Reduced-order modelling of sloshing dynamics for a floating liquid-hydrogen terminal

Master's thesis proposal at the Marine Offshore Renewable Energy Lab, Politecnico di Torino

Recommended profile:
Mathematical Engineering, Mechatronic Engineering, Mechanical Engineering

Topics involved:
Reduced-order modelling, grey-box modelling, system identification, data-driven modelling, surrogate models, sloshing dynamics, offshore floating structures, hydrodynamics, CFD data analysis, OrcaFlex modelling and mooring-system design

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A curricular internship can also be associated with the thesis.

Proposal description

Background and motivation

Floating offshore platforms are increasingly being considered for the storage, processing and transfer of energy carriers (such as hydrogen) and other fluids. The design of these systems requires an accurate representation of the coupled interaction between the floating structure, environmental loads, internal fluid dynamics and the stationkeeping system.

When partially filled tanks are installed on a floating structure, the platform motions induced by waves, wind and current can generate *sloshing*, namely the oscillatory motion of the liquid inside the tank. Sloshing may produce time-dependent forces and moments on the tank walls, as well as it can enhance heat and mass transfer within the tank, promoting liquid-hydrogen vaporisation and boil-off, with consequent economic losses due to the reduction of the stored liquid inventory. These effects can modify the global dynamic response of thefloating structure, influence its stability and affect the loads transmitted to the mooring system.

The relevance of sloshing depends on several parameters, including the tank geometry, liquid filling level, excitation frequency, motion amplitude and combination of translational and rotational motions. Particularly significant responses may occur when the excitation frequencies approach the natural frequencies of the internal liquid motion. Consequently, neglecting or excessively simplifying these effects may lead to an inaccurate estimation of platform motions and mooring-line loads.

High-fidelity Computational Fluid Dynamics (CFD) simulations can provide a detailed description of the free-surface evolution and of the resulting hydrodynamic loads. However, their computational cost generally prevents their direct integration into long-duration time-domain simulations and design procedures, in which a large number of operating conditions and system configurations must be evaluated.

Reduced-order models (ROMs) provide a possible solution to this limitation. Starting from a database of high-fidelity simulations, a ROM can reproduce the dominant dynamic relationship between the imposed tank motions and the corresponding sloshing-induced loads and dynamics, while requiring substantially lower computational effort.

The development of a computationally efficient and sufficiently accurate ROM would make it possible to include internal liquid dynamics within global models of floating terminal structures. The resulting coupled model could then be used to assess the influence of sloshing on platform motions, stability and mooring-system loads, as well as to support the design of the overall offshore system.

Research aim

The main objective of the thesis is to develop and validate a ROM capable of reproducing the dominant sloshing dynamics occurring inside liquid-hydrogen storage tanks. The ROM is intended to provide a computationally efficient representation of the relationship between the motions imposed on the tank and the resulting sloshing-induced loads and dynamics. In this way, the main effects of the internal fluid dynamics can be evaluated without directly performing computationally expensive high-fidelity CFD simulations for every operating condition.

The model will be identified from an available database of high-fidelity simulations and assessed over different excitation conditions, motion combinations and liquid filling levels. Particular attention will be devoted to the dataset analysis and preprocessing, the ROM prediction accuracy, computational efficiency and definition of the model validity range.

As a final verification activity, the possibility of integrating the developed ROM into the dynamic model of a floating terminal will be investigated. A numerical interface with OrcaFlex will be implemented and tested to verify that the platform motions can be supplied as inputs to the ROM and that the corresponding sloshing-induced loads can be returned to the global dynamic model. This activity will demonstrate the suitability of the ROM for future coupled vessel-tank-mooring analyses and design applications.

Proposed methodology, activities and expected outcomes

The thesis activity will be organised according to the following main steps:

1. **Analysis and preprocessing of the high-fidelity simulation dataset.**
   Expected outcomes: the analysis, preprocessing and documentation of a structured database derived from the available high-fidelity CFD simulations.

2. **Dynamic characterisation of the sloshing response.**
   Expected outcomes: a dynamic characterisation of the main sloshing phenomena and their dependence on excitation conditions, motion combinations and liquid filling level.

3. **Development and comparison of candidate ROMs.**
   Expected outcomes: the investigation and comparison of different reduced-order modelling approaches for predicting sloshing-induced loads and dynamics.

4. **ROM identification and validation.**
   Expected outcomes: a validated ROM capable of reproducing the dominant sloshing dynamics with significantly lower computational cost than the corresponding high-fidelity CFD simulations.

5. **Definition of the model validity domain.**
   Expected outcomes: the definition of the ROM range of applicability and the quantification of its prediction accuracy under different operating conditions.

6. **Assessment of computational efficiency.**
   Expected outcomes: an assessment of the trade-off between model complexity, prediction accuracy and computational efficiency.

7. **Preliminary integration test with the floating-terminal model.**
   Expected outcomes: a preliminary numerical interface for testing the integration of the ROM into the dynamic model of a floating terminal