International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 28, No. 1, March 2018, pp. 19–30; https://doi.org/10.17736/ijope.2018.jc711

http://www.isope.org/publications/publications.htm

Time-Domain Analysis of Motion Responses of Side-by-Side Vessels During Offshore Installations and Underway Replenishment

Xi Chen, Ren-chuan Zhu and Yun-tao Yang
SKL Ocean Engineering, Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration
Shanghai Jiao Tong University, Shanghai, China

During offshore installations and underway replenishment, two vessels are arranged side by side in close proximity. In the present study, a time-domain high-order Rankine panel method is employed to analyze the hydrodynamic interactions of such side-by-side vessels in waves. The effects of the hydrodynamic interactions on the hydrodynamic coefficients, wave forces, and motion responses are examined. The motions of side-by-side ships at different separation distances and forward speeds are also investigated. In the case of forward speed, the lateral forces generated by the ships advancing in waves are computed by solving the steady-ship wave problem. In addition, double-body flow linearization is implemented in the time-domain computation in concert with the steady-flow effects on an unsteady flow. A numerical program is developed, and validation studies are performed for a side-by-side arranged Wigley hull and rectangular barge under a zero-speed condition, and a supply ship and frigate on a parallel course, advancing with a forward speed. The predicted results of the wave forces, hydrodynamic coefficients, and motions agree well with related model test data. When comparing the results of the double-body flow and uniform stream linearization computations, the steady flow effects on the ship motions are evident. The results also demonstrate that the hydrodynamic interactions for a smaller ship are significant, particularly during heave and roll motions. In addition, both the resonant frequencies and amplitudes of side-by-side ship motions vary with the gap distance and forward velocity. A more detailed discussion of the results is provided in this article.

INTRODUCTION

Studying the hydrodynamic interactions of close-proximity, side-by-side vessels in waves is of tremendous importance. The scenarios where such an arrangement is found include offshore installations; Liquefied Natural Gas-Floating, Production, Storage, and Offloading (LNG-FPSO) systems; and underway replenishment of ships advancing in waves. In these cases, the hydrodynamic forces and motion responses of the vessels would be quite different from those in single-body conditions and therefore should be studied carefully.

The potential flow theory is promising for the hydrodynamic analysis of a ship owing to its practicability. The research in this area was initiated by Korvin-Kroukovsky (1955), Silverstein (1957), Hess and Smith (1964), and other researchers. Subsequently, various scholars have studied ship seakeeping predictions. Among them, in the early years, Tasai (1967), Ogilvie and Tuck (1969), and Salvesen et al. (1970) proposed the strip theory, rational strip theory, and Salvesen, Tuck, and Faltinsen's (STF) method, respectively. The strip theory is restricted by a low-speed and a high-frequency assumption and the requirement that the ship be slender; therefore, it cannot be widely applied in marine and ocean engineering. Subsequently, a three-dimensional (3D) potential method applicable to ships and floating bodies having arbitrary forms was developed. This method is classified into the free-surface Green function method and the Rankine source method. The former adopts a Green function that satisfies the linearized free surface and radiation conditions so that the source and dipole are only required to be distributed on the ship hull. Noblesse (1982), Newman (1984), and Faltinsen and Michelsen (1974) used the free-surface Green function method to solve the wave–body interactions in the frequency domain. Clement (1998), Bingham (1994), and Qiu and Peng (2013) performed a time-domain simulation of the ship seakeeping using a transient Green function. The Rankine source method employs basic solution 1/r of the Laplace equation as the Green function. Dawson (1977) first applied the Rankine source method to evaluate a steady ship wave. Nakos and Sclavounos (1990) studied steady and unsteady ship wave problems through a quasi-linear formulation and frequency-domain Rankine source method, respectively. Kring et al. (1996) and Kim et al. (2011) developed a weak-scattering time-domain nonlinear method for the forward speed problem.

The above-mentioned research studies are mainly focused on single-ship seakeeping predictions. In recent years, many researchers have examined multi-body hydrodynamic interactions. Among them, Kashiwagi et al. (2005) investigated the wave drift forces and moments of closely arranged side-by-side ships without including the forward speed in either their experimental or numerical approaches. They used a frequency-domain free-surface Green function method to solve the boundary value problem and showed that the hydrodynamic interactions could be well accounted for by their method. Hong et al. (2005) computed the wave forces and motion responses of side-by-side moored multiple vessels by considering LNG-FPSO, LNG Carrier (LNGC), and shuttle tankers. To predict the motions of the moored vessels, Hong et al. (2005) employed an indirect time-domain method in their work. They also conducted a model test for the verification of the method.

With respect to underway replenishment with a forward speed, Li (2001) and McTaggart et al. (2003) used a zero-speed frequency-domain Green function in combination with a speed correction method to solve the problem, and the results thus obtained were verified by model tests. Similarly, Chen and Fang

Received July 10, 2017; updated and further revised manuscript received by the editors August 24, 2017. The original version (prior to the final updated and revised manuscript) was Best Student Paper presented at the Twenty-seventh International Ocean and Polar Engineering Conference (ISOPE-2017), San Francisco, California, June 25–30, 2017.

KEY WORDS: Side-by-side vessels, hydrodynamic interactions, time-domain Rankine, double-body linearization, HOBEM.