Liquid Lead Sloshing in the ELSY Reactor Vessel

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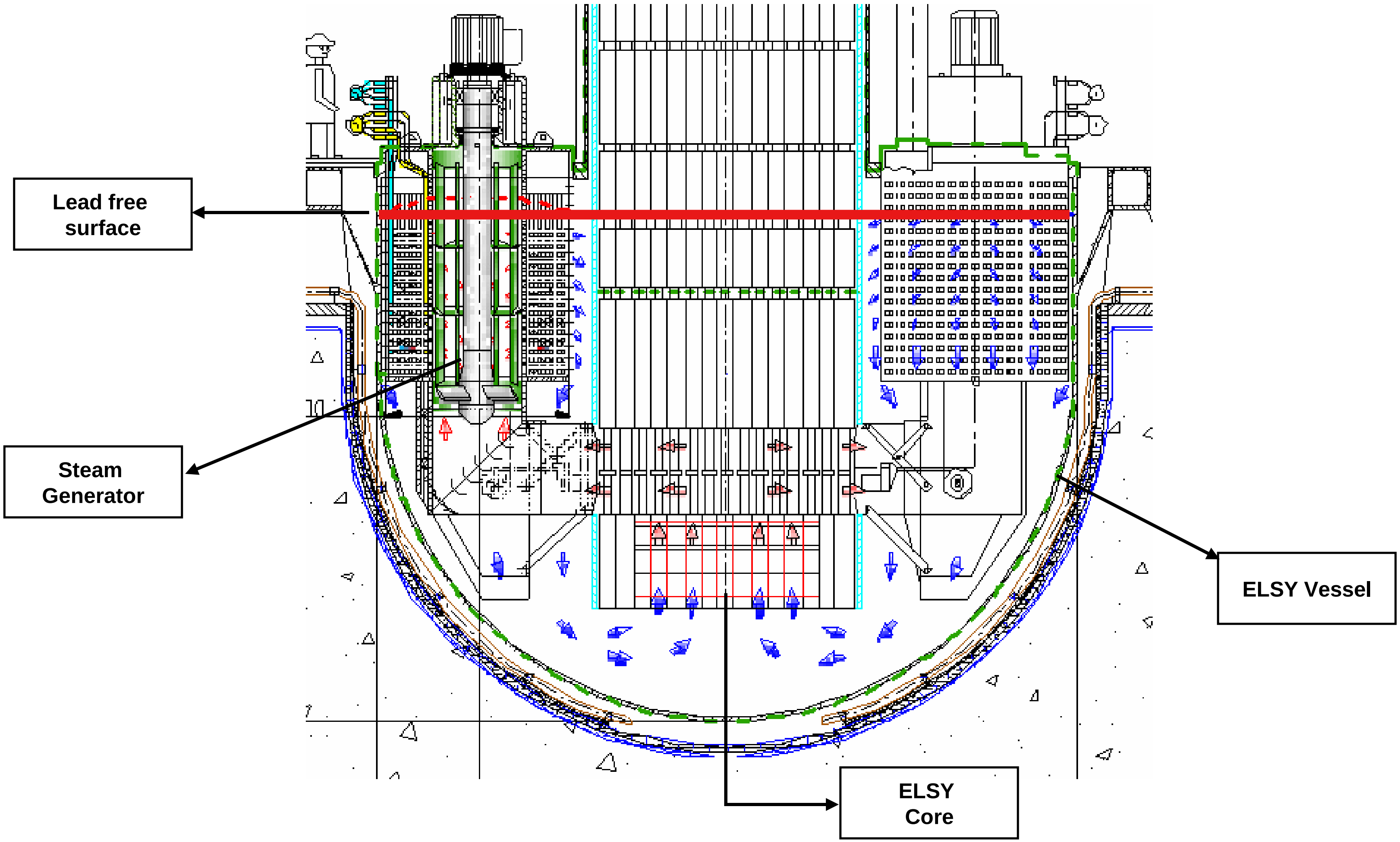
Introduction



Objectives

- Demonstrate the sloshing motions of the lead free-surface in the ELSY vessel using CFD.
- Determine the forces on the internals of the ELSY vessel induced due to sloshing.

Numerical Approach

CFD (Computational Fluid Dynamics) to study the sloshing effects:

- OpenFOAM CFD solver based on finite volume method (FVM).
- Lead free-surface tracking using volume of fluid method (VOF).
- Coupled solid body motion of the walls.
- Validation of the CFD approach using
  - 2d tank – Analytical solution
  - 3d Dam break with an obstruction - Experiments
- Application of the CFD approach to ELSY.

Interface Tracking
Volume of Fluid (VOF) Method

A color function or phase indicator function "α" is defined such that:

$$\alpha = 0 \rightarrow \text{phase 1 (air)}$$
$$\alpha = 1 \rightarrow \text{phase 2 (Lead)}$$
$$0 < \alpha < 1 \rightarrow \text{interface}$$

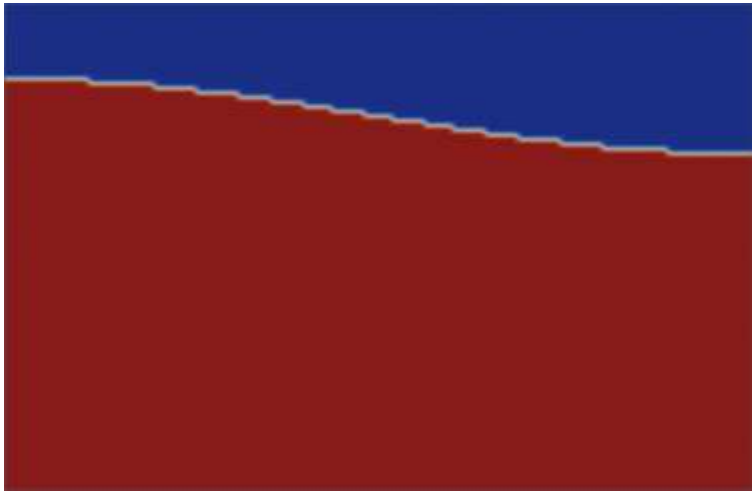
A transport equation for the phase indicator function is solved:

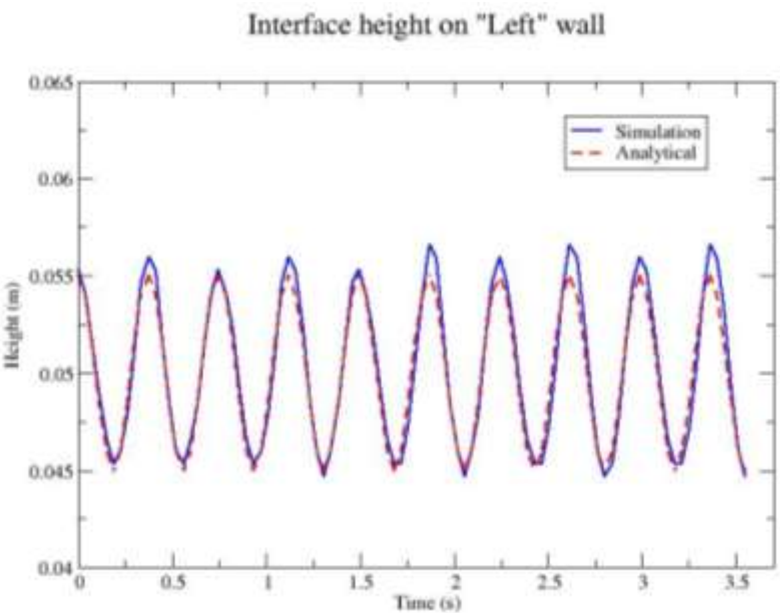
$$\frac{\partial \alpha}{\partial t} + \frac{\partial u_j \alpha}{\partial x_j} = 0$$

Properties like density and viscosity are calculated based on the linear dependence over the phase indicator function:

$$\Phi = \alpha \cdot \Phi_2 + (1 - \alpha) \cdot \Phi_1$$

Model Validation
2D-Tank: Analytical vs. Simulation





Validation of the interface tracking method:

2D Fixed Tank

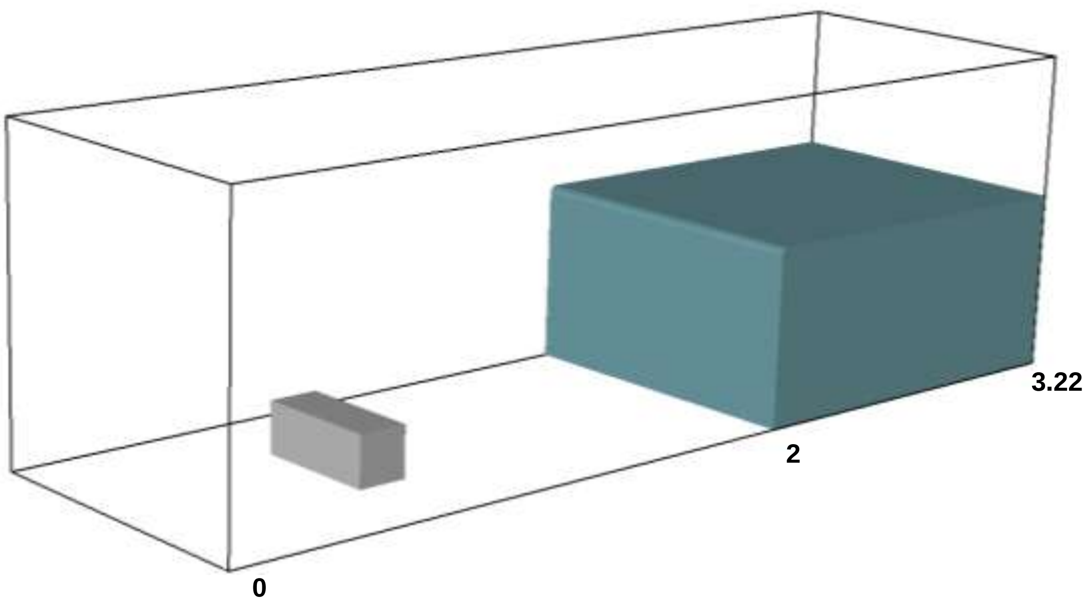
- Water (red) and Air (blue)
- Initial condition: Cosine wave with small amplitude super imposed on interface.
- Sloshing solely under the influence of gravity.
- Comparison of the height of the interface on the left wall :

  analytical vs. simulation.

Model Validation

Dam break with an obstruction (1/4)

Validation of pressure/forces originating from the fluid-structure interaction



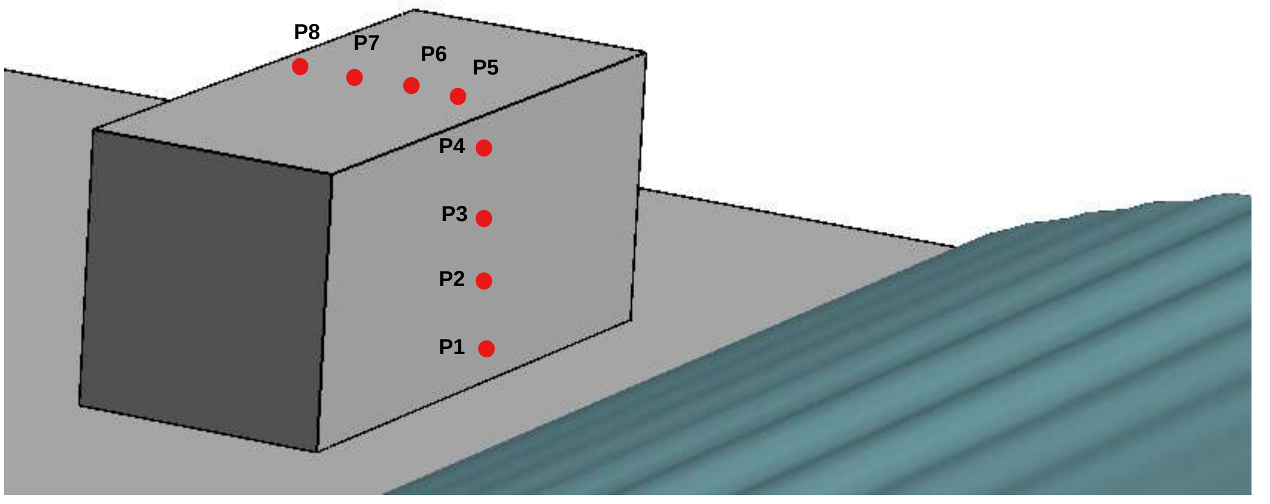
Dam break with a scaled model of a container (obstruction)

- 3d domain with dimensions: (3.22 m x 1 m x 1 m)
- Open roof
- Water column: 2 m to 3.22 m, height: 0.55 m
- Container is a box: 16 cm x 40 cm x 16 cm

Comparison against the experiments at the Maritime Research Institute Netherlands (MARIN)[1]

1 http://www.math.rug.nl/~veldman/comflo/dambreak.html

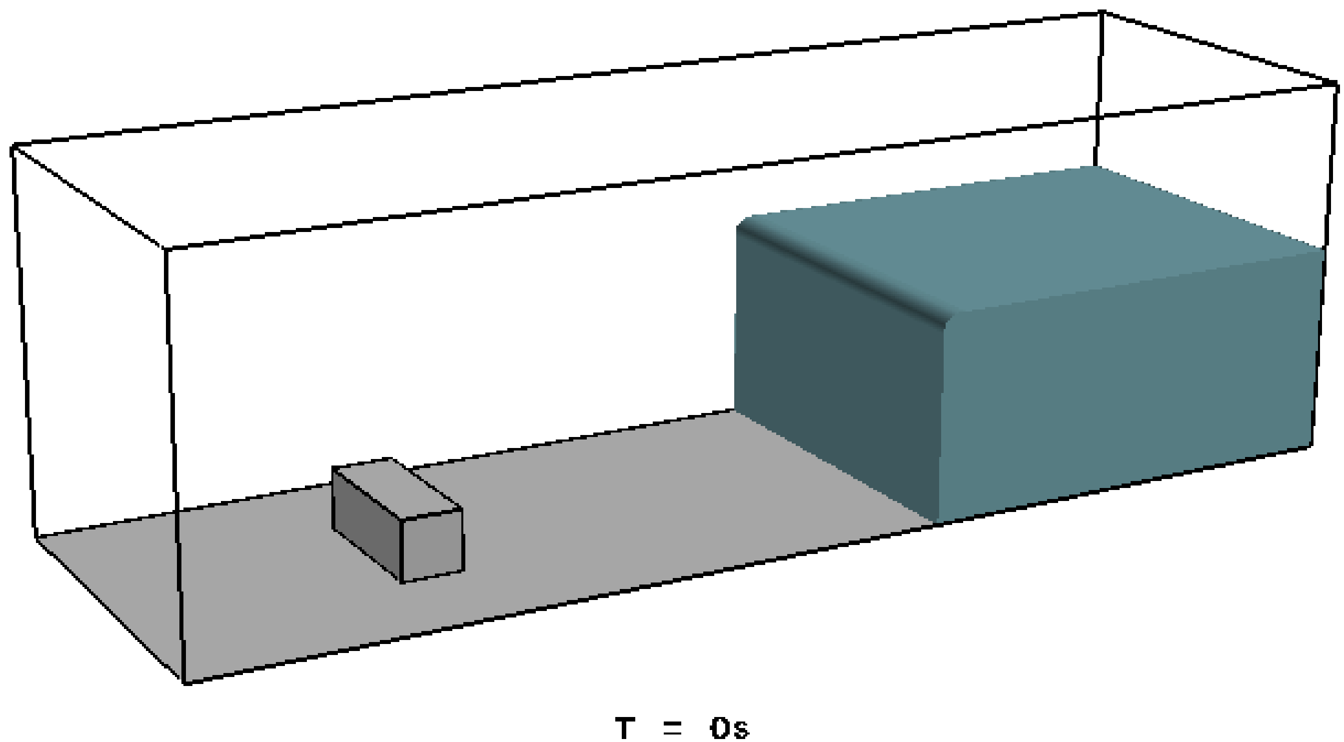
Model Validation
Dam break with an obstruction (2/4)



- OpenFOAM with VOF for tracking interface
- Computational mesh: 1.2 million hexahedral cells
- Up to 6 seconds of real time simulation
- Computational time: 9 hours
- 8 Pressure probes for comparison against experiments.

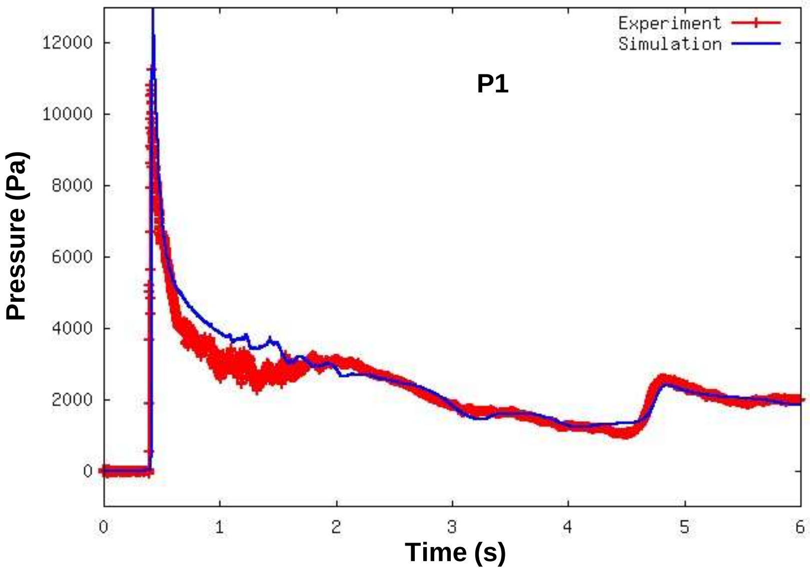
Model Validation

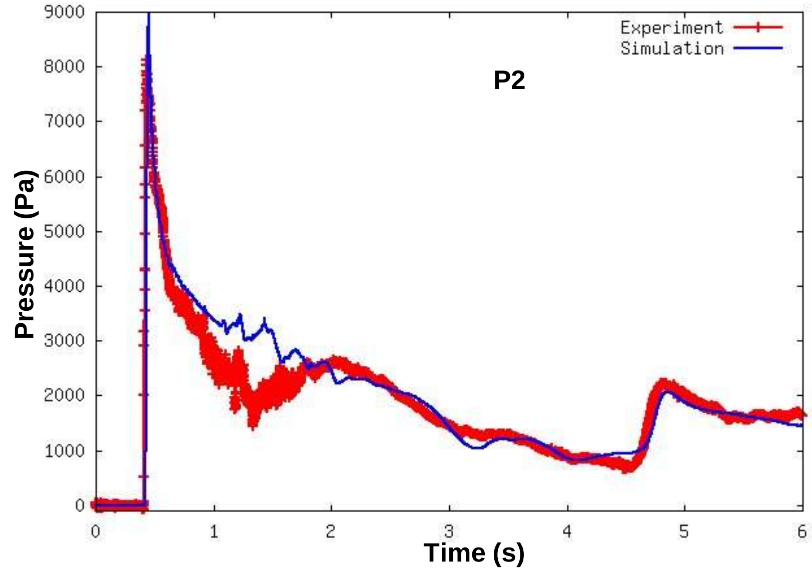
Dam break with an obstruction (3/4)

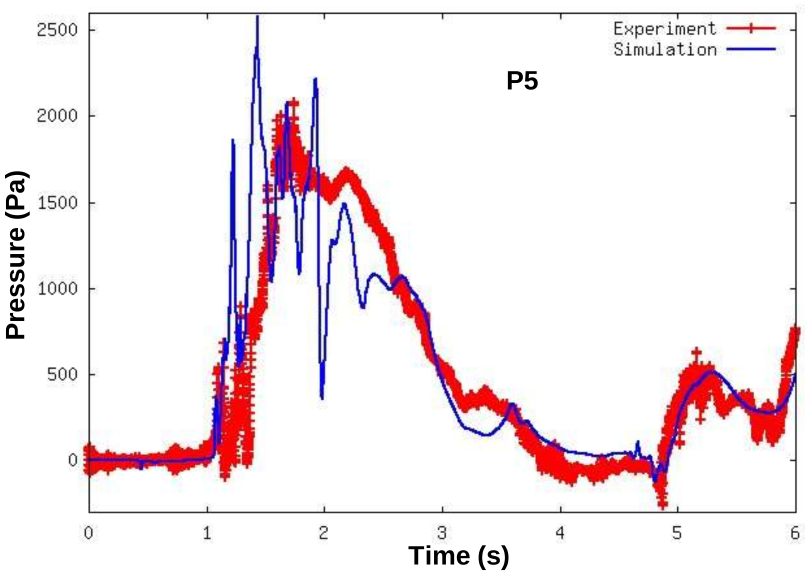


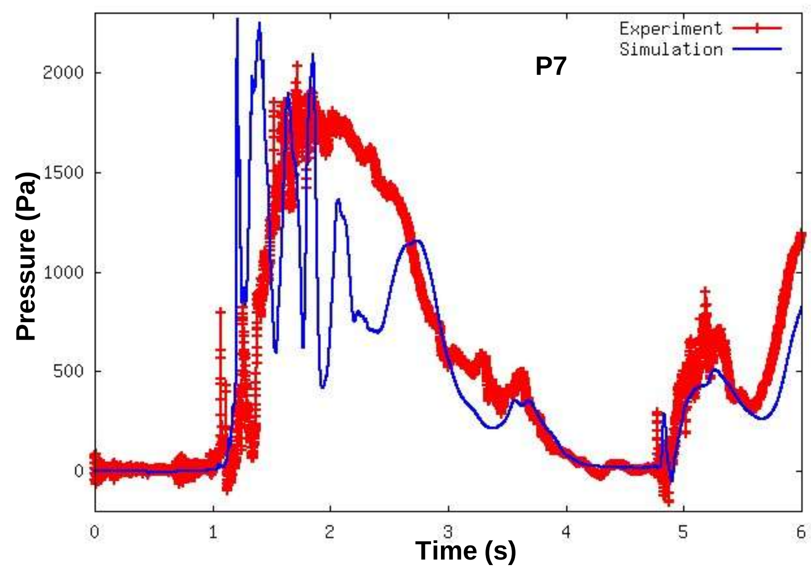
Model Validation

Dam break with an obstruction (4/4)



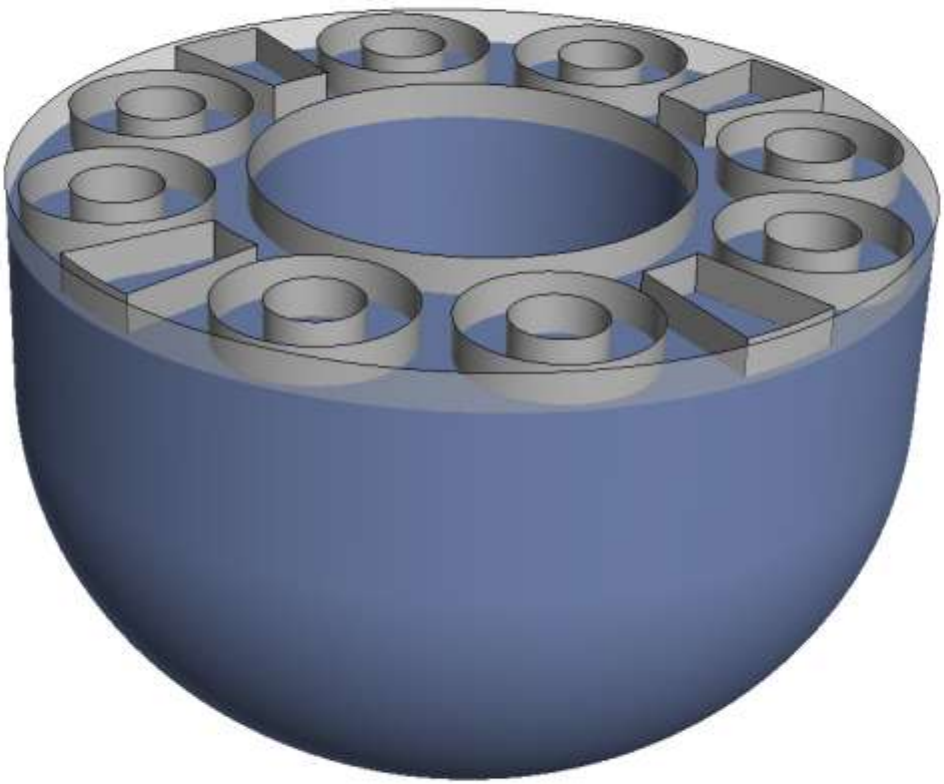






ELSY Vessel

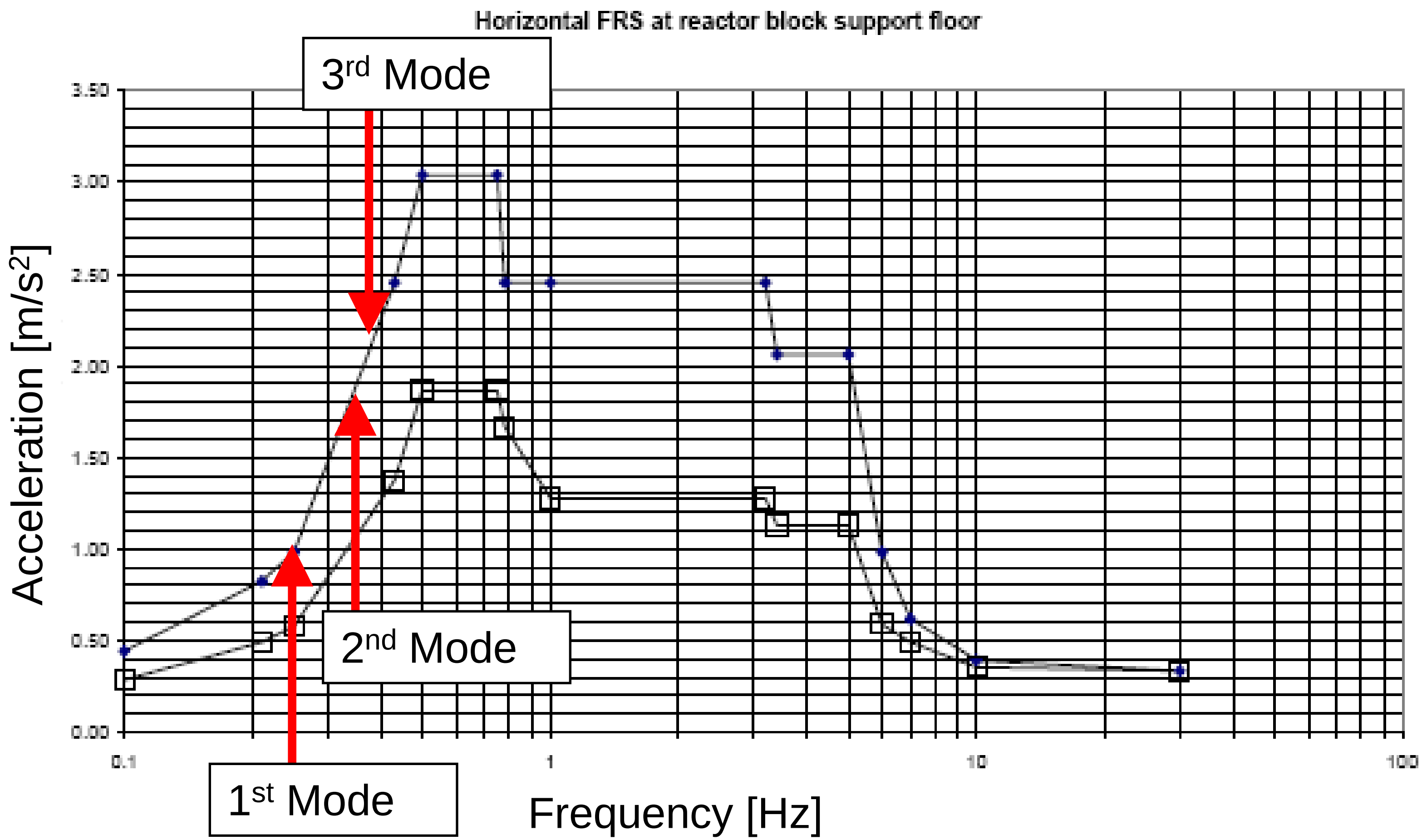
Geometrical Model



- Lead free surface
  - Properties of lead at a core outlet temperature of 480 ˚C
- ELSY vessel top closed
- Wall boundaries.

Horizontal Seismic Response Spectrum

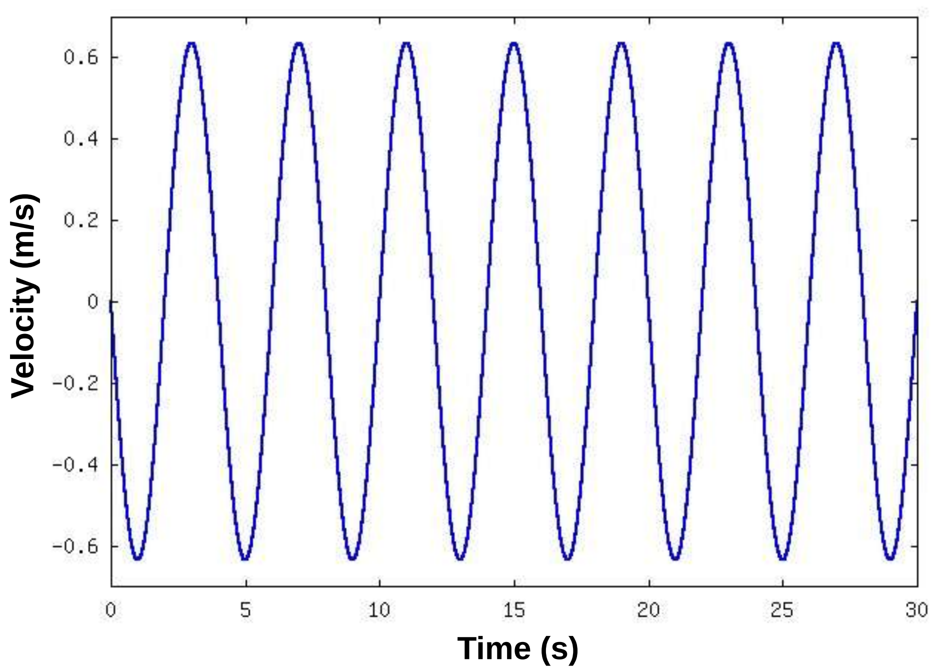
From preliminary Natural frequency analysis (using FEM) first 3 natural modes are determined



Results

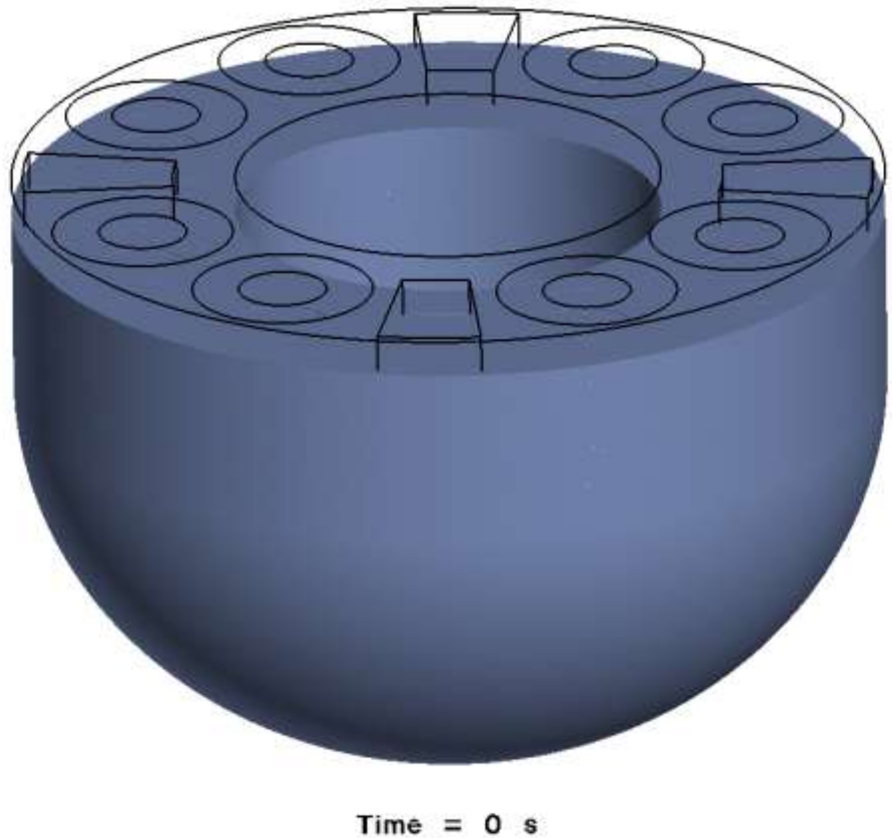
Case: 1st Mode

- From horizontal seismic response 1st mode corresponds to:
  - Acceleration: 1 m/s^2
  - Frequency: 0.25 Hz
- Using Simple Harmonic Motion equations: velocity field for the ELSY vessel is determined.



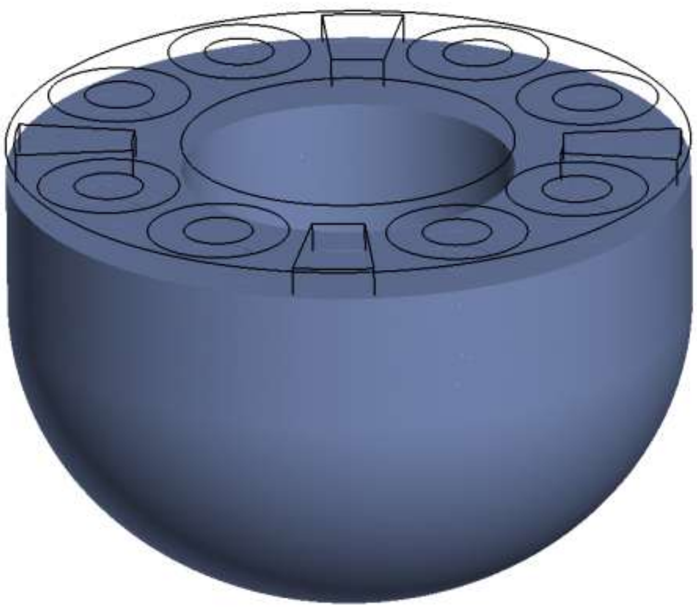
Results

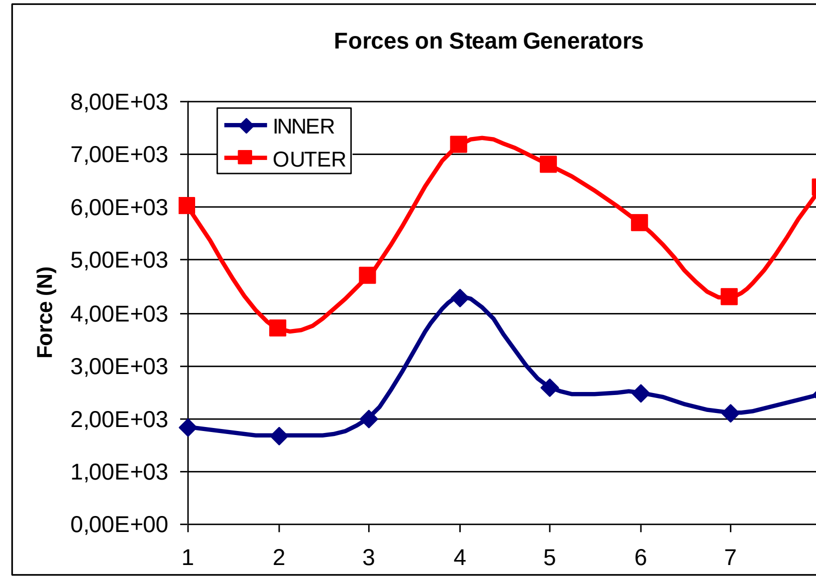
Case: 1st Mode

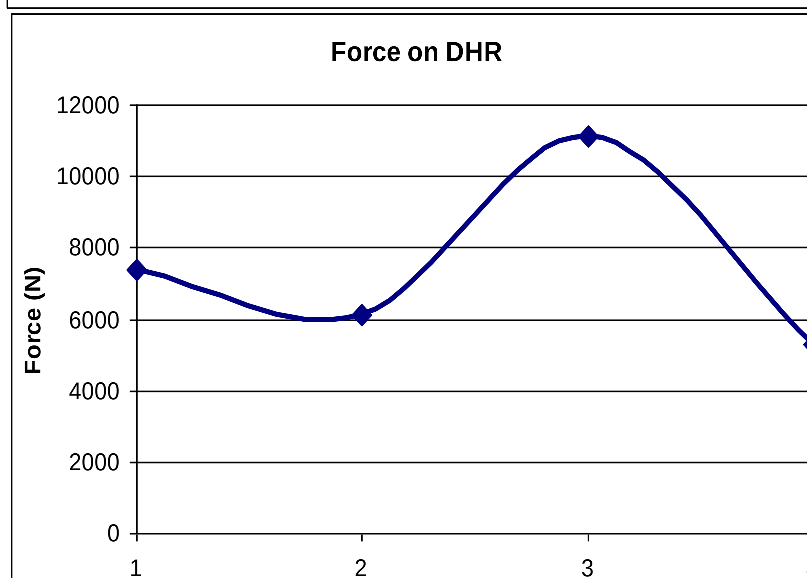


Results

Case: 1st Mode - Forces on ELSY internals







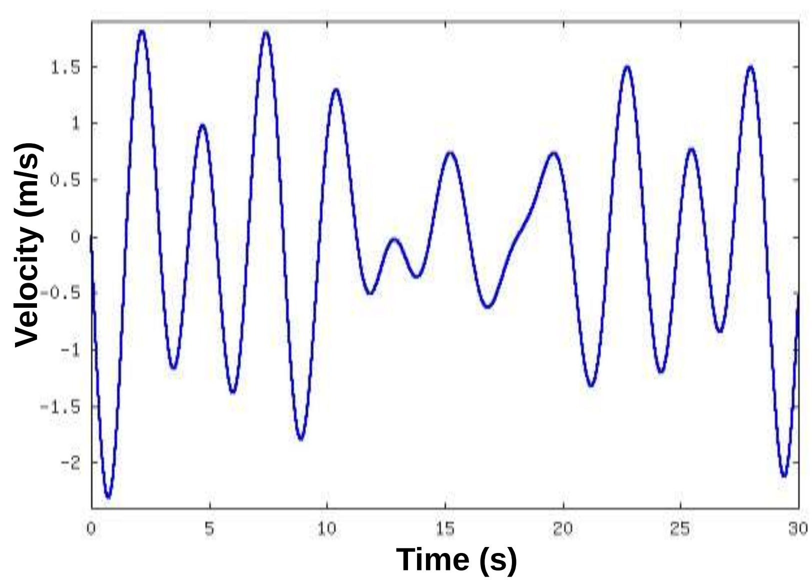
Summary & Future work

- CFD is used to study the effects of Lead sloshing in the ELSY vessel
  - OpenFOAM solver with VOF method to track the free surface of Lead.
  - Coupled solid body motion (rigid).
- The CFD approach is validated using:
  - 2d tank: demonstrating the accuracy of the interface tracking method.
  - 3d dam break with an obstruction: validate the pressure/forces calculated due to the fluid-structure interaction.
- ELSY vessel filled with Lead is subjected to a simple harmonic motion: 1st Mode natural frequency
  - Sloshing is not symmetric.
  - Sloshing effects are mainly observed in the ELSY internals (steam generators and the decay heat removal systems).
  - The average force loads on the internals for the first 10 seconds of the simulation is determined.

Future work

- Combination of 3 modes
- Detailed natural frequency analysis using FEM will provide the essential natural modes.

Modes	Acceleration (m/s^2)	Frequency (Hz)
1	1	0.25
2	1.85	0.35
3	2.15	0.38



“Thanks for your attention”