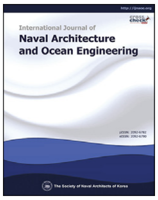
ARTICLE IN PRESS

International Journal of Naval Architecture and Ocean Engineering xxx (2017) 1–17

Contents lists available at ScienceDirect

International Journal of Naval Architecture and Ocean Engineering

journal homepage: http://www.journals.elsevier.com/international-journal-of-naval-architecture-and-ocean-engineering/



Numerical simulation for a passing ship and a moored barge alongside quay

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ARTICLE INFO

Article history:
Received 7 March 2017
Received in revised form
11 August 2017
Accepted 22 October 2017
Available online xxx

Keywords:
Passing ship
Barge
Quay
Time-domain simulation
Potential flow
Finite element method

ABSTRACT

A moored barge alongside quay can be influenced by a nearby passing ship and its ship-generated waves. In this study, a time-domain numerical method based on a three-dimensional potential flow solver is developed to investigate the passing ship problem with a moored barge alongside quay. Potential flows around the passing ship and the moored barge alongside a quay is directly solved by using a classical finite element method. Total computational meshes including a passing ship, a moored barge and a quay is updated at each step with an efficient re-mesh algorithm. To validate the developed numerical method, a conventional ship wave problem and a passing ship problem on the open sea has been solved and the solutions are compared with the existing data. Then, a series of numerical computations were carried out to investigate the passing ship effect on a moored barge alongside quay. The characteristics of the passing ship effects are studied with varying the simulation parameters such as passing ship speed, separation distance, wall distances and waves. Focus is made on hydrodynamic forces due to the passing ship effect and its ship waves.

1. Introduction

When a harbor area is busy with heavy ship traffic, moving ships may pass closely by a moored vessel in the harbor. In this case, the passing ships and their ship-generated waves induce considerable hydrodynamic forces acting on the moored vessel. Unwanted large motions of the vessel and high mooring forces can be caused by the passing ship effect, which may result in various marine accidents. For example, lifting operation with a crane vessel alongside a quay or cargo transfer operations can be limited by the unacceptable motions induced by the nearby passing ship. Also, small fishing ships can be exposed to the risk of capsizing due to the ship waves from a large passing ship. NTSB (1991) mentioned the damage case of the ship mooring due to the passing ship effect.

These passing effects can be categorized into two types depending on the passing ship speed. The first type is low-speed passing ship effect, which usually happens in harbor and canal. Due to the low-speed movement of the passing ship, the ship-generated wave is not significant. Thus the hydrodynamic forces due to the passing ship are mainly caused by the pressure variation due to the presence of the passing ship, which implies that these passing ship effects are influenced by the size of the passing ship, the separation distance between the two vessel and blockage effect with side wall and bottom. The other type is high-speed passing ship effect, in which the hydrodynamic forces acting on the moored barge is mainly transferred by the ship-generated waves of the passing ship. So, how large and closely the ship waves are generated is critical parameter for this type of passing ship effect. Also, complex wave-body interactions between the ship-generated wave and the moored barge or the quay may reinforce or reduce the hydrodynamic forces.

Various numerical methods based on potential flow model have been applied to study the passing ship effect. Among them, the classical slender body theory still remains useful to predict the main features of the ship-to-ship interactions. Tuck and Newman (1974), Wang (1975) and Yeung (1978) used slender body theory for the computation of the hydrodynamic forces between two ships. Varyani and Krishnankutty (2006) also used the slender body theory to calculate the hydrodynamic interaction forces acting on a moored ship due to the passage of another ship in its proximity. Wag (2007) derived an analytic solution for two slender bodies of revolution translating in very close proximity based on the slender body theory. However, since the slender body approaches are based on two-dimensional flow solutions with rigid wall conditions on the free

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Peer review under responsibility of Society of Naval Architects of Korea.

https://doi.org/10.1016/j.ijnaoe.2017.10.008

Please cite this article in press as: Nam, B.W., Park, J.Y., Numerical simulation for a passing ship and a moored barge alongside quay, International Journal of Naval Architecture and Ocean Engineering (2017), https://doi.org/10.1016/j.ijnaoe.2017.10.008

surface, three dimensional effect due to general ship geometries as well as free-surface effect are not taken into account correctly.

In order to reflect the three-dimensional effect with exact hull shapes, a few potential flow analyses with boundary element methods have been applied to the passing ship problems. Regarding the slow-speed passing ship effect, Pinkster (2004) adopted two numerical models (double-body model and free-surface model) based on 3-dimensional potential flow to solve the passing ship problem with the focusing of the free-surface effect. He also investigated the effect of quay based on the numerical simulations and reported that the passing forces on a ship moored in open water are not a good measure for the forces on a ship moored alongside a quay. His results show that the presence of the quay increases the surge force by about 80% and reduces by about 60% the sway force and the yaw moment. As for the high-speed passing ship effect, Dong et al. (2009) carried out a numerical analysis of the forces exerted on the hemisphere by ship waves. They modeled the ship wave using Michell's thin-ship theory and then by using a conventional boundary element method, the diffraction problem wave solved in time-domain to obtain the forces exerted on the hemisphere by ship waves. Although both numerical methods improve the solutions by considering three-dimensional effect and free-surface effect, they solved the diffraction problem for the moored vessel only under the assumption of the disturbed wave (or potential) due to the passing ship is not affected by the moored vessel. In principle, the disturbed wave (or potential) of the passing ship may also interact with the moored ship especially in close proximity or high speed conditions. In addition, to consider the wave effect and vessel motion, direct time-domains flow analysis method is required in combination with the computational meshes including both the passing ship and the moored vessel.

Direct Computational Fluid Dynamics (CFD) calculations can be a possible solution method to investigate the ship-to-ship interaction effect without any assumption in the passing ship problem. In particular, if the viscous effect is significant, CFD approaches is necessary. Huang and Chen (2007) applied an unsteady RANS solver to determine the forces on a moored ship perpendicular to the passing ship path. Bunnik and Toxopeus (2011) computed the passing ship effect with small drift angle. They pointed out that for drift angles higher of 7.5°, the viscous effect should be taken into account for a good prediction. Wang and Zou (2014) showed CFD simulation results for hydrodynamic interaction between a berthed ship and a ship passing through a lock. However, because the passing ship problem requires a huge computational domain with the movement of two floating bodies, the computational time of the CFD methods is still too expensive. Moreover, the treatment of the floating body motions and accurate wave propagation is still challenging problems in the CFD methods.

Owing to the numerical limitations, a lot of experimental campaigns including scaled model tests or full-scale measurements have been carried out to study the hydrodynamic interaction forces due to the passing ship effect. To name a few, Remery (1974) carried out a pioneering experimental investigation with the effects of the passing ship size, separation distance, and forward speed. Measured captive forces were used to determine motions and loads in mooring lines. Dand (1981) conducted a series of model tests involving a ship passing a stationary ship. He also developed empirical formulae to predict the forces due to the passing ship effect. Vantorre et al. (2002) conducted extensive model tests for ship-ship interaction forces and derived semi-empirical mathematical formulations of the forces. Pinkster and Ruijter (2004) suggested full scale measurements in Noordzee canel. Good agreements are found between the computational results and full scale measurements. Kriebel (2005) reported laboratory scale model tests to measure the loads on a moored ship resulting from a passing ship moving parallel to the moored vessel. In the tests, the effect of various parameters like the passing vessel speed, vessel displacement, water depth, and separation distance between the two ships were studied.

In this study, the passing ship problem with a moored barge alongside quay is investigated by applying newly developed simulation method in which potential flows around the passing ship and the moored barge alongside a quay is directly solved by a classical finite element method and total computational meshes is updated at each time step with an efficient re-mesh algorithm. Two validation problems, a conventional ship resistance problem and a passing ship problem on the open sea, were solved and the solutions are compared with the existing experimental data. A series of numerical simulations were carried out to investigate the passing ship effect on a moored barge along quay. Discussion is made on the effect of the several important parameters such as passing ship speed, separation distance, wall effect and wave effect.

2. Numerical method

2.1. Boundary value problem

In this study, there is a moored barge alongside quay and a passing ship with a forward speed, in which the gap distance between the barge and quay is normally quite smaller than the separation distance between the barge and the passing ship. Fig. 1 shows the schematic diagram for the present passing ship problem. Boundary value problem can be formulated with respect to an earth-fixed coordinate system because the relative positions of the passing ship and the barge continuously change.

It is assumed that the passing ship is moving at a constant forward speed and motions of two vessels due to the hydrodynamic forces are neglected. Linearized boundary value problem for given passing ship problem is like followings;

$$\nabla^2 \phi^{(1)} = 0 \quad in\ \Omega(t) \tag{1}$$

$$\frac{\partial \phi^{(1)}}{\partial t} = -g\zeta^{(1)} \quad on\ z = 0 \tag{2}$$

$$\frac{\partial \zeta^{(1)}}{\partial t} = \frac{\partial \phi^{(1)}}{\partial z} \quad on\ z = 0 \tag{3}$$

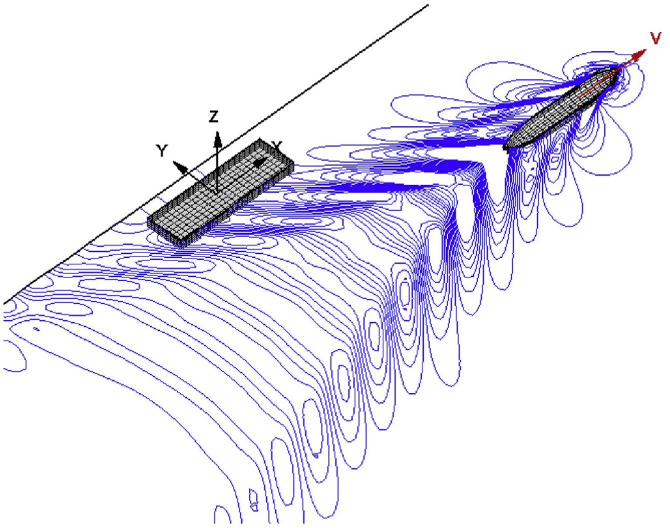

Fig. 1. Schematic diagram for the passing ship problem.

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