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Numerical Analysis on Motion Responses of Adjacent Multiple Floating Bodies by Using Rankine Panel Method

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This study considers the motion responses of multiple floating bodies in waves. As a method of solution, a Rankine panel method using the B-spline basis function is applied. In particular, this method adopts a time-domain approach, which can extend more flexibility to nonlinear problems and coupling with nonlinear external loads. For the validation of the developed numerical method, the motion responses of 2 adjacent Series 60 hulls and a ship-barge model in waves are obtained, and the motion RAO are compared with other numerical and experimental results, showing favorable correspondence.

INTRODUCTION

There is significant engineering demand for solving the seakeeping problem of multiple adjacent bodies in waves. For instance, since LNG has been developed as an alternative energy resource, the relative motion between LNG-FPSO and LNG carriers has become an important issue in offshore structure design. Thanks to such demand, there have been many previous studies of this problem.

Ohkusu (1974) solved the multiple-body problem for cylinder array, and Oortmerssen (1979) considered a similar problem using a 3-dimensional sink-source method. Kodan (1984) measured the motions of an adjacent barge and ship in waves. For the problems involving ships, the strip theory, e.g. Kim and Fang (1986), has been a popular approach. As computational capacity has evolved, 3-D approaches have become popular. For instance, computational methods such as that using the wave green function (WGF) or the higher-order boundary element method (HOBEM) have been applied. Some examples include the works of Chen and Fang (2001), and Choi and Hong (2002). In addition, Kim (2003a) applied a unified theory, and Kashiwagi et al. (2005) and Hong et al. (2005) measured mean drift forces on multiple bodies. Recently, Zhang (2007) applied a Rankine panel method (RPM) to a multiple-body problem. Most of these numerical schemes, with the exception of the RPM, are limited to linear motion and frequency-domain approaches. Some studies have applied the impulse response function (IRF), which is regarded as a time-domain approach, but it should be noted that the IRF method requires frequency-domain solutions. On the other hand, the RPM can be applied to nonlinear problems, such as a fully nonlinear free-surface problem or body-nonlinear problem, by considering the exact-wetted surface. The RPM is then a popular method currently being applied to single-ship motion problems. The method was initiated by Dawson (1977) for the wave-resistance problem in the steady state, and Sclavounos and Nakos (1988) conducted a stability analysis. Nakos (1990) developed it into a frequency-domain solver on an unsteady problem. Lin and Yue (1990) and Kring (1994) then developed it into a time-domain solver, and later extended it to nonlinear problems (Lin et al., 1994; Kring et al., 1996). However, there are a few research cases in which the RPM is applied to multiple-body problems.

This paper presents the mathematical background concerning a time-domain multiple-body problem by using the RPM. The method is applied for 2 adjacent Series 60 ($C_B = 0.7$) hulls and to a ship-barge problem which was tested by Kodan (1984). By comparing the present results with existing experimental and other computational results, the accuracy of the present method is validated.

MATHEMATICAL FORMULATION

Equation of Motion

In a multiple-body problem, the degree of freedom is determined by the number of multiple bodies. For example, if there are 2 freely floating ships and each body is rigid, it has 12 degrees of freedom. Fig. 1 shows the definition of the coordinate system and notations. The motion of each body is defined in each local coordinate system. In this figure, β is the wave heading angle, and D_L is the distance at the center position of the 2 bodies—Body—A and Body-B. Eq. 1 is the equation of motion in 2-body problems:

$$
\begin{aligned}
&[M]_A\{\ddot{\xi}_i\} + [C]_A\{\xi_i\} = \{F_{F.K.} + F_{H.D.}\}_A \quad i = 1, 2, \cdots, 6 \\
&[M]_B\{\ddot{\xi}_j\} + [C]_B\{\xi_j\} = \{F_{F.K.} + F_{H.D.}\}_B \quad j = 7, 8, \cdots, 12
\end{aligned}
\tag{1}
$$

where $[M]$, $[C]$ are the body mass and restoring coefficient, and $F_{F.K.}$ and $F_{H.D.}$ are the Froude-Krylov force and the hydrodynamic force, respectively. In Eq. 1, there is an impulsive term in the hydrodynamic force that is proportional with acceleration, which causes the equation to be unstable; this is well described in Kring and Sclavounos (1995). In order to maintain stability in the equation of motion, decomposition into memory and local component can be applied, as presented by Cummins (1962) and Ogilvie (1964).

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