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Numerical simulation of the free surface around a circular column in regular waves using modified marker-density method

In-Jun Yang[1], Young-Gill Lee[2] and Kwang-Leol Jeong[3]

[1]*Department of Naval Architecture and Ocean Engineering, Graduate school of Inha University, Incheon, Korea*
[2]*Department of Naval Architecture and Ocean Engineering, Inha University, Incheon, Korea*
[3]*Research Center, NEXTfoam Co., Ltd., Seoul, Korea*

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ABSTRACT: *In this paper the wave run-up around a circular column in regular waves is numerically calculated to investigate the applicability of the Modified Marker-Density (MMD) method to prediction of wave run-up around an offshore platform. The MMD method is one of the methods to define the highly nonlinear free surface. The governing equations are the Navier-Stokes equations and the continuity equation which are computed in Cartesian grid system. To validate incident waves generated by numerical simulation, those are compared with the solutions of the Stokes 5th order wave theory. The wave run-up simulations are performed varying the steepness and period of incident waves as referred experimental data. The numerical results are compared to the experimental data and the results show good agreements.*

KEY WORDS: Wave run-up; Free surface; Circular column; Cartesian grid; Modified marker-density method.

INTRODUCTION

The accurate prediction of wave height which is distorted by the column is an important design factor for determining the air-gap under offshore platform decks. For a ratio of the diameter of a column to the length of the incident wave of less than 0.2 such as jackets, it is assumed that the incident wave is not distorted by the column. For a ratio greater than 0.2, however, the crest height amplification caused by interactions between the column and the incident wave must be considered. Therefore, to predict the run-up along the column, a method for considering the nonlinear contribution rather than linear diffraction theory is required.

In the case of diffraction for a single bottom-mounted column in regular waves, McCamy and Fuchs (1954) provided an analytic solution based on linear potential theory. Kim and Yue (1989) provided the complete second order diffraction solution for an axisymmetric body. Many studies based on potential theory have been useful at the initial design stages in the case of low wave steepness. Moreover, numerical simulation based on potential theory has advantage of the less computer CPU times to complete the calculations rather than using nonlinear tools. On the other hand, as wave steepness increases, it is difficult to

Corresponding author: *Young-Gill Lee*, e-mail: *younglee@inha.ac.kr*

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predict the maximum crest height along the column (Buchmann et al., 1998; Kristiansen et al., 2004; Stansberg and Kristiansen, 2005). Therefore, it is quite difficult to consider the nonlinear effect in high wave steepnesses using numerical simulation based on potential theory. Moreover, it is common that model test data is essential to confirm the positive air-gap and to estimate empirical corrections.

In order to improve prediction of maximum crest height or wave run-up around a circular column, Kristiansen et al. (2004) and Morris-Thomas and Thagarajan (2004) investigated numerical simulations of first and second order diffraction using an industry standard numerical tool and the panel program WAMIT and compared with model test performed in the MARINETEK. They investigated in more detail contributions from high order terms by discrepancy between measurements and numerical results. However, it was insufficient to explain the gap of sum-frequency terms. It might be influence from high order effects, or viscous effects. Nam et al. (2008) investigated wave run-up around truncated cylinder using numerical results based on finite element method and model test data. In order to improve efficiency and accuracy of calculation, multi-mesh was adopted and numerical damping zone was implemented as a radiation condition. In comparison with experimental data, first harmonic components showed a good agreement while discrepancy of second order components was observed. The discrepancy was caused by nonlinear contribution in steep and short wave.

Another method to predict the run-up along column is using nonlinear tools based on Navier-Stokes equations. For defining the free surface, Volume of Fluid (VOF), Level-Set (LS), Smoothed Particle Hydrodynamics (SPH) and Marker-Density (MD) methods are used in various application field such as wave simulation and ship hydrodynamics (Kristiansen et al., 2005; Lee et al., 2007; Danmeier et al., 2008; Rudman and Cleary, 2009; Park et al., 2011). Some research confirmed that wave run-up simulation has applicability in qualitative.

The VOF method captures the free surface using the volume fraction of water and air densities. Many studies have been performed by a commercial code using the VOF method for determination of the free surface (Park et al., 2001; Stansberg et al., 2005; Iwanowski et al., 2009). On the other hand, as the calculation time increases, minute numerical error occurs near the free surface because of its vague volume fraction. The marker-density (Park et al., 1999) method, which uses only water and air densities in the entire grid, has been suggested and used to calculate the free surface in waves. Furthermore, the modified marker-density (Lee et al., 2012) method that there is no spatial discontinuity of the governing equations caused by the difference between water and air densities was investigated. For the VOF method, when physical quantities such as density and viscosity in a grid cell are calculated from volume fraction function, it yields no spatial discontinuity and instability in numerical calculation, however, the effect of a thick free surface interface. Therefore, several technics have been developed in order to maintain a sharp interface in the VOF method. Whereas, the MMD method does not use the volume fraction function, but uses solely water and air densities to determine the free surface and maintain it sharply.

The purpose of this paper is to investigate the applicability of the MMD method to prediction of wave run-up around an offshore platform. As a classical problem, the free surface around a circular column in regular waves is numerically calculated. Before wave run-up simulations, the validation of incident waves is performed by comparing the incident waves by the numerical result with the analytic solutions based on Stokes 5^{th} order wave theory. The wave run-up simulations are performed according to various wave conditions and the records of wave elevation around the circular column are analyzed. The analyzed results of linear amplification factors (RAOs) and Quadratic Transfer Functions (QTFs) of the disturbed waves by the column were compared with experimental data (Kristiansen et al., 2004; Nam et al., 2008) in various wave steepnesses and periods. The maximum crest heights around the circular column according to wave steepness and two wave periods were compared with the experimental data (Kristiansen et al., 2004).

THE NUMERICAL MODEL

Govern equation and scheme

In this paper, governing equations are the filtered Navier-Stokes equations in Eq. (1) and the filtered continuity equation in Eq. (2). Pressures are coupled with velocities through a two-step projection method. The Kawamura-Kuwahara scheme and Adams-Bashforth scheme were used for the space and time discretization in the convection term, respectively. Second-central differencing scheme and first-forward differencing scheme were used for the space and time discretization in all terms expect

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