Numerical Study of Wave-Structure Interaction with HOS-CFD Method

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ABSTRACT

In the present work, a HOS-CFD coupled method is validated with wave-structure interaction. The HOS-CFD method is applied to simulate a fixed CALM buoy in regular waves with overset grids. Firstly, a periodic wave simulation is carried out to make a better parameter choice in HOS-CFD method combined with overset grids. Secondly, the forces and scattered waves around the CALM buoy are obtained through computations. The results are compared with experimental results to validate the coupled method. The results of the numerical method are compared with other numerical methods, including CFD methods and other potential-viscous methods. It is shown that the coupled method with overset technique is reliable in predicting wave-structure interactions. At last, a Q-criterion and Liutex view of turbulence flow are considered both in overset grids and static grids, give the difference between these two mesh generations in HOS-CFD coupled method.

KEY WORDS: HOS; HOS-CFD coupled method; naoe-FOAM-SJTU solver; CALM buoy

INTRODUCTION

With the developing and exploiting marine resources into deep sea, the study of hostile environment and wave-structure interaction became essential. The floating platforms in deep sea may face freak waves which induce large movement. Traditional CFD method with dynamic mesh technique may have some weaknesses in solving this kind of problem, for example, source cost due to long-time simulation and mesh break due to large motion amplitude. Therefore, a new coupled method on studying wave and structure interaction is required. As we want to solve this kind of problem efficiently and accurately, the viscous effect around the body need to be included. Thus, the potential-viscous coupled method is adopted, including the overset grid method.

The coupling method of potential and viscous method can be divided into two categories, functional-decomposition coupling and domain-decomposition coupling (Li, 2018). The functional-decomposition coupling method considered solving the whole problem in the same computational domain, for example, Helmholtz velocity decomposing theorem (Morino, 1986) is a common functional-decomposition coupling method. Dommermuth (1998) applied this method into hydrodynamic problem, and he used this method to study the bow wave. Zhao et al (2016, 2017) applied Helmholtz velocity decomposing theorem into the open source software OpenFOAM, solving the flow around the SUBOFF and a cylinder. Another functional-decomposition coupling method is SWENSE (Spectral Wave Explicit Navier-Stokes Equations) (Ferrant, 2002, 2003). This method divided the computational variables into incident variables and radiation variables. The domain-decomposition coupling method combined potential computational domain and viscous computational domain together, just match the boundary condition of these two methods. The advantage of domain-decomposition method is the ability to achieve the two-way coupling easily. For example, Kim et al (2010) applied two-way coupling of BEM and VOF method to study the random waves. However, the two-way coupling method is still complex and cost time on the iterate solution. Therefore, many studies applied one-way coupling method, such as Lachaume et al (2003) and Biausser et al (2003, 2004). They combined BEM and VOF to solve the wave propagating on the slope. In general, the potential-viscous method applied BEM method as the potential method. However, Ducrozet et al (2014) mentioned that BEM method needs to be improved in efficiency.

In the present work, we combine our in-house CFD solver naoe-FOAM-SJTU with a pseudo-spectral method High-Order-Spectral method (HOS). HOS method is a pseudo-spectral method (Dommermuth, D.G. and Yue, D.K.P, 1987). It based on the partial difference equation on dynamic and kinematic free surface boundary condition. The potential on the surface are wrote in a perturbation series and expanded each order in a Taylor series. Thanks to the Fast Fourier Transform (FFT), the communication between discretization space and modal space is very fast. With the given initial variables, the unknown potential can be obtained. Therefore, HOS method can generate nonlinear wave in a fast and efficient way. The combination of CFD method and HOS have done in previous work (Zhuang et al, 2018, 2021), including freak wave with ship motion interaction (Zhuang et al, 2020) and combination with overset grids (Zhuang et al, 2020). The HOS-CFD coupled method with