Coupled Seakeeping Analysis and Sloshing Load for LNG and FPSO Vessels

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ABSTRACT

In this paper, two methods are studied for determination of the sloshing load in tanks of LNG and FPSO vessels. The first method is based on potential theory; and the second one is a hybrid method with linear potential model solution of ship motion and nonlinear CFD tank flow simulation. A special treatment with adoption of an artificial damping is proposed in the potential method to improve the accuracy of the cases close to natural frequencies of the tank flow. A simplified approach for quick estimation of tank flow natural frequency is also discussed. Results of both methods are compared with the experimental data, and feasibility and accuracy of the two methods are discussed.

KEY WORDS: sloshing load; coupled ship motion; linear potential method; nonlinear CFD model; artificial damping; tank flow natural frequency.

INTRODUCTION

Accurate prediction of the load due to sloshing of the liquid in a partially filled tank is important for the structural analysis in design of LNG and FPSO vessels. Significant sloshing load can be observed near the natural frequencies of the liquid flow in the tank, and it may cause structural damage. In most design practices by now, this sloshing load is still estimated using the empirical formula based on experimental observation. A CFD model is generally required to simulate the violent strong non-linear flow in the tank. However, the required computation is very costly and not practical, considering that the liquid motion in the tank needs to be solved together with the ship motion, since they are fully coupled with each other. Instead, the linear velocity potential model is usually applied in the analysis of this coupled seakeeping problem. In this paper, we study two methods for determination of the sloshing load. In the first method, linear velocity potential theory is applied for both the inner tank flow problem and the outer ship wave making problem. The radiation potential of the tank flow will be solved first, and the hydrodynamic forces on the tank due to the ship motion of unit amplitude for each degree of freedom will be computed. The coupled ship motion amplitude is solved with the radiation hydrodynamics on ship hull and tank boundary, and the diffraction force and incident wave force on the ship hull. Finally the sloshing load on tank wall will be estimated using the results of the coupled ship motion. In the second method, the coupled ship motion and the sloshing tank flow are solved separately. We assume that the nonlinearity of sloshing flow in the tank has less effect on the coupled ship motion; the linear velocity potential theory can be used for both inner and outer problem to determine the coupled ship motion. A three-dimensional CFD model is then applied to simulate the sloshing flow in a moving tank driven by the coupled ship motions. Prediction of the coupled ship motion with acceptable accuracy is fundamentally important in both methods. The linear potential model has been found quite accurate on the coupled ship motion for most of the frequency cases except those around the natural frequencies of the tank flow. The reason of the inaccurate response prediction around the natural frequency is that the assumption of small flow disturbance used in potential theory is not valid any more for simulating the resonant inner tank flow. To improve the motion prediction, we introduced an artificial damping on the liquid surface in the tank and a simplified algorithm was used to automatically identify the natural frequencies of tank flow along two horizontal directions. The radiation forces of the tank flow are decreased by the artificial damping, and the coupled ship motion prediction is improved significantly. The three-dimensional CFD model was constructed using the OpenFOAM CFD library. Two different models, one with coarse mesh and one with finer mesh, were tested by the CFD method for the sloshing load computation. Sloshing load results obtained by both velocity potential method and CFD method are compared with the experimental data. Feasibility and accuracy of the two methods are discussed.

POTENTIAL FLOW APPROACH

For applying the velocity potential theory to the sloshing problem, we assume the effects of the nonlinearity of the sloshing flow in tank can be ignored; the fluid domain consists of the water out of ship hull, \( \Omega \), and the liquid body bounded by the tank wall, \( \Omega^T \). The unsteady velocity potential, \( \Phi \), can be expressed in term of