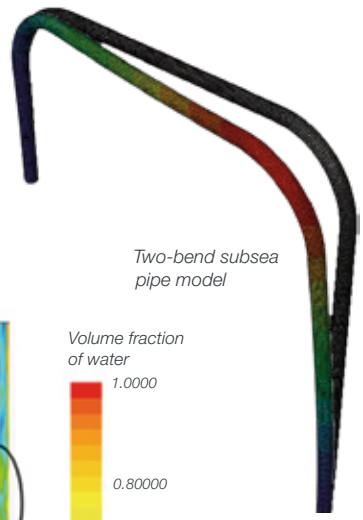
Co-simulation of Two-phase Flow in an M-shaped Subsea Piping Component



Components in a subsea production system require different types of pipelines, such as a jumper (a short U-shaped section of pipe to connect one pipeline to another), to transport fluids. The internal flow in pipes involves an interaction between fluid and structure, which is important to understand since their interaction can generate high amplitude vibrations, also known as "flow-induced vibration." Consequently, these vibrations can result in fatigue damage of the structure. This phenomenon has become a great concern in the oil & gas industry where subsea jumpers are exposed to this type of vibration when transporting production fluid. The industry is currently putting a lot of effort into investigating vibration-induced fatigue cases to prevent negative effects on revenue, production, environmental safety and health.

Production fluid flowing through subsea components is usually a mixture of oil, gas, and water. When a gas and liquid flow through a pipe, a potential slug flow is formed, and consequently this generates vibration issues in the structure. A slug is an intermittent flow in which long gas bubbles are separated by chunks of liquid causing large pressure fluctuations and corrosion. The amplitude of the vibrations increases and creates a potential risk of failure of the pipe when the natural frequency of the structure is close to the frequency of the slugs as they are transported along the pipeline.

To assess the impact of this type of flow in the structure, Leonardo Chica, a researcher at the College of Technology, University of Houston, conducted an analysis of the fluctuation of stress with time to predict the number of cycles that the jumper can withstand without failure. The best option to represent this fluid-structure interaction problem is to perform a two-way coupling simulation or co-simulation between Abaqus and a computational fluid dynamics (CFD) program, such as CD-adapco's STAR-CCM+. In this process, the pressure fluctuations are exported from the CFD tool into Abaqus, and then Abaqus computes the stresses and displacements. These displacements are exported back to the CFD program and the cycle starts again. Both programs run simultaneously and exchange data at each time step.

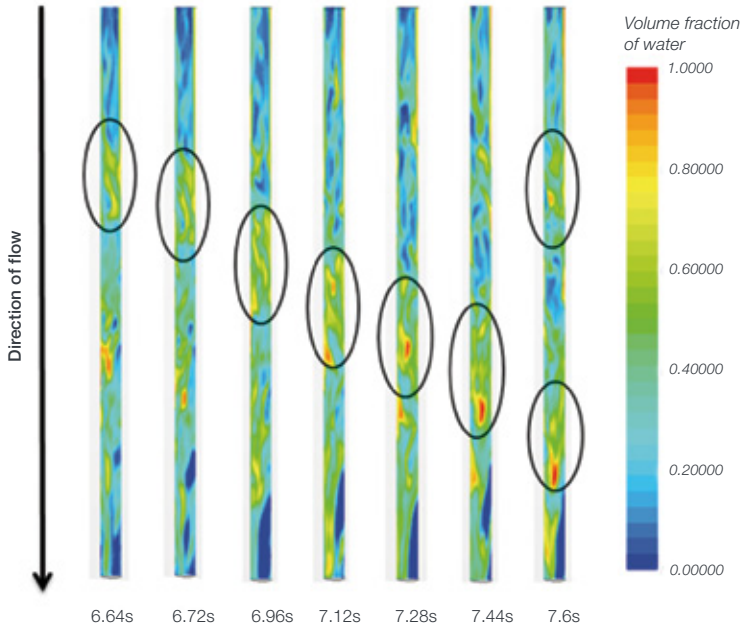


Figure 1. Slug travelling in vertical section of two-bend model.

To set up the analysis, we imported the CAD model and then extracted the natural frequencies in Abaqus. Next, the simulation was set up in the CFD program with the appropriate mesh and physics, and the co-simulation was initiated to communicate the CFD code to Abaqus. After initializing the solution with 50% air and 50% water, the results showed that irregular slugs are developed at the vertical section of a two-bend model. Slug frequency was determined to be 1.0417 Hz (see Figure 1), which is close to the fundamental natural frequency (1.079 Hz), so amplitude of the vibrations could be intensified and the fatigue life of the jumper might be reduced. In this case, the co-simulation results of the von Mises stress vs. time graph obtained in Abaqus show a sinusoidal pattern with a response frequency of 0.167 Hz. Based on the material's S-N curve, fatigue life is infinite (below the fatigue limit curve), due to the small stress range, and the two-bend structure can withstand cyclic loading from the pressure fluctuations of the two-phase flow.

In this initial investigation, only water-air mixture was simulated to understand the behavior of this two-phase flow and to determine the response in the jumper.

For future work, oil-gas-water flow will be simulated and analyzed to compare with experimental results. The Fluid-Structure Interaction (FSI) analysis should also be extended to include the entire jumper model in order to draw solid conclusions about fatigue damage.

This type of FSI co-simulation is becoming more valuable in subsea engineering to understand how the internal or external flow affects the fatigue life of subsea components. The Abaqus co-simulation capability for FSI allows the user to perform a co-simulation between Abaqus and third party software, such as STAR-CCM+. One of the advanced features of Abaqus is to perform either a one-way coupling or two-way coupling simulation depending on the magnitude of the displacements. This selection would be made on a case-by-case basis to achieve a balance between computational cost and accuracy of the results. Either way, co-simulation for FSI is rapidly becoming a requirement in the subsea industry to provide greater reliability, safety, and performance in complex subsea systems.

For More Information

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