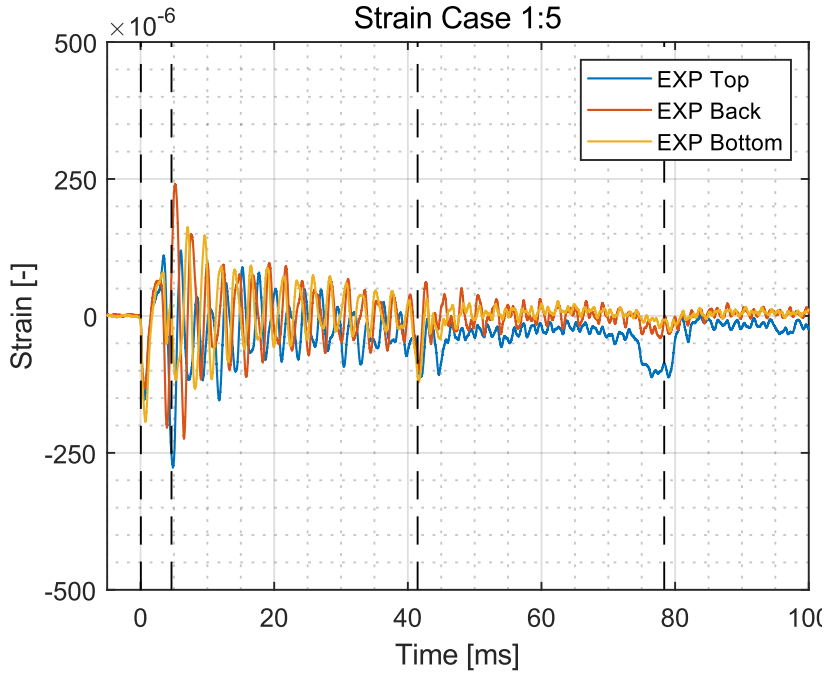
- Distance 0.75 m
- Expected contact with bubble

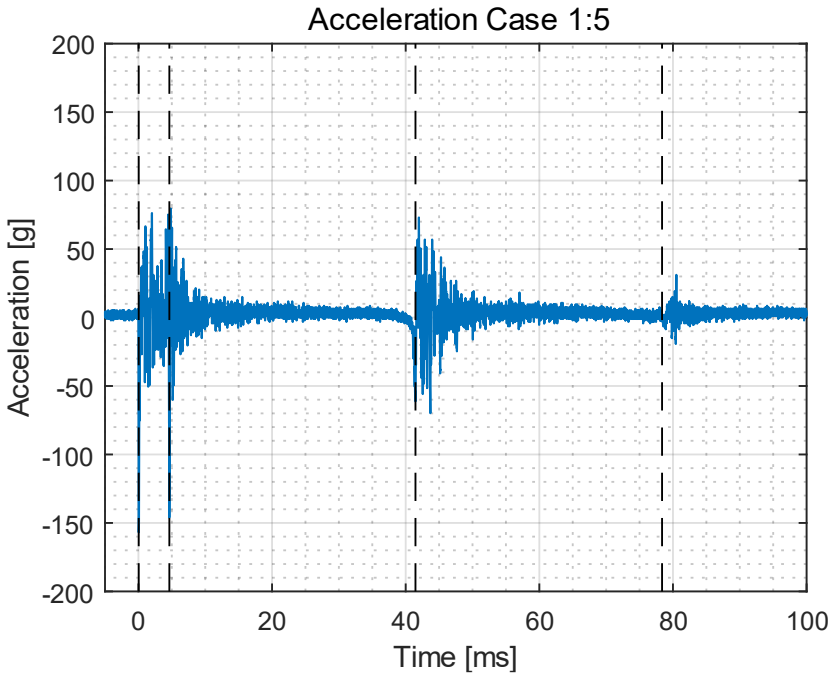


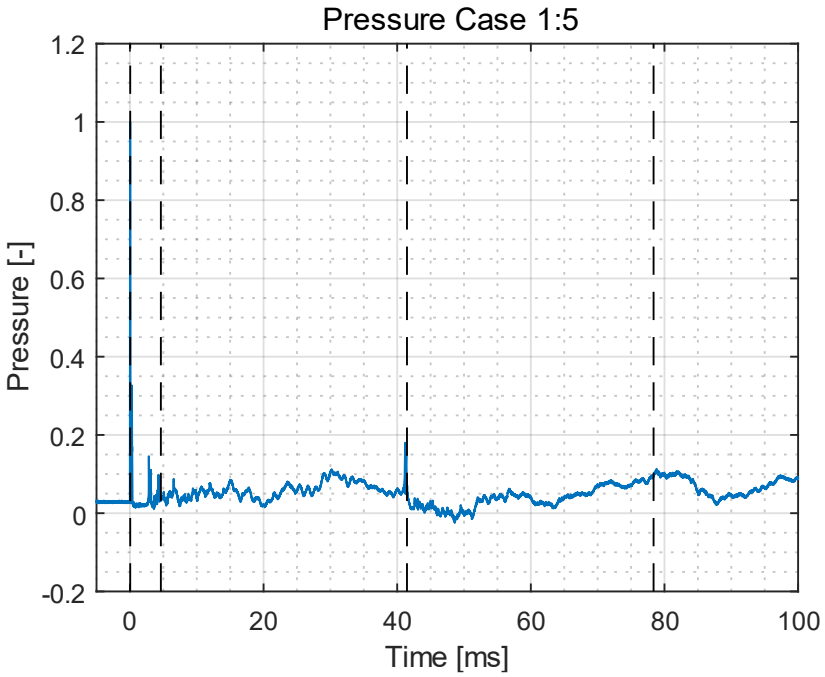


Case 1:5 – Experiment

- Shock wave
- Possible snatch from strings
- 1st Bubble pulse
- 2nd Bubble pulse

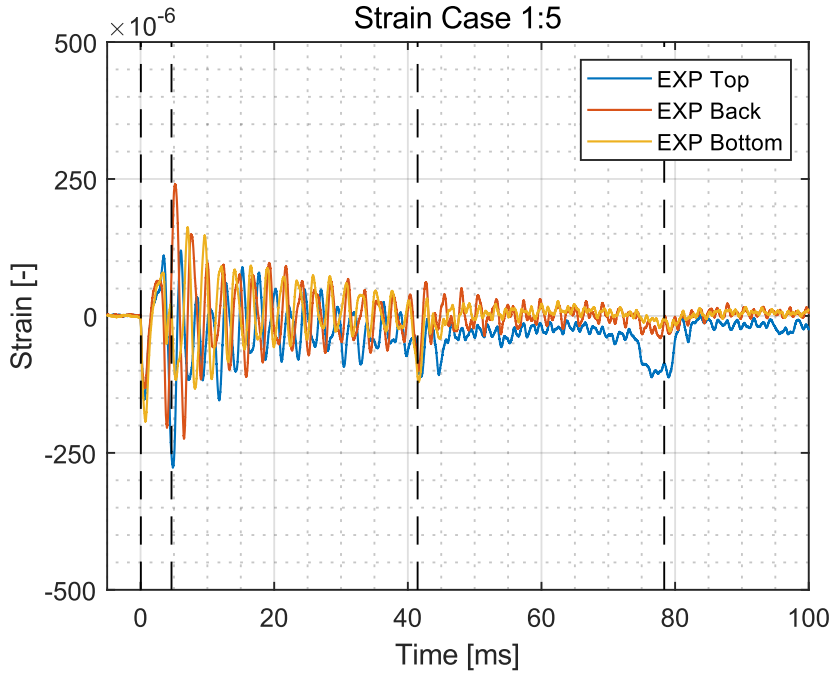


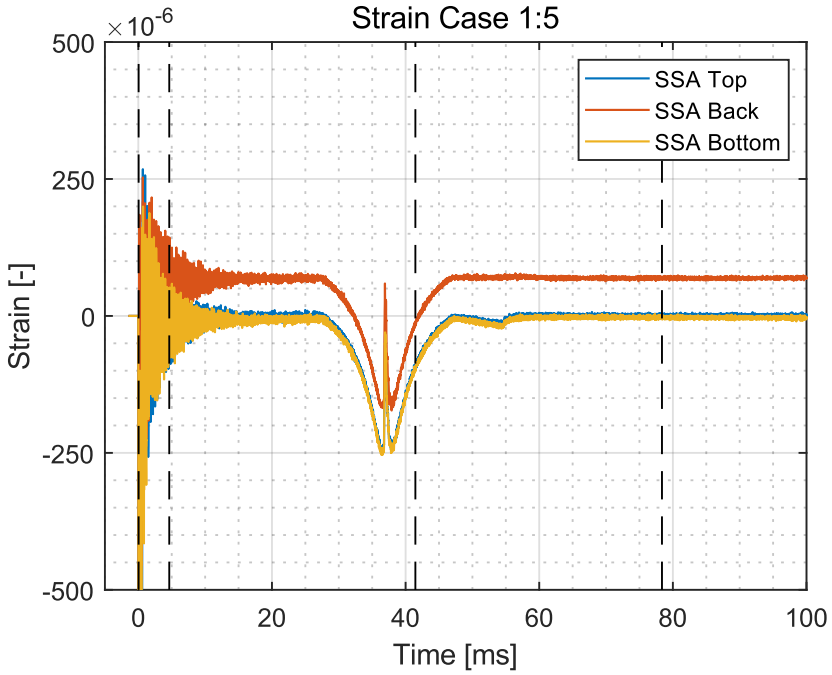


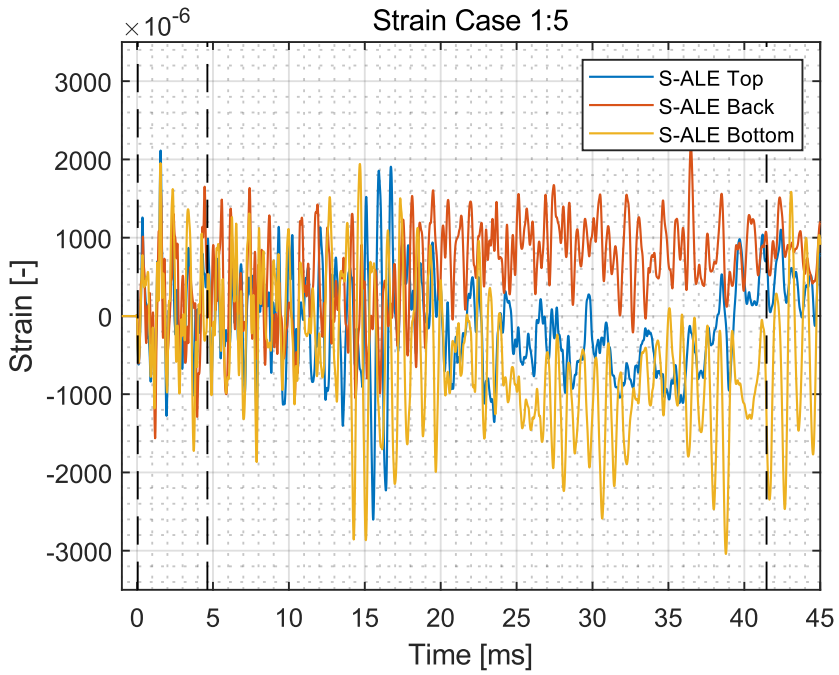


Case 1:5 – Comparison

- SSA has a clear bubble pulse effect
  - Oscillations correlates to natural frequencies
- Experiments and SSA has similar magnitude
- S-ALE oscillates
  - Reflections
  - Natural frequencies







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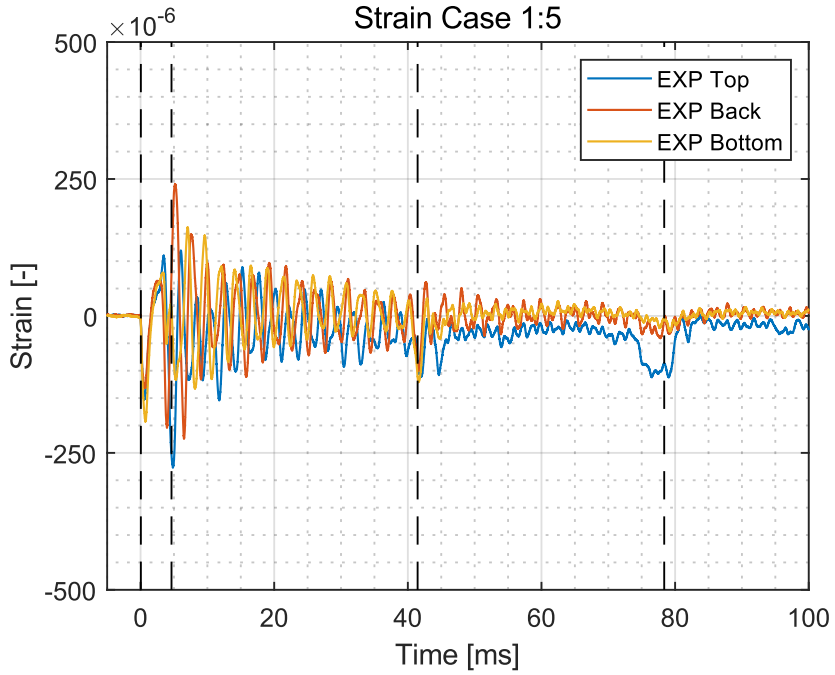
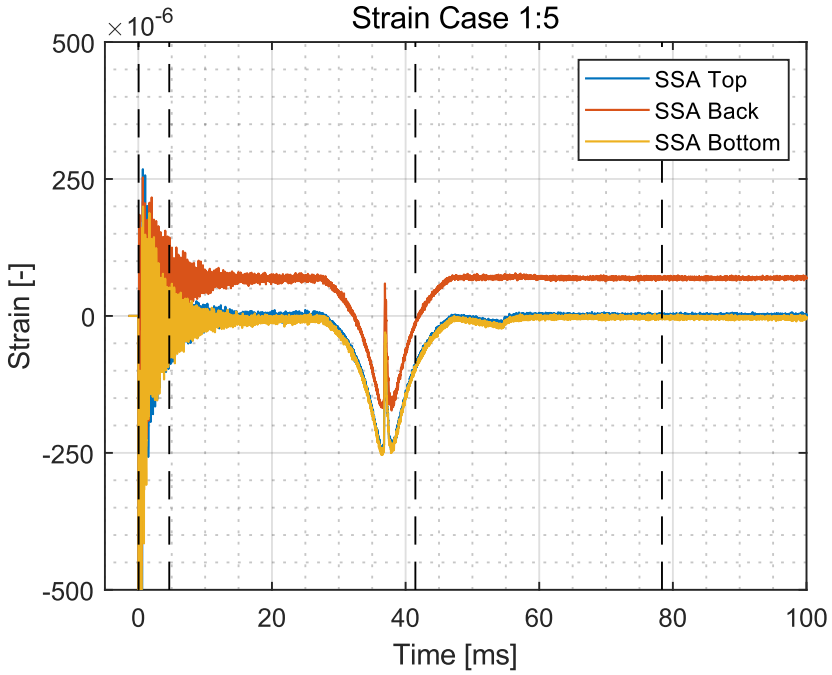
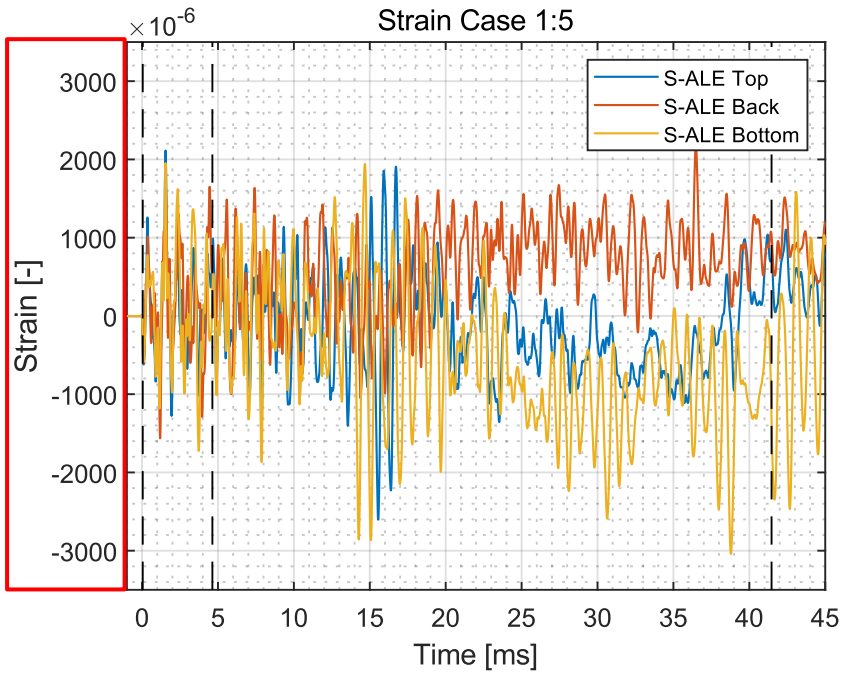
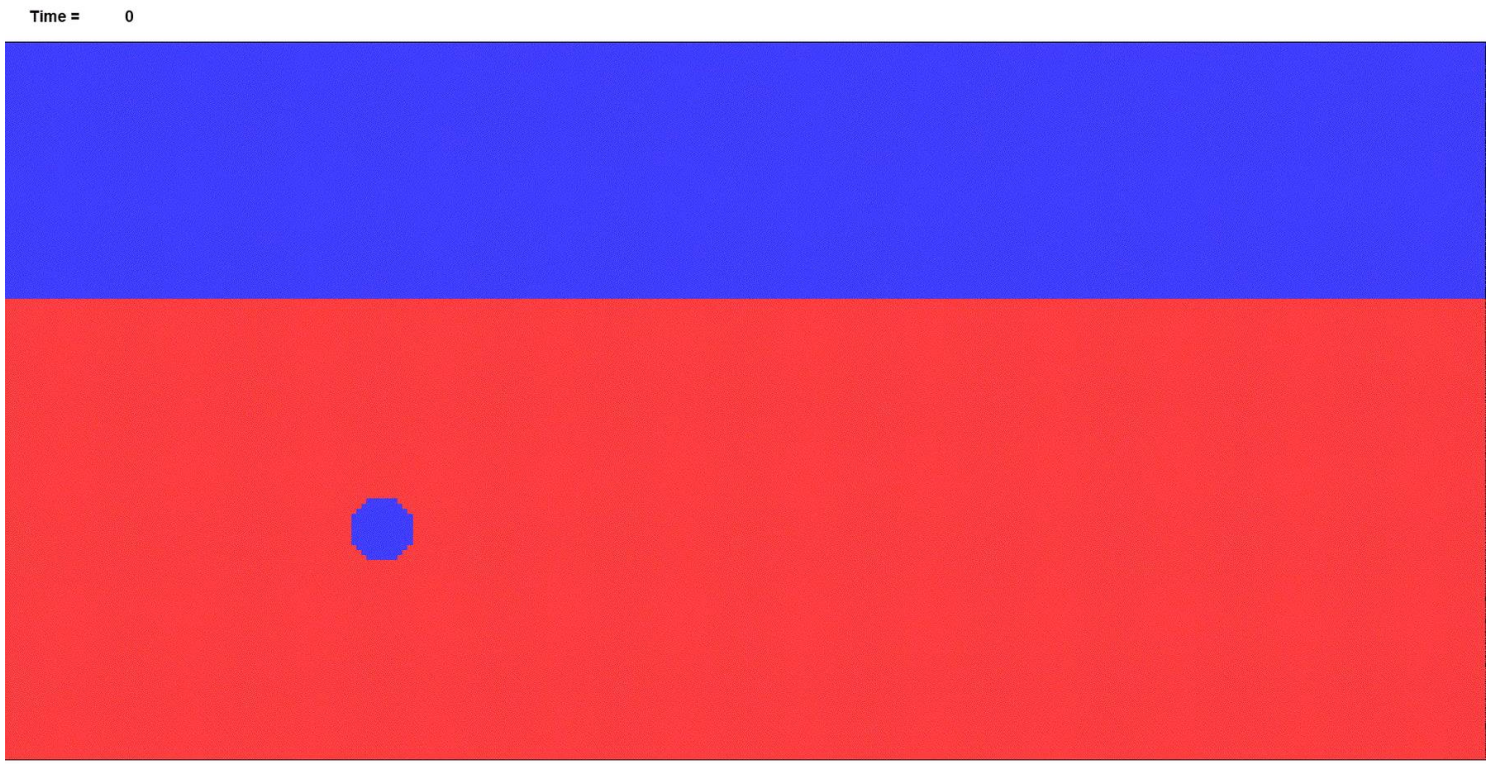




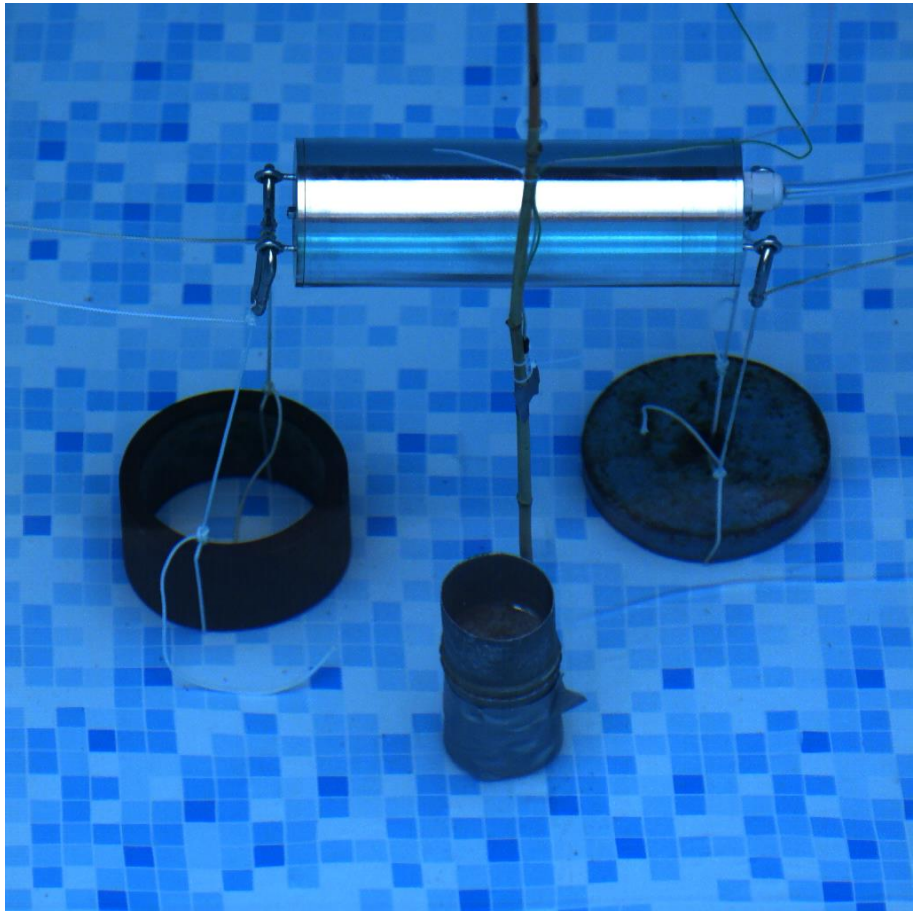


Case 1:5 – S-ALE bubble

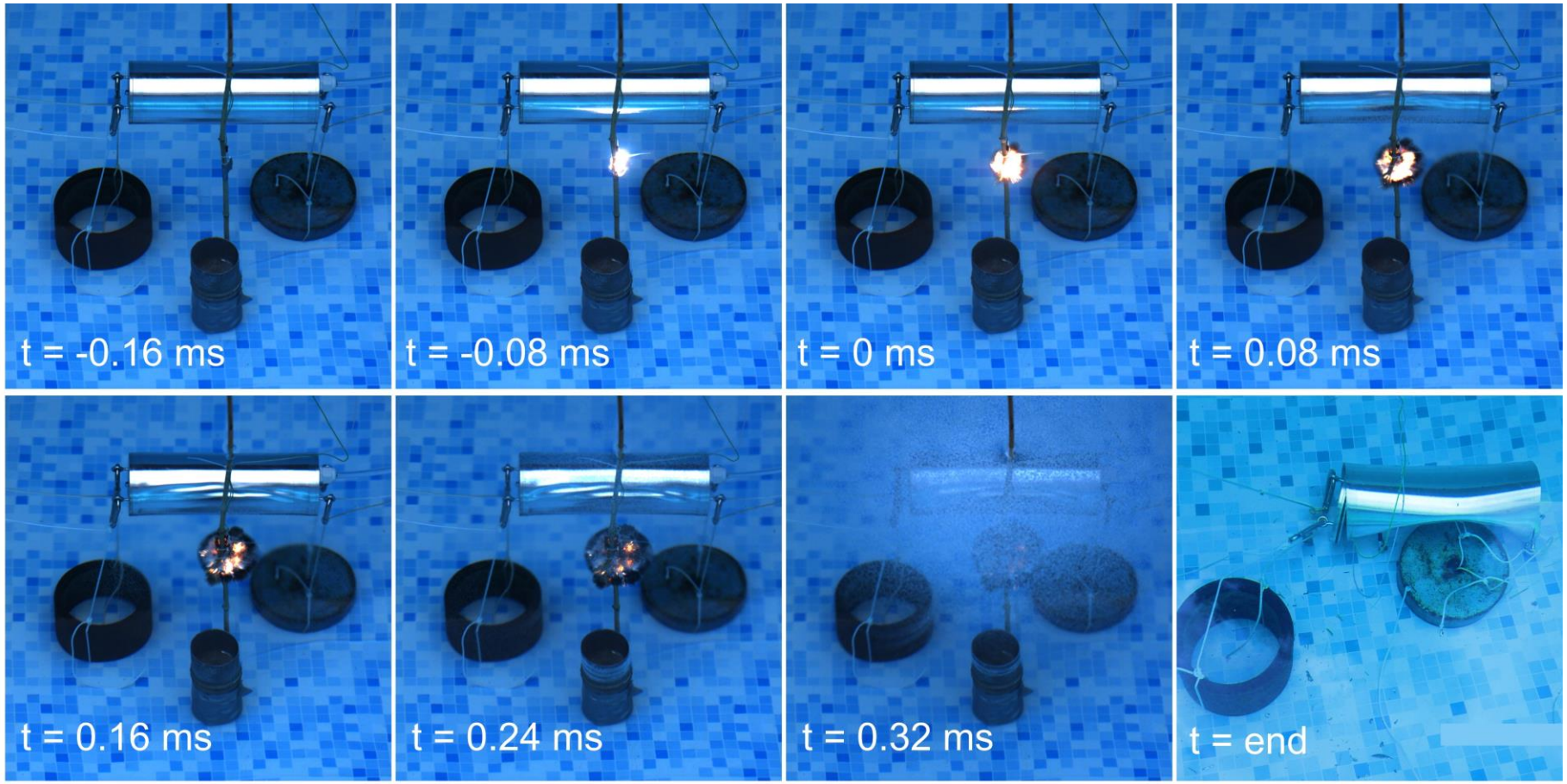
- Bubble radius
  - 0.8 m analytical
  - 0.2 m with S-ALE
- No contact with the bubble
- Can be due to the distance to the water surface



Case 2:5 – Experiment

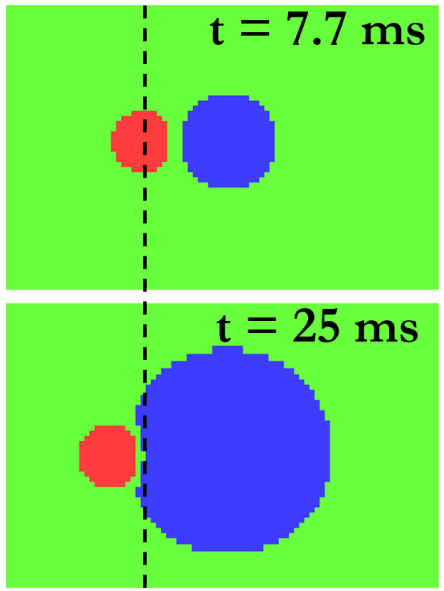


Case 2:5 – Experiment

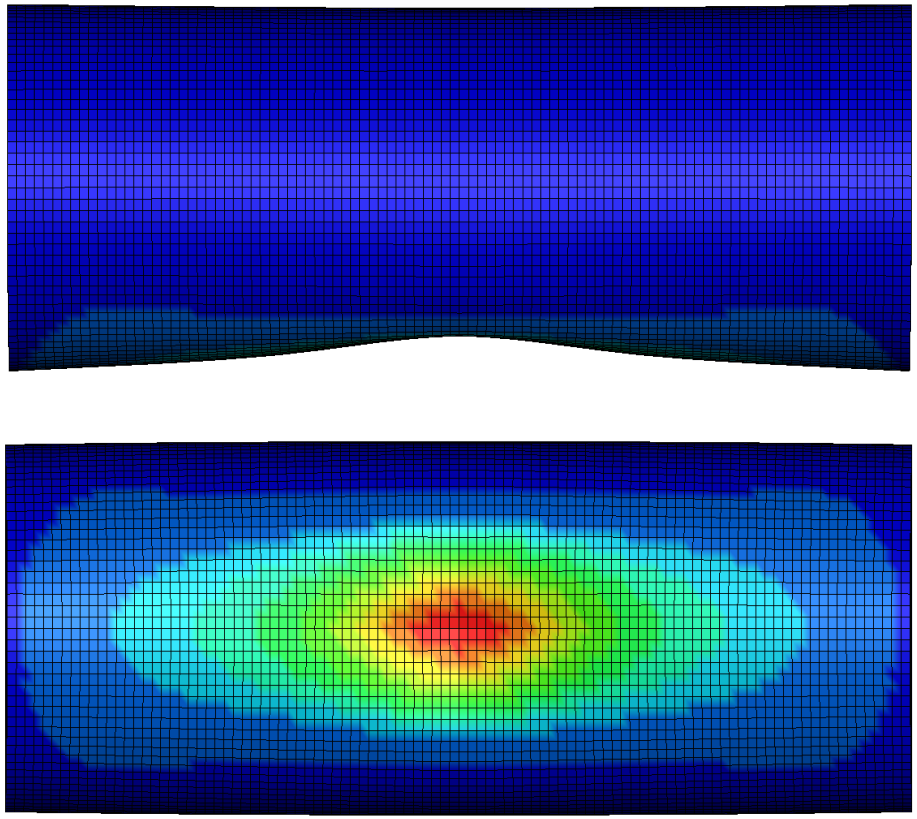


Case 2:5 – Numerical results

- The bubble collides with the cylinder
  - SSA displaces it 0.1 mm
  - S-ALE displaces it 70 mm



Displacement in y-direction, from detonation point



Conclusions

STRUCTURAL RESPONSES DUE TO UNDERWATERDETONATIONS

Conclusions

- Natural frequencies have a significant impact on the results
- SSA
  - No damping function from the water
  - Only models the load applicaton as analytical functions
  - Only accounts for the first bubble pulse
- S-ALE
  - Difficult to avoid reflections at the boundaries
  - Load transfer to cylinder aggreable with experiment
  - Better pressure resolution can be obtained for larger explosive charge
- Large impact of how detailed the structure is modelled
- Experiments are sensetive to disturbances

Future work

STRUCTURAL RESPONSES DUE TO UNDERWATERDETONATIONS

Future work

- More experiments
  - Larger water domain
  - Stiffer structure
- SSA
  - Validate with upscaled experiments
  - Mass scaling to account for water
  - Combine with S-ALE
- S-ALE
  - Investigate BCs with no reflections
  - Validate with experiments with increased charge load
- Model the test object more accurate

Thanks for listening!

STRUCTURAL RESPONSES DUE TO UNDERWATERDETONATIONS