

Chimera RANS Simulations of Slamming and Wave Overtopping around Offshore Structures

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ABSTRACT

Greenwater damage to offshore structures results from high pressures and dynamic loads that occur when wave crests inundate the structure far above the waterline in areas not designed to withstand such pressures. In the present study, a Navier-Stokes method has been employed in conjunction with a level-set interface-capturing method for the prediction of slamming forces and green water on offshore platforms. The governing equations are formulated in curvilinear coordinate system and discretized using the finite-analytic method on a non-staggered grid. For the additional level set equations of evolution and re-initialization, we use the 3rd-order TVD (total variation diminishing) Runge-Kutta scheme for time derivative, and the 3rd-order ENO (essentially non-oscillatory) scheme for spatial derivatives. The present method was validated first for the impact pressure prediction in a sloshing LNG tank. Simulations were then performed for the slamming of a 2D half-cylinder and a 3D hemisphere to illustrate the capability of the present method to deal with complex free surface flows involving relative motions between different computational blocks. The level-set RANS method was then employed for time-domain simulations of 2D and 3D offshore platforms in a numerical wave tank. Both The wave runup and greenwater on the platform decks were successfully predicted.

KEYWORDS: Navier-Stokes equations; Level-Set Method; LNG tank sloshing; Greenwater; Slamming.

INTRODUCTION

Greenwater loads on offshore platform occur when an incoming wave significantly exceeds the free board and water runs on the deck. The primary difficulty in the simulation of the greenwater phenomena lies in the tracking of the air-water interface. Many methods have been proposed to predict the interface between two different fluids. They could be classified into two different approaches: the interface-tracking methods and the interface-capturing methods. The interface-tracking methods follow the free surface motions and use boundary-fitted grids which are re-adjusted in each time step whenever the free surface moves. In contrast, the interface-capturing methods do not define a sharp free surface boundary. The computation is performed on a fixed grid, which is extended beyond the free surface and the shape of this

free surface is determined by cells that are partially filled. A variety of numerical methods in this interface-capturing approach have been developed over the past several decades. Three of the most commonly used interface-capturing methods are Marker and Cell (MAC) method (Harlow and Welch, 1965), volume of fluid (VOF) method (Nichols et al., 1980; Hirt and Nichols, 1981) and level-set method (Osher and Sethian, 1988).

In the present study, we employ the level-set Navier-Stokes method of Chen and Yu (2006) for time-domain simulation of sloshing, slamming, and greenwater effects. The present interface-capturing method was developed based on the level set method of Osher and Sethian (1988). In the level set formulation, the level set function ϕ is typically defined as a signed distance from the interface; $\phi < 0$ in air region, $\phi > 0$ in liquid region, and $\phi = 0$ on the air-liquid interface. The value of ϕ is initialized by the physical distance from the interface. Then it is advected by the local velocity field using the advection equation

$$\frac{\partial \phi}{\partial t} + \vec{V} \cdot \nabla \phi = 0 \quad (1)$$

The interface can be identified at any time by locating the zero level set. However, the computed ϕ may not remain the signed distance from the interface after several numerical iterations. It is necessary to perform the following redistancing process for every time step:

$$\frac{\partial \phi}{\partial \tau} = \text{sign}(\phi_0) \cdot (1 - |\nabla \phi|) \quad (2)$$

This equation guarantees that ϕ has the same sign and zero level as ϕ_0 and satisfies the condition that $|\nabla \phi| = 1$. The level set method was shown to lower the difficulties in handling topological merging for violent free surface motion problems. For additional level set equations of evolution and re-initialization, we use the 3rd-order TVD (total variation diminishing) Runge-Kutta scheme for time derivative, and the 3rd-order ENO (essentially non-oscillatory) scheme for spatial derivatives.