Numerical Analysis of Flow Kinematics in Green Water on Deck

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ABSTRACT

Wave impact loads prediction is very important for marine structure design. However, it is still a great challenge in wave impact loads prediction, since relationship between flow kinematics and impact loads is not very clear now. In this study, a coupled potential-viscous flow method is used to simulate green water on a rectangular structure. In the coupled method, potential theory is applied for wave generation in the far field, while CFD in-house code (Liao et al., 2017) is adopted to simulate green water on deck. The potential theory method is coupled with the CFD in-house code by EOM (Euler Overlay Method) based on the domain partitioned strategy. Relationship of flow kinematics and impact pressure distribution is analyzed in detailed based on a benchmark model test (Lee et al., 2020).

KEY WORDS: Green water; Flow kinematics; CFD.

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 the design of marine structures.

In addition to model tests (Lee et al., 2016; 2020), numerical simulations based on CFD have been widely used for predicting wave impact load with the rapid development of computer technology. 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 wave and the response condition wave. A new Lagrangian meshless method, based on the WLS (Weighted-Least Squares) operators, was proposed for simulating green water on marine structure (BAŠIĆ J et al., 2020). Several cases were carried out to validate their proposed method. 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 pressure on the deck of a container ship. They found that in case of λ/L = 1.3 (λ is wave length and L is the Length of the vessel) and at the highest instantaneous pitch amplitude where the water propagates far downstream and across the deck, the green water on the deck has the largest impact on the deck. The influence of different bow shapes on the evolution of green water was studied by Chen et al. (2019) with the open source code OpenFOAM. It was found that different bow shapes have obvious effects on the flow on deck, but have little effect on the horizontal forces. Khojasteh et al. (2020) simulated the green water on a stepped platform using the InterFoam solver. Results showed that turbulent model has great influence on the wave impact loads. Although there are intensive studies on green water on deck with numerical methods, it is still a great challenge in predicting impact loads, since the relationship between flow kinematics and impact loads in green water phenomenon is not clear now.

In this study, a coupled potential-viscous flow method (Liao et al., 2018) is applied to simulate the green water on a fixed rectangular structure, and the flow kinematics and impact pressure are calculated. 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 briefly introduction of the coupled potential-viscous flow method is presented in the second part. Numerical results and discussions are given in the third part. The final part shows some conclusions based on the results.

NUMERICAL METHOD

The governing equations of incompressible viscous flow are:

\[ \frac{\partial u_i}{\partial x_i} = 0 \]  \hspace{1cm} (1)

\[ \frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = - \frac{\partial p}{\partial x_i} + \frac{1}{\rho} \frac{\partial \tau_{ij}}{\partial x_j} + f_i \]  \hspace{1cm} (2)

where, \( i = 1, 2, 3 \), \( u_i \) represents three velocity components in the flow field; \( p \) is the pressure; \( \rho \) is the density; Shear stress \( \tau_{ij} = \frac{1}{2} \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \), \( \mu \) is the dynamic viscosity coefficient of the fluid; and \( f \) is volume force.

The free surface is captured by the THINC/SW (Tangent of Hyperbola for INterface Capturing with Slope Weighting) scheme which is a multi-