Non-linear modelling of pipe whip phenomenon induced by fluid transients with a coupled 2D/3D approach

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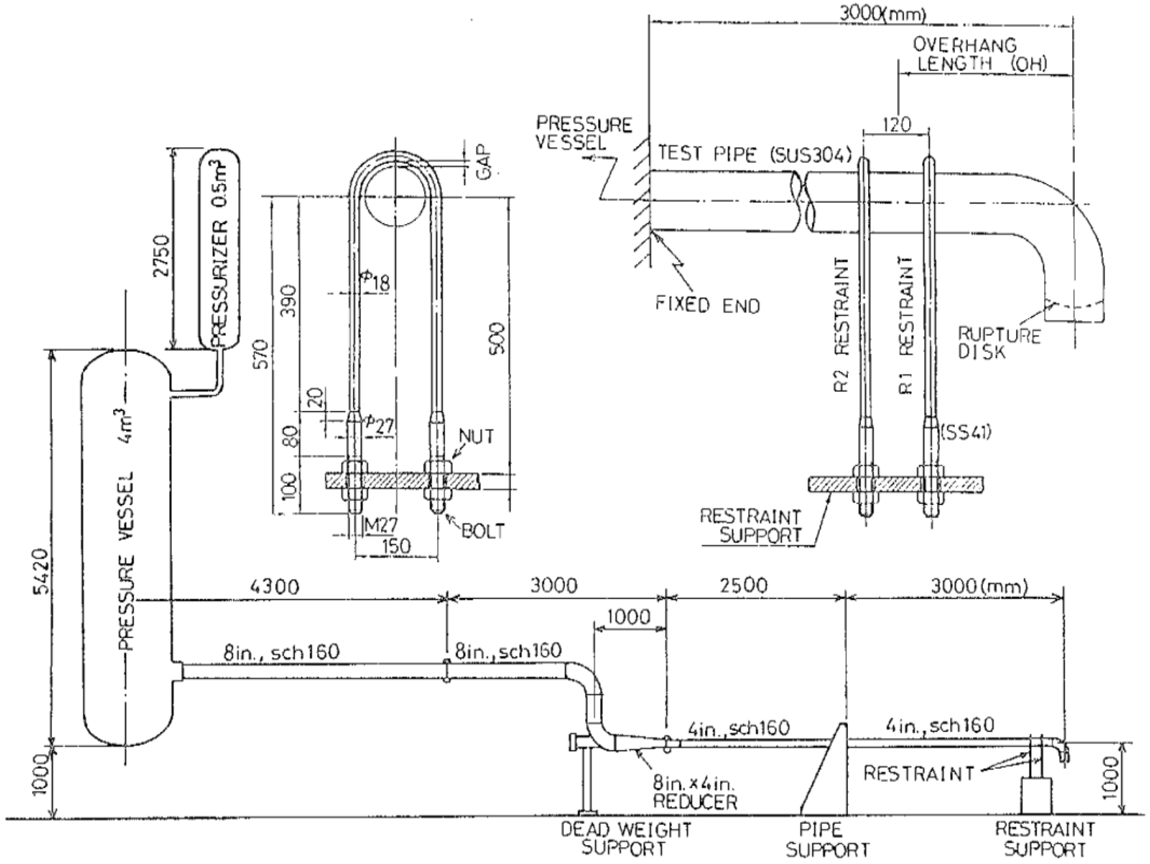
Outline

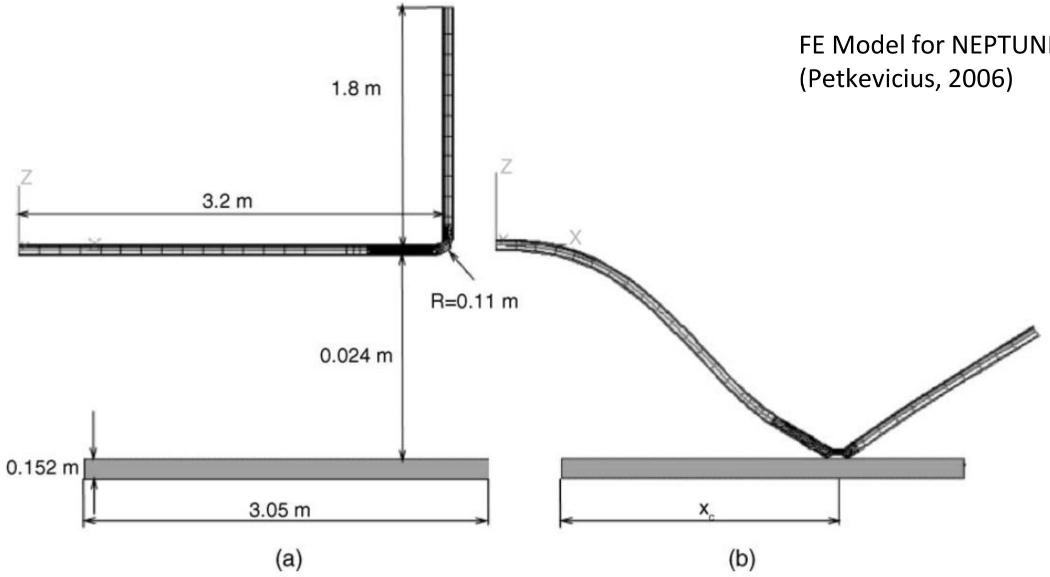
Research Background

1. Fracture / Membrane break → sudden spike in operating pressure in NPP pipes
2. Causes water hammer effect → induces pipe whip phenomenon
3. Pipe Whip → Dynamic behaviour → Fatal impacts on pipes and surroundings
4. French Commissariat a l'Energie Atomique (CEA) → Pipe whip experiments
5. Numerical modelling attempts → 2D / 3D / 1D modelling approaches
6. Finite Volume Method (FVM) & Finite Element Method (FEM) coupled
7. Mesh generation time and No. of elements is a major

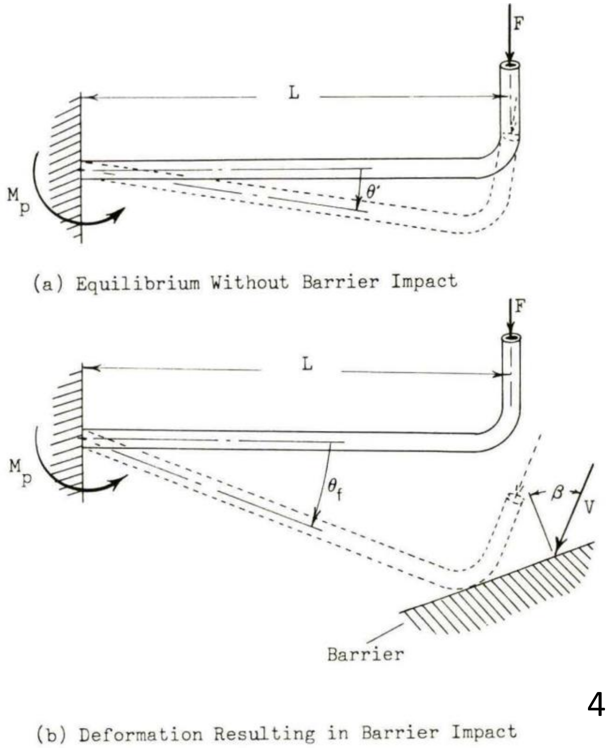
Computational Pipe Whip Models



Test Model for ADINA
(Miyazaki, 1984)

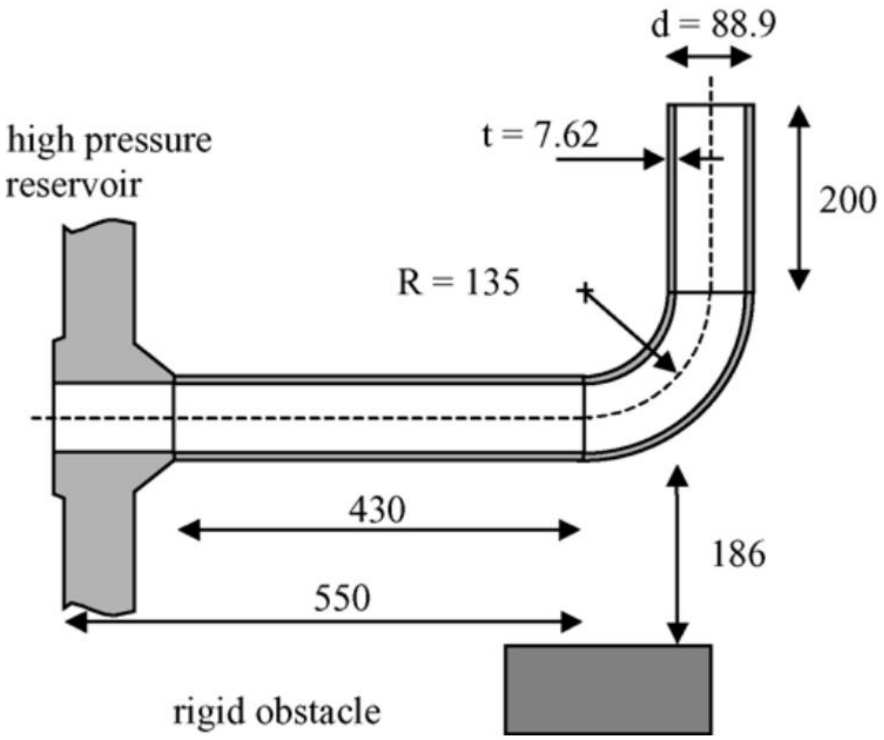


FE Model for NEPTUNE code
(Petkevicius, 2006)

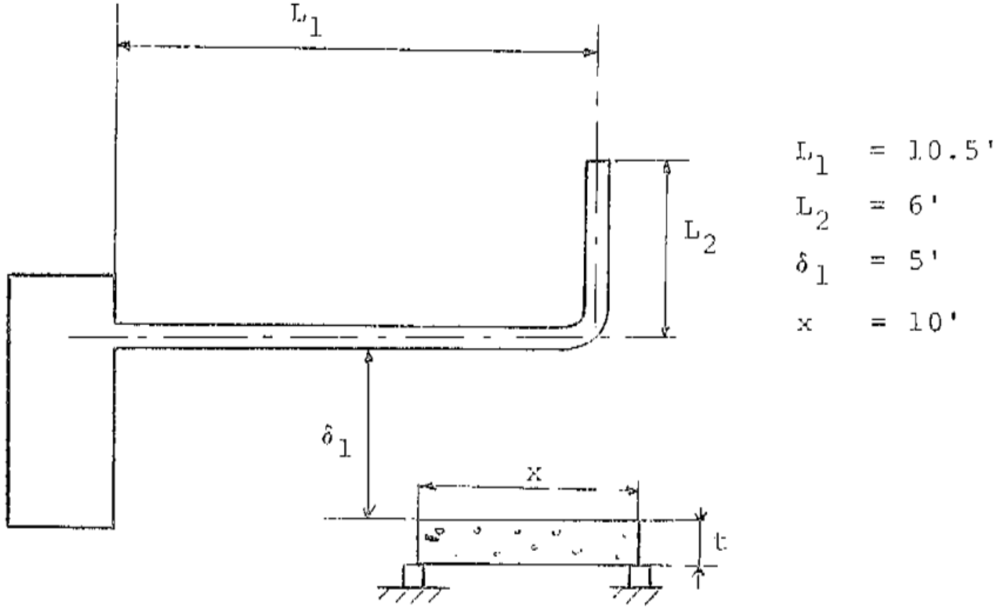


Pipe on barrier model
(Roemer, 1980)

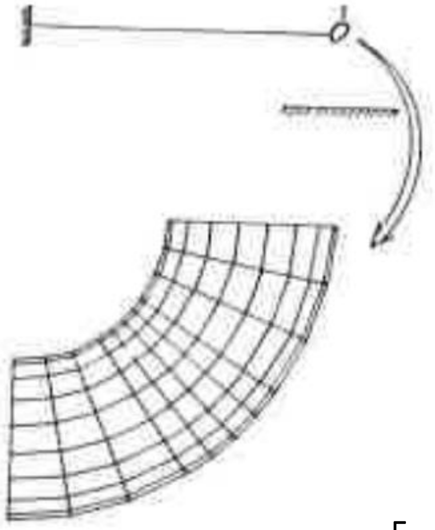
CEA Experiment Pipe Models



Aquitaine – Europlexus model
(Potapov, 2005)

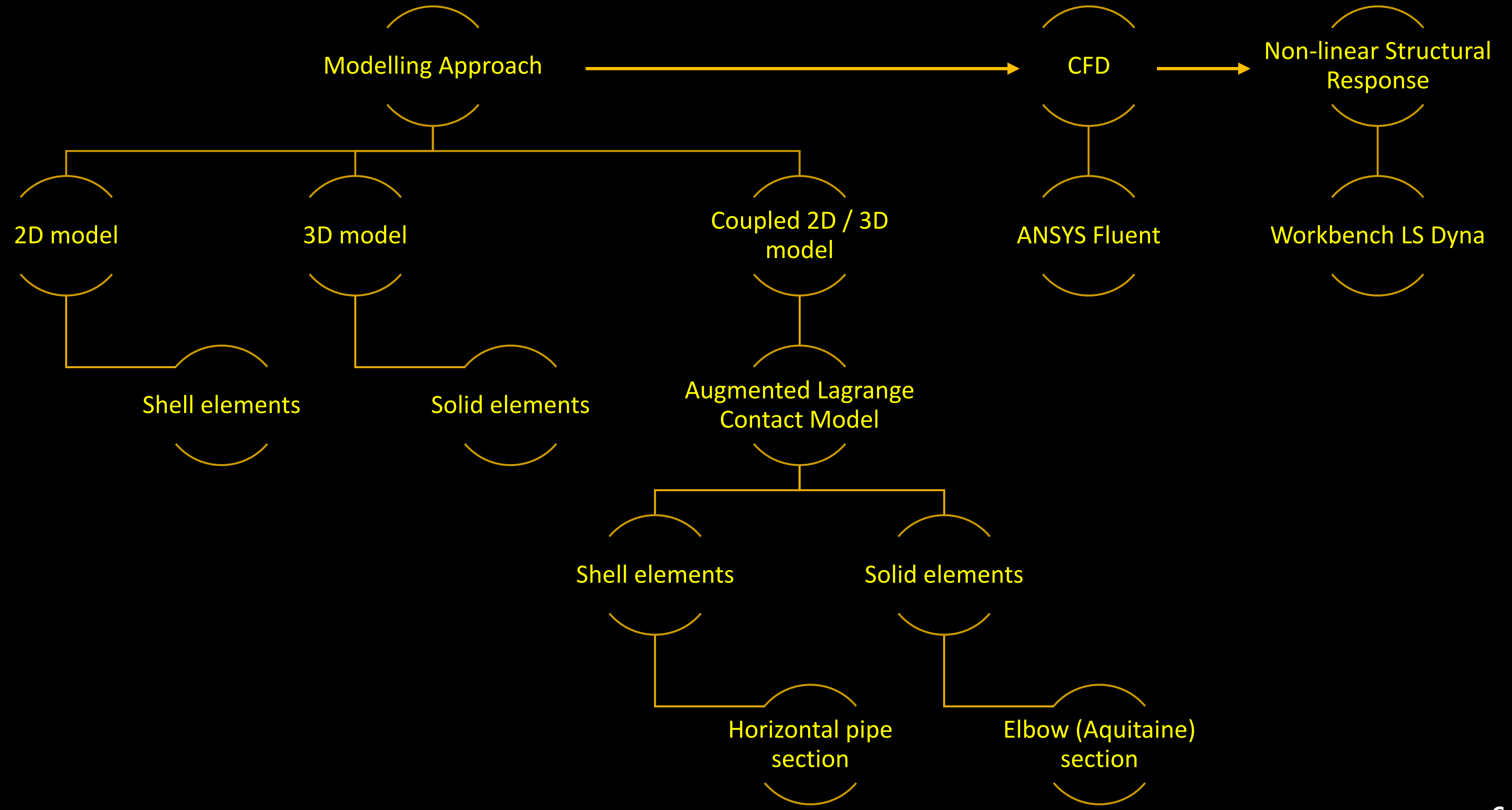


Typical pipe whip experiment schematic
(Garcia, 1987)

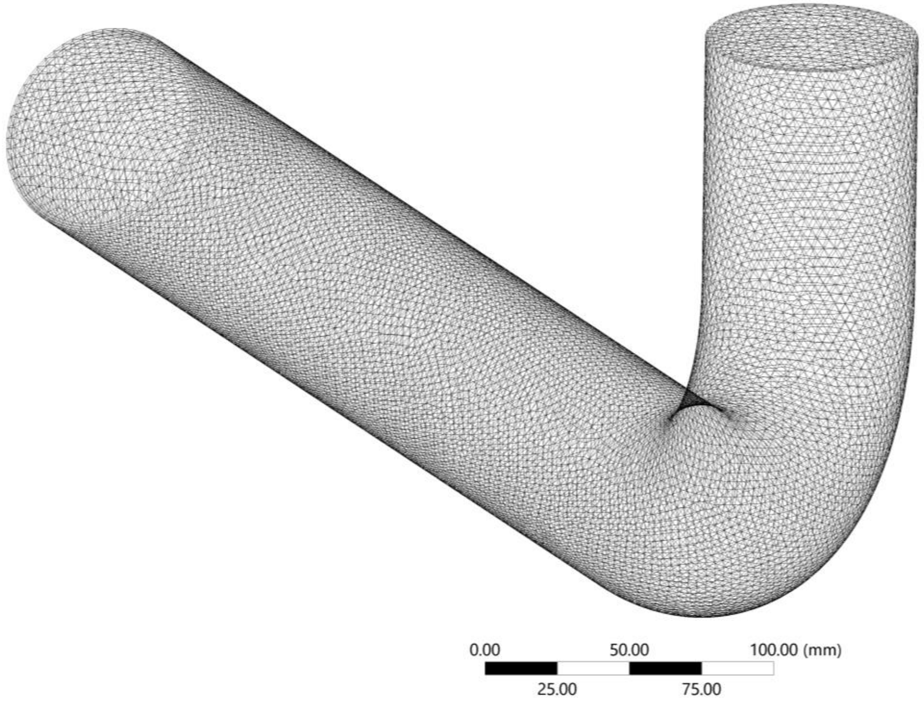


FEA Framatome model – Abaqus Epgen
(Hsu & Kuo, 1983)

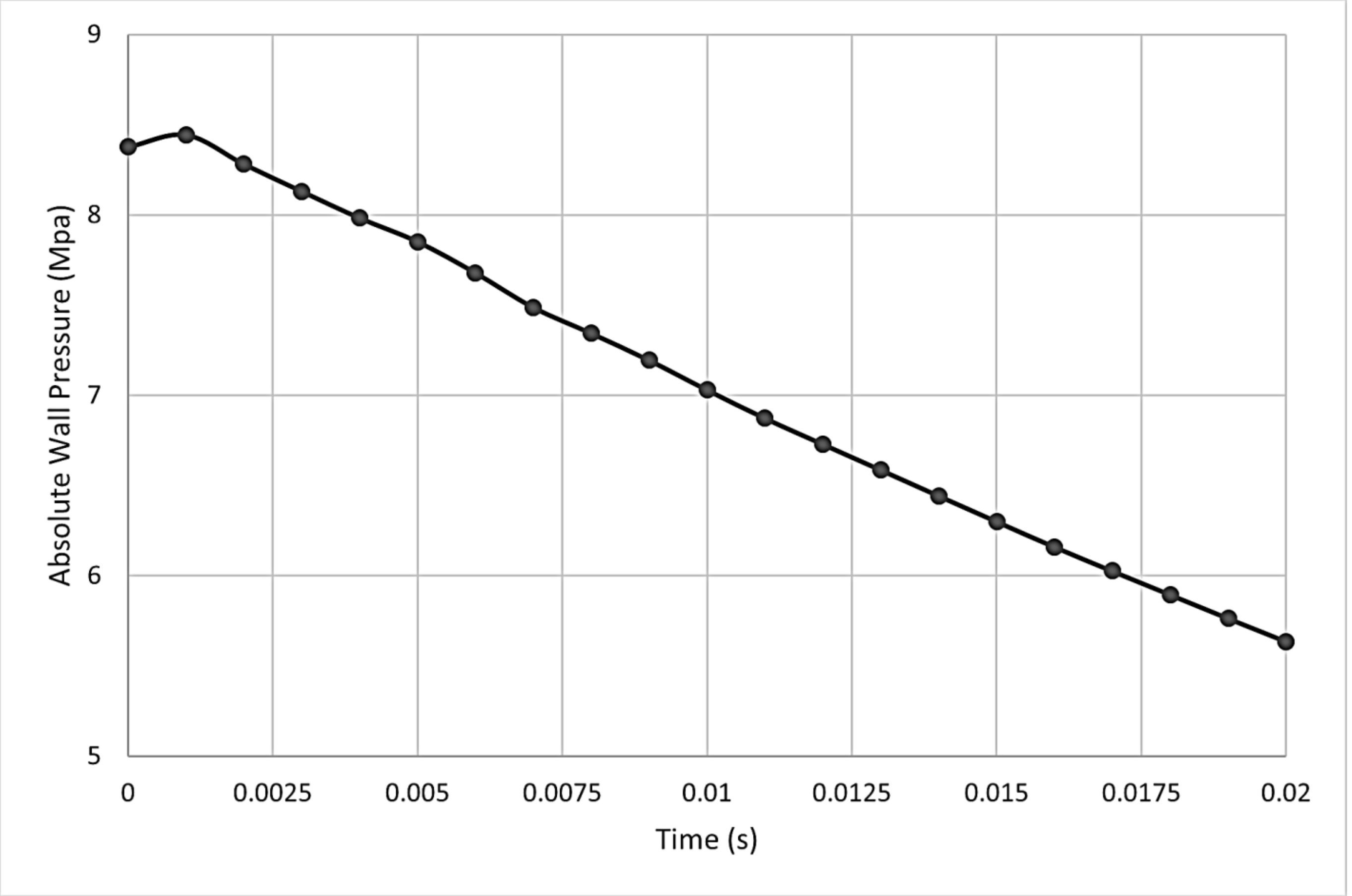
Research Approach



CFD ANSYS Fluent Simulations



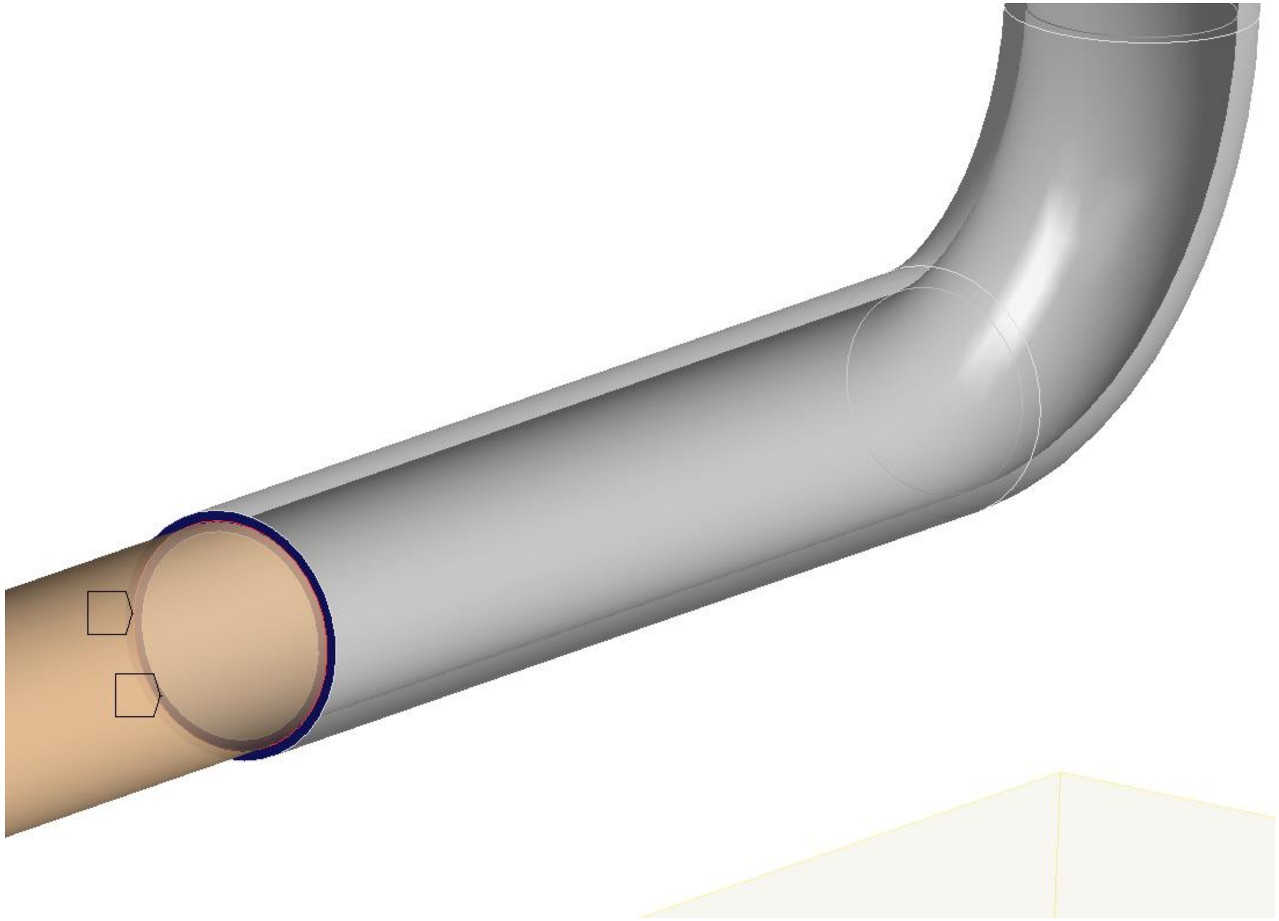
- Solid tetrahedral mesh with inflation
- Reproducing sudden membrane break
- Water as fluid medium
- Pressure of 166 bar
- Fluid flow for 20 microseconds (0.02 s)
- ∇v & ∇p are observed



Pressure response on the walls of the pipe

2D – 3D Contact

- Shell / Solid contacts not supported in ANSYS dynamic non-linear simulations
- Augmented – Lagrange Contact Formulation
- Accurate contact detection algorithm
- Minute penetration is allowed
- Less sensitive to contact stiffness coefficient
- Less convergence issues



Material properties

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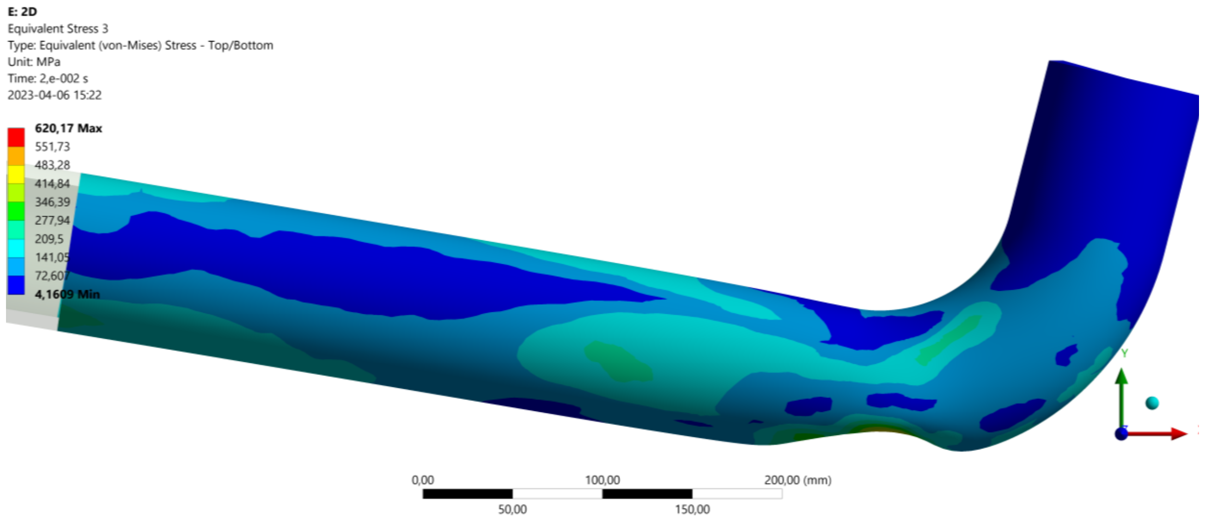
A106 Grade B carbon steel

Density (kg/m^3)	7844.2
Young's Modulus (GPa)	207
Poisson's ratio	0.3
Yield Stress (MPa)	220.6
Tensile Stress (MPa)	399.8
Plastic Modulus (MPa)	586.1

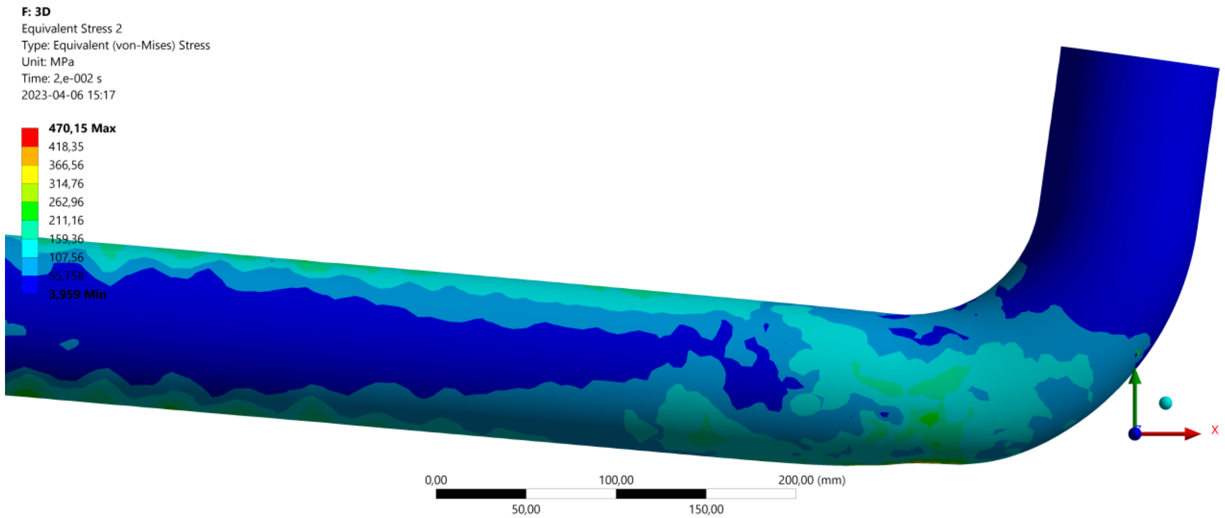
Concrete

Density (kg/m^3)	2400
Young's Modulus (GPa)	27
Poisson's ratio	0.2
Tensile Stress (MPa)	1.5
Compressive Strength (Mpa)	17

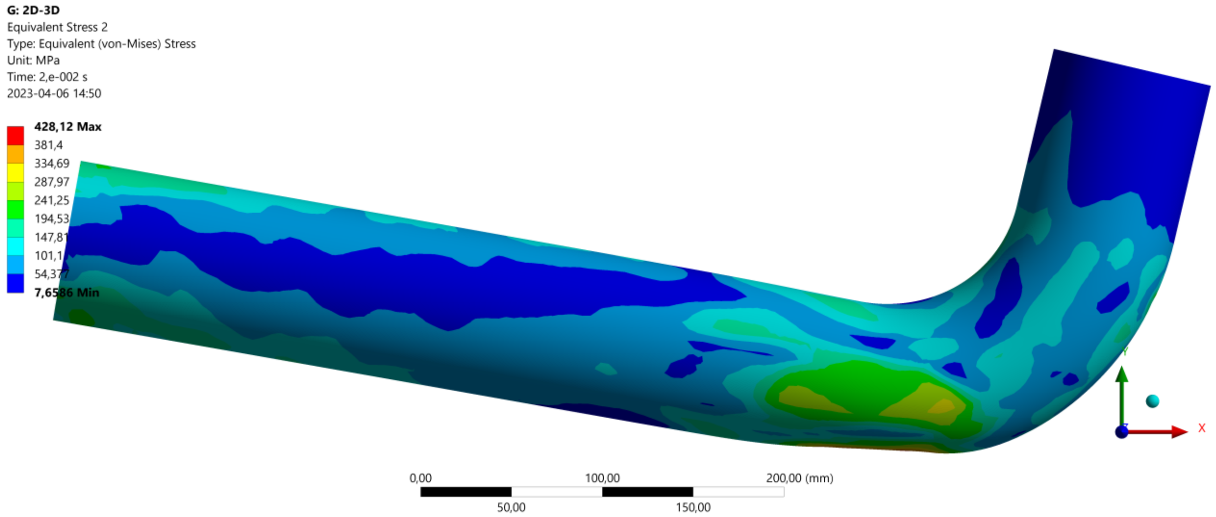
Structural Modelling Response from CFD Simulations



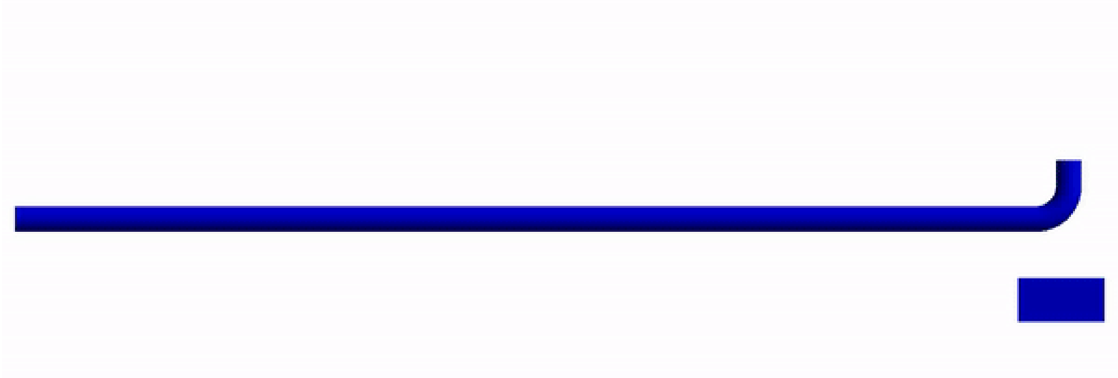
Stress distribution of the 2D model



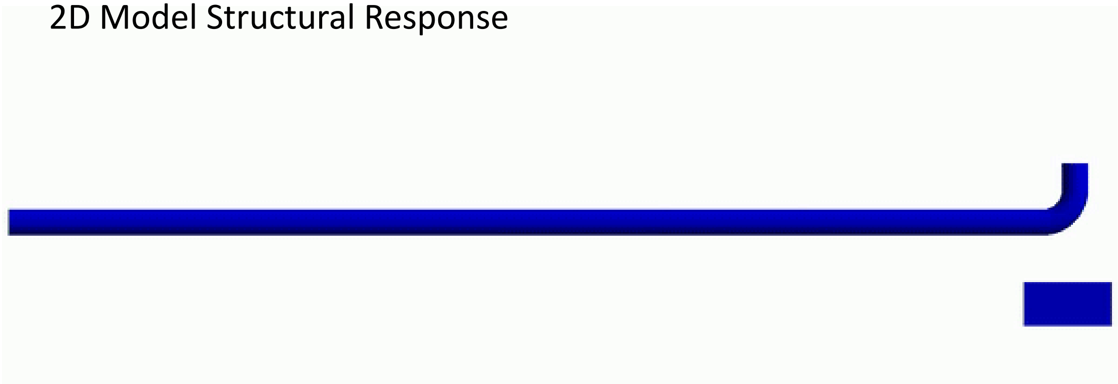
Stress distribution of the 3D model

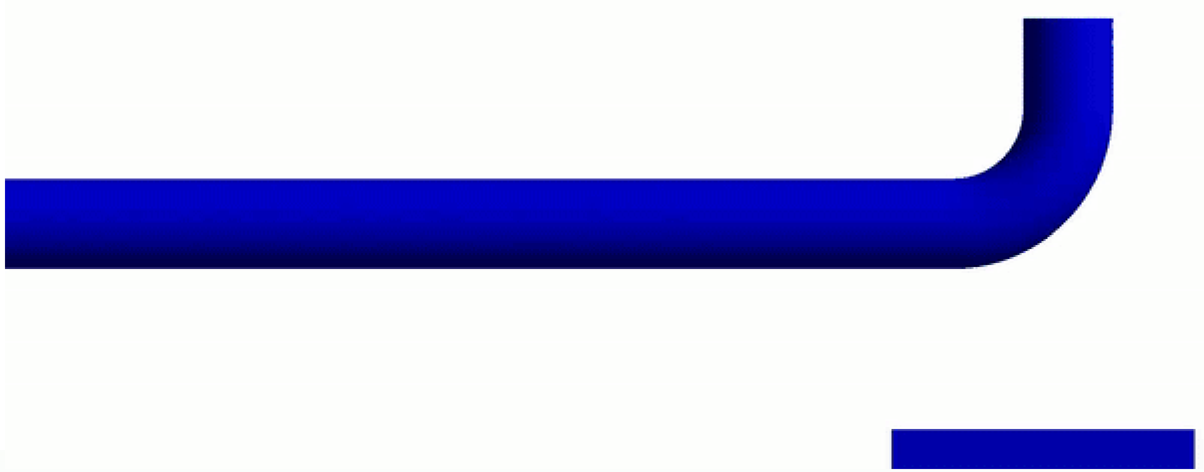


Stress distribution of the Coupled 2D / 3D model



2D Model Structural Response

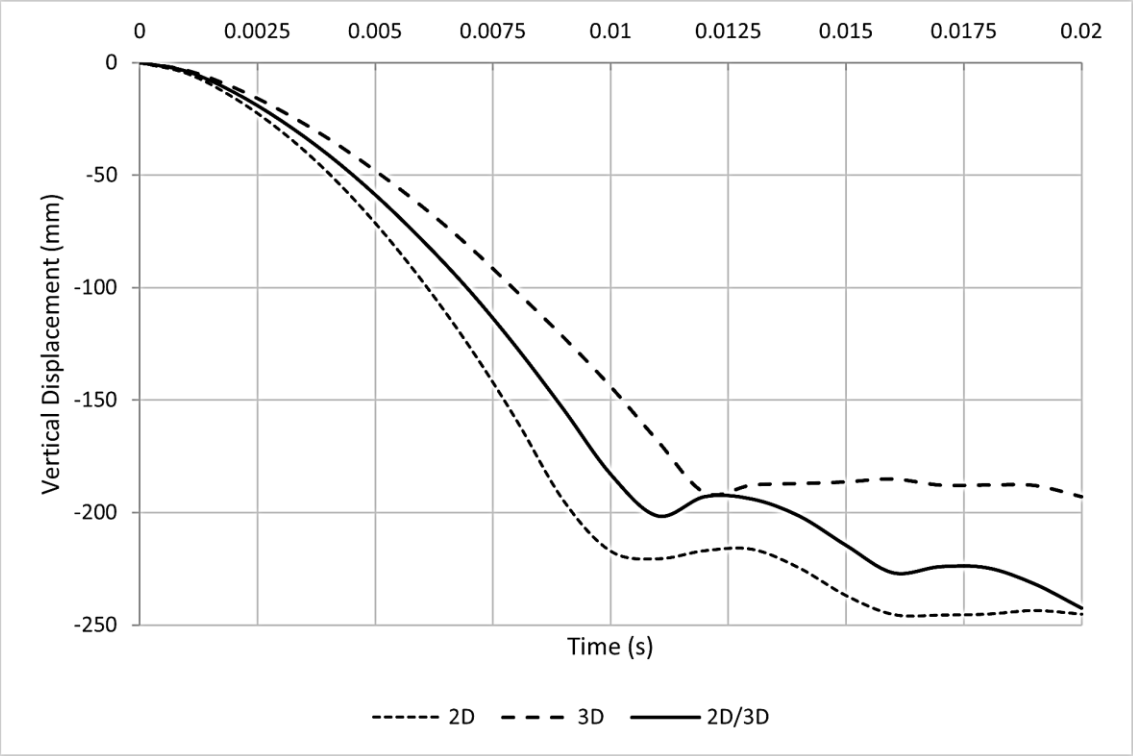


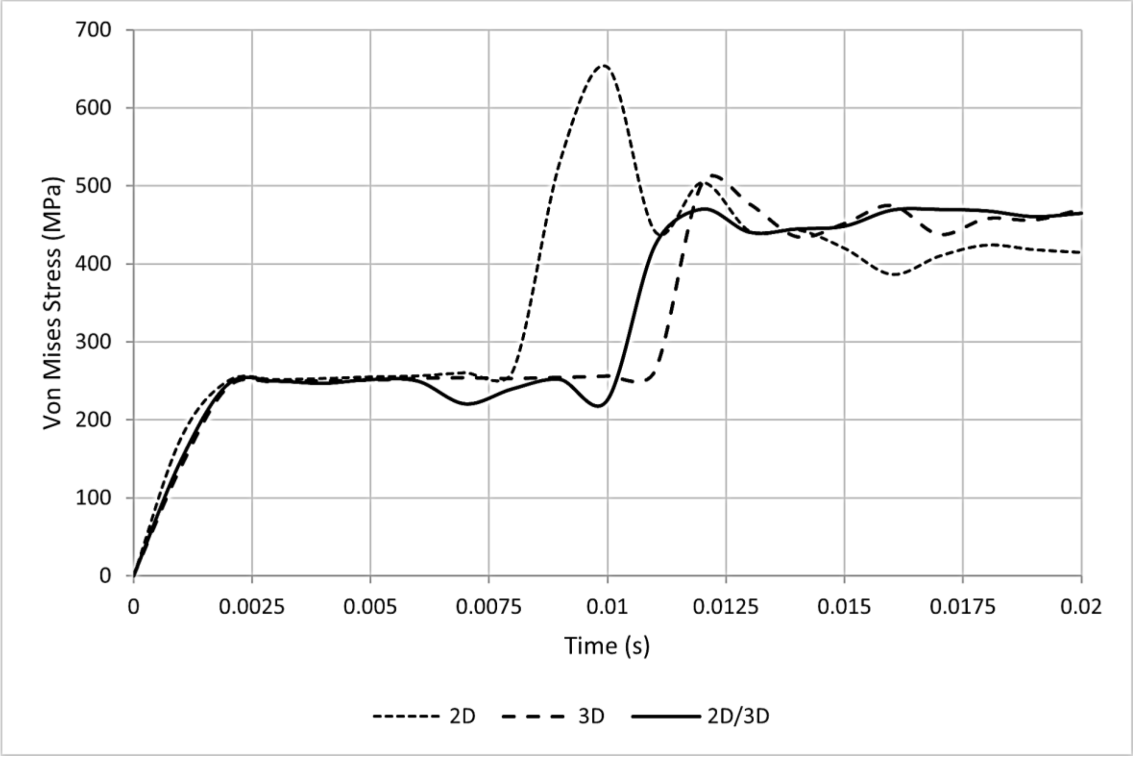


3D Model Structural Response

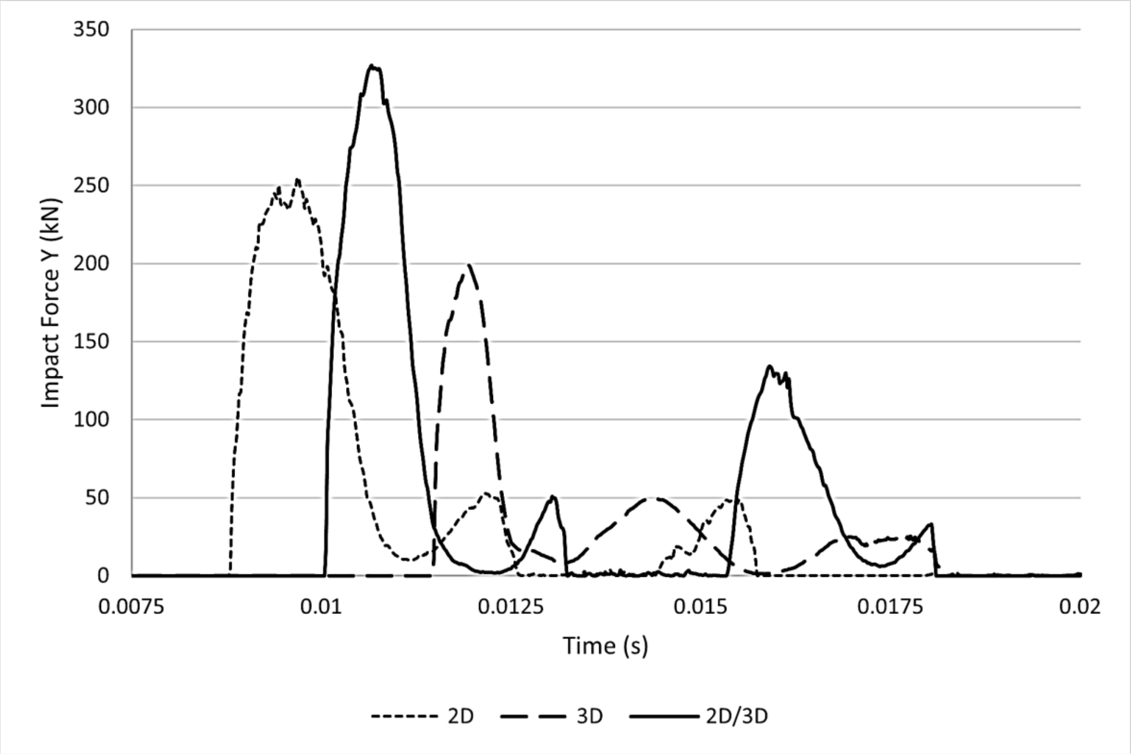
Coupled 2D – 3D Model Structural Response

Displacement & Stress distribution





Dynamic Impact Parameters



Model Type	Impact Time (ms)	Impact Force (kN)`
2D	9.4	250.39
3D	11.8	200.25
Coupled 2D/3D	10.7	324.74
Experiment	10.1	385

Coupled 2D/3D model					
Calculated Impact Time (ms) Tc	Experimental Impact Time (ms) Te	Calculated Impact Force (kN) Fc	Experimental Impact Force (kN) Fe	$\frac{Te - Tc}{Te}$ (%)	$\frac{Fe - Fc}{Fe}$ (%)
10.7	10.1	324.74	385	5.94	15.58

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Conclusions

1. A non-linear numerical approach for a coupled 2D/3D model is proposed for modelling fluid pipelines with fluid structure interaction due to incompressible flows.
2. Three types of FSI models (2D, 3D and coupled 2D/3D) were simulated in Workbench LS Dyna for the incompressible flow inside the pipe medium
3. CFD → Instantaneous membrane break; Structural → Pressure load based on pipe wall response for 166 bar inlet pressure .
4. The resultant pipe whipping phenomenon based on material non-linearity were validated with the experimental results.
5. The proposed 2D/3D coupled model show promising convergence for the numerical results validated with the experimental results with minimal deviation percentage.
6. Hence the coupled 2D/3D model with the corresponding contact models can be utilized for determining material non-linearity for workbench LS Dyna simulations for impact study.

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