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Numerical Analysis of Flow Kinematics in Green Water on Deck

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Wave impact load prediction is very important for marine structural design. However, it is still a great challenge to predict wave impact loads, since the relationship between flow kinematics and impact loads is not very clear. In this study, a coupled potential-viscous flow method is applied. In the coupled method, the irrotational Green–Naghdi (IGN) model based on potential theory is used for wave generation in the far field, while a computational fluid dynamics (CFD) in-house code (Liao et al., 2017) is adopted to simulate green water on deck. The IGN model is coupled with the CFD in-house code by the Euler overlay method. Characteristics of the wave impact loads and the flow kinematics are analyzed in detail based on a benchmark model test.

INTRODUCTION

In rough sea conditions, marine structures may suffer from extreme wave impact loads, which seriously threaten their safety and stability. Therefore, the prediction of wave impact loads is very important for marine structural design.

In addition to model tests (Chuang et al., 2018; Lee et al., 2016, 2020; Rosetti et al., 2019), numerical simulations based on computational fluid dynamics (CFD) have been widely used for predicting wave impact loads with the development of computer technology. Rosetti et al. (2019) applied Star-CCM+ to analyze the characteristics of green water on the floating production storage and offloading (FPSO) deck. Yan et al. (2018) developed a numerical scheme in which the immersed boundary method and the level set method were used for treating solid boundary and free surface flow, respectively, to simulate green water on a fixed structure deck. Extreme green sea loads upon a vertical deck structure of an ultra large container ship were analyzed by Gatin et al. (2019). Two different methods were used to define the equivalent wave: the conventional equivalent design wave and the response condition wave. A new Lagrangian meshless method, based on the weighted least-squares (WLS) operators, was proposed for simulating green water on a marine structure (Bašić et al., 2020). Kudupudi et al. (2019) applied a commercial CFD solver (ANSYS-Fluent) to study the effects of wavelength, wave steepness, and bow rake angle (α) on the appearance of green water and peak value of impact pressure. Chen et al. (2019) used the open source code OpenFOAM to study the influence of different bow shapes on the evolution of green water. They found that different bow shapes have obvious effects on the shipping flow on deck but little effect on the horizontal forces. Khojasteh et al. (2020) simulated green water on a stepped platform using the InterFoam solver. Their results showed that turbulent models have great influence on wave impact loads.

Compared with traditional CFD methods based on viscous flow theory, the coupled potential-viscous flow method with the strategy of domain decomposition has advantages, such as smaller computational domain, lower computational cost, etc. According to the way of information communication between domains, it can be divided into one-way coupling method and two-way coupling method. A two-way coupling method was proposed by Ferrer et al. (2016) in which a multi-region compressible/incompressible scheme (multi-physics) was implemented in the OpenFOAM framework to deal with aerated impact in numerical wave tanks. Verbrugghe et al. (2018, 2019) proposed a coupled fully nonlinear potential flow (FNPF) smoothed particle hydrodynamics (SPH) method for wave–structure interaction. Kemper et al. (2019) coupled FNPF and Reynolds-averaged Navier–Stokes (RANS) volume-of-fluid (VOF) models to study hydrodynamics around wave energy converter (WEC) arrays. The one-way coupling method, which was first proposed by Guignard (1999), has been widely applied and studied because of its simple and practical characteristics. The Euler overlay method (EOM), a one-way coupling scheme, has been successfully applied to simulate steep irregular waves with duration of three hours (Huang and Guo, 2017). Liao et al. (2018) proposed a potential-viscous flow method, which is coupled with mooring/riser numerical wave basin (MrNWB) dynamic libraries using the EOM (Baquet et al., 2017). The accuracy and efficiency of the coupled potential-viscous flow method has been discussed in Liao, Duan, et al. (2021) and Liao, Wang, et al. (2021).

Although green water on deck has been studied intensively with numerical methods, predicting impact loads remains a challenge, since the relationship between flow kinematics and impact loads in green water phenomenon is not clear. In this study, a coupled potential-viscous flow method (Liao et al., 2018) is applied to simulate green water on a fixed rectangular structure, and the flow kinematics and impact pressure are analyzed. The numerical results are compared with the model test data in reference (Lee et al., 2020). The rest of the paper is arranged as follows. A brief introduction of the coupled potential-viscous flow method is presented in the second part. Numerical results and discussions

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KEY WORDS: Green water, flow kinematics, coupled potential-viscous flow method.