STUDY ON SLOSHING COUPLED MOTION OF A FLNG SECTION IN WAVES USING WHOLE-FLOW-FIELD CFD METHOD

QI LI, YUAN ZHUANG, DECHENG WAN*

Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, State Key Laboratory of Ocean Engineering, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai 200240, China

**Corresponding author: dcwan@sjtu.edu.cn*

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INTRODUCTION

To reduce the cost of long distance transport of ocean resources, ship-like structures FPSO and FLNG with liquid tanks are designed, and they are widely used in ocean engineering field. For those with partially liquid filled tanks, ship motion in waves will affect the liquid sloshing in tanks, and the sloshing will influence the ship motion and stability in return. Besides, the violent flow in tanks may create high impact pressure on bulkhead. Therefore, the coupling effect is important for ship and tank structure design. The study on sloshing coupled ship motion have been conducted by many researchers for several decades. However, the further research is required as it is still a complex phenomenon with the effect of strong non-linear characteristic.

With the help of HPC, CFD method is used to simulate sloshing coupled effects, and it soon became popular. Different from the potential-CFD combined method, this paper illustrates a whole-flow-field simulation method to solve sloshing coupled problems of a FLNG section with two liquid tanks. The internal tank sloshing and external wave flow field can be solved simultaneously using this method. Based on our in-house solver naoe-FOAM-SJTU[1] which was developed on top of the open source platform OpenFOAM, the sloshing coupled FLNG motion in waves can be effectively simulated. The validation work was done to verify the accuracy and the capability of the solver by comparing numerical results with experimental results. VOF method is used to capture the free surface of the whole flow field and waves2foam toolbox is selected to generate and absorb waves. The moment on the internal tank and the external hull induced by sloshing flow and waves can be computed respectively in this solver, and the differences of the moment phases can be obtained. Moreover, the influence of several wave frequencies and wave heights are investigated. Better than potential method, violent flow sloshing and large amplitude motion can also be simulated and shown using CFD.

NUMERICAL METHOD

The viscous flow in this paper is investigated by solving the incompressible Navier-Stocks equations. Based on dynamic deformation mesh technology, the equations are as follows.

$$\nabla \cdot U = 0 \tag{1}$$

$$\frac{\partial \rho U}{\partial t} + \nabla(\rho(U - U_g)U) = -\nabla P_d - g \cdot x\nabla\rho + \nabla(\mu\nabla U) + f_\sigma \tag{2}$$

Sloshing is a fluid motion which has properties of high nonlinear and randomness. And these properties will make the shape of the free surface more complex. For this problem, VOF method is applied to capture the water free surface by tracking the water and air fraction in each cell. With the advantages of good mass conservation, computational efficiency, and easy implementation, this method has become one of the most popular methods [2].

Dynamic Meshes Technology

During the computation, the moving-mesh technique is needed to solve the ship motion. Dynamic meshes are used in the cases of this paper. The mesh deforms with the motion of the FLNG section. The position of mesh nodes will be solved using the Laplace's equation with variable diffusivity as following.

$$\nabla \cdot (\gamma \nabla x_g) = 0 \tag{3}$$

$$\gamma = \frac{1}{r^2} \tag{4}$$

Where x_g is the displacement of mesh node; γ is the diffusivity field, determined by r which is the distance from cell center to the moving body boundary.

Forces and Moments Calculating of Divided Patches

To investigate the relation between the moment phase difference and the coupled hull motion, the ship section is divided into two patches to get the moments from internal and external tank wall respectively. After that, the results are accumulated as a whole for the calculation of the hull motion. The calculation algorithm is shown as Figure 1.

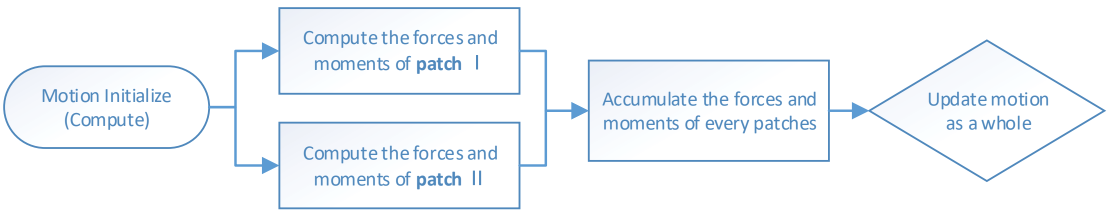

Figure 1 The algorithm of forces and moments calculating of each patch[3]

Wave Generation and Absorption

In this paper, the liquid tank will be subjected to several wave conditions. Therefore the wave generation is of vital importance. An open-source toolbox waves2foam is selected to generate and absorb waves. By modifying the velocity and phase boundary conditions, and setting the relaxation zones near the inlet and outlet boundaries, the required waves can be generated near the inlet boundary and absorbed near outlet boundary [4]. The following relaxation function and equation are applied inside the relaxation zones.

$$\alpha_R(\chi_R) = 1 - \frac{\exp(\chi_R^{3.5}) - 1}{\exp(1) - 1} \tag{5}$$

$$\phi = \alpha_R \phi_{\text{computed}} + (1 - \alpha_R)\phi_{\text{target}} \tag{6}$$

Where ϕ represent the velocity or phase value, and α_R is the relaxation function which changes along with the value of χ_R. The relation between α_R and χ_R can be seen in Figure 2.

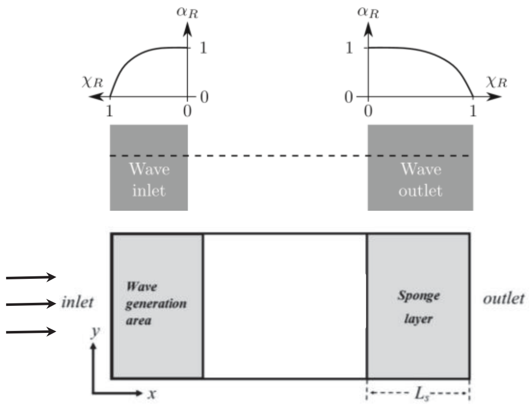

Figure 2 A variation sketch of α_R in inlet and outlet relaxation zones [4]

RESULTS AND DISCUSSIONS

Related work has been conducted by Yin and Zhuang [5][6] using whole-flow-field method to simulate a two-tank LNG ship in beam waves. Further researches are investigated in this paper. A FLNG section with two liquid tanks is made to study the sloshing coupled motion under several influence factors.

Validation of the Whole-Flow-Field Method and Solver

The naoe-FOAM-SJTU solver and the whole-flow-field method are applied and validated by the partial filling tank simulation cases under several wave excitation frequencies. The numerical results agree well with the experimental results [7], and the results are better than that of potential flow method under some wave frequencies. The comparison and the fluid flow field are shown as Figure3.

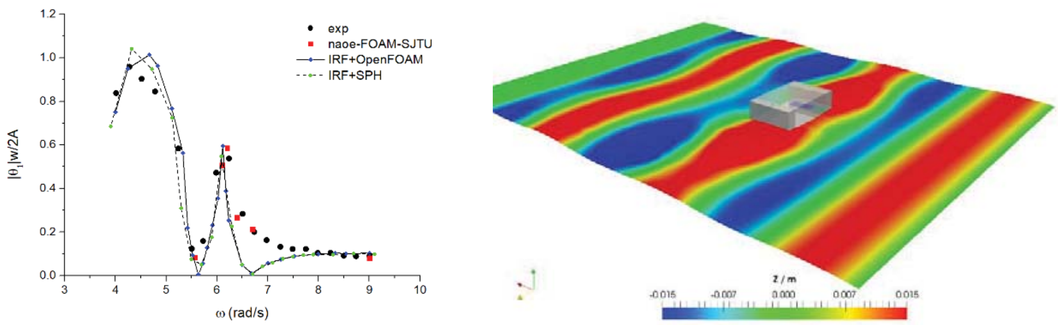

Figure 3 Results comparison and the instantaneous whole flow field

Sloshing Coupled Motion Under Different Filling Ratios

The sloshing coupled motion will be influenced by the factor of tank filling ratios. Five filling ratios are simulated in current research. Time series of tank motion, internal tank moment and external tank moment can be recorded respectively as Figure 4. The results show that the phase difference and amplitudes of sloshing coupled motion and moment can be obtained using whole-flow-field method through naoe-FOAM-SJTU solver.

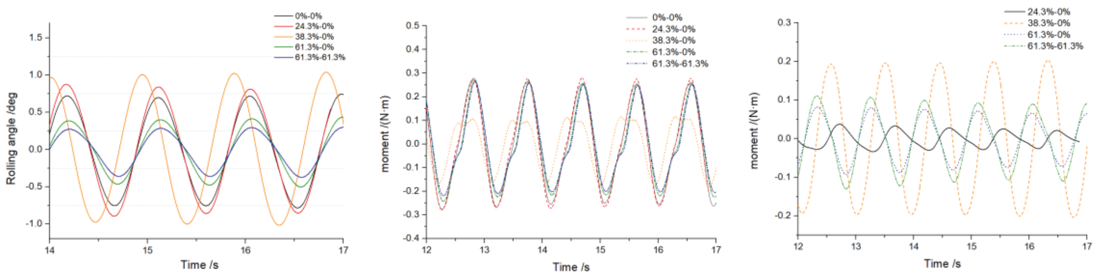

Figure 4. Time series of tank motion, external tank moment and internal tank moment

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