Ocean Engineering 88 (2014) 409–425

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Numerical study on hydrodynamic interaction between a berthed ship and a ship passing through a lock

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ARTICLE INFO

Article history:
Received 22 August 2013
Accepted 2 July 2014
Available online 24 July 2014

Keywords:
Ship–lock hydrodynamic interaction
Ship–ship hydrodynamic interaction
Numerical simulation
Dynamic mesh method

ABSTRACT

Hydrodynamic interaction between a berthed ship and a passing ship always occurs in a single way lock. This interaction will have significant influences on safe navigation of ships in a lock, and thus the hydrodynamic mechanism behind it should be well understood. In this paper, a numerical study on the hydrodynamic interaction between a berthed ship and a passing ship entering and leaving a single way lock is carried out. By solving the unsteady RANS equations in conjunction with a RNG $k-\varepsilon$ turbulence model, numerical simulation of the three-dimensional unsteady viscous flow around the two ships is conducted, and the hydrodynamic interaction is numerically predicted. Dynamic mesh method and sliding interface technique are used to deal with the relative motion between the passing ship and the lock. The numerical results are obtained under different ship speed, water depth, transverse and longitudinal positions of the berthed ship; and the influences of these factors on the ship–ship and ship–lock hydrodynamic interaction are analyzed. This study can provide certain guidance on safe manoeuvring and control of a ship passing through a lock affected by a berthed ship.

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1. Introduction

When navigating in restricted waterways, such as passing through a lock, the ship hydrodynamic behavior is quite different from that in unrestricted waters due to the ship–ship and ship–waterways interaction. A ship passing through a lock will experience a particular hydrodynamic force caused by the hydrodynamic interaction with the lock and other ships. The interaction scenario occurs mostly when a ship is leaving or entering a single way lock and passing a berthed ship. The hydrodynamic interaction has a significant influence on the ship navigation safety, and the study on this influence is of crucial importance for safe operation and effective control of ships passing through a lock.

Ship–ship interaction has been studied for a long time. During the last decades, some experiments were conducted to study the hydrodynamic interaction between ships. Newton (1960) presented the overtaking results of two ship models in deep water. Müller (1967) investigated two ships meeting and overtaking in a narrow channel. Vantorre et al. (2001) presented the model test based formulations of ship–ship interaction forces for simulation purposes. Many numerical methods are also developed to study the ship–ship hydrodynamic interaction. Tuck and Newman (1974) used the method of matched asymptotic expansions based on slender-body theory to calculate hydrodynamic forces between two ships in deep water; Yeung (1978) solved the problem of ship–ship interaction in shallow water by using a similar approach. Kijima (1987) investigated ship manoeuvrability in narrow channel. Kaplan and Sankaranarayanan (1987) analyzed the problem of two ships interacting in a shallow asymmetric channel. Gourlay (2009) calculated the sinkage and trim of two ships passing each other on parallel course. Varyani et al. (1998, 2002) obtained interactive forces and moments between several ships meeting in restricted waters. Chen et al. (2002) used the chimera RANS method to compute multi-ship interaction in a navigation channel. Lee and Lee (2007) predicted the hydrodynamic forces of two ships sailing in confined water under wind-effect. Zhang et al. (2012) used a CFD code to calculate the hydrodynamic interaction of two ships meeting in shallow water.

There are also many relevant investigations focusing on the hydrodynamic interaction between a berthed ship and a passing ship. Remery (1974) conducted model tests to measure the surge force, sway force and yaw moment experienced by a berthed ship due to a passing ship. Muga and Fang (1975) used a theoretical method to calculate the interaction forces and moments on a fixed elliptic cylinder induced by a moving elliptic cylinder. Dand (1981)

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http://dx.doi.org/10.1016/j.oceaneng.2014.07.001
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conducted scale model experiments involving a ship passing a stationary ship and developed empirical formulae to predict the forces and moments due to ship–ship interaction. Using the results from Remery (1974) and Muga and Fang (1975), Flory (2002) presented a set of equations to calculate the peak forces and moments of a moored ship induced by a passing ship, and provided a method to develop the time histories of these forces and moments. Kriebel (2005) conducted physical scale model experiments to measure the forces and moments on a berthed ship due to a passing ship in open shallow water. Duffy and Renilson (2009) presented some results of hydrodynamic interaction between a berthed ship and a passing ship from physical scale model experiments. Swiegers (2011) measured the surge force, sway force and yaw moment on a berthed bulk carrier hull due to the effects of a passing container ship.

Some studies have been conducted to investigate ship behaviors in a lock. Vrijburcht (1988) calculated the wave height and speed of a ship entering a lock. Vergote (2012) improved the mathematical model based on Vrijburcht (1988). Vrijburcht (1991) and Chen and Sharma (2001) gave a more general model to discuss the translation waves. Chen (2010) calculated the ship sinkage and trim in a more general way. De Mulder (2009) investigated the mooring forces and ship behavior in navigation locks. Delefortrie et al. (2008, 2009) assessed the navigation behavior of three different ship models in the Third Set of Panama Locks and analyzed the influences of approach wall configurations, eccentricities, propeller rates, approaching scenarios and under keel clearances. Verwilligen and Richter (2012) analyzed the entering manoeuvre of full form ships into the Terneuzen West Lock by means of model testing, full scale trials and real-time simulations. In the 1990s, a systematic captive model test series was carried out in the Towing Tank for Manoeuvres in Shallow Water (co-operation Flanders Hydraulics Research and Ghent University) in Antwerp as a first step in a feasibility study for receiving bulk carriers with larger beam in the Pierre Vandamme Lock in Zeebrugge, Belgium (Vantorre et al., 2012; Vantorre and Delefortrie, 2013).

In this paper, the CFD software ANSYS FLUENT is used to simulate the unsteady viscous flow around a ship passing through the Pierre Vandamme Lock, with a ship berthed near the lock entrance. By using the numerical method, quantitative predictions of the most interesting hydrodynamic quantities, such as the longitudinal force, lateral force and yaw moment are achieved. Numerical results are obtained at different ship speed, water depth, lateral and longitudinal positions of the berthed ship and compared to investigate the effects of these factors on the hydrodynamic forces.

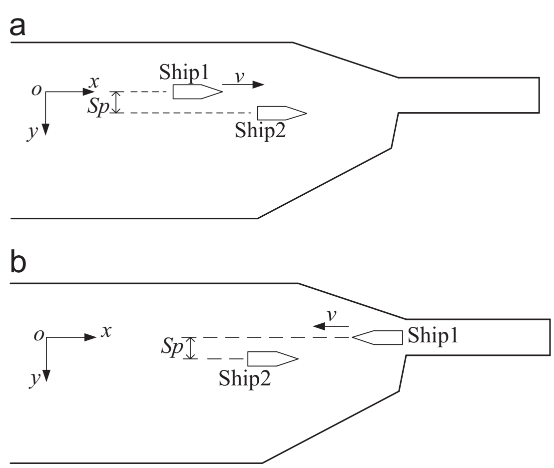

Fig. 1. Coordinate system and the interaction scenario. (a): Ship passing a berthed ship and entering the lock and (b): Ship leaving the lock and passing a berthed ship.

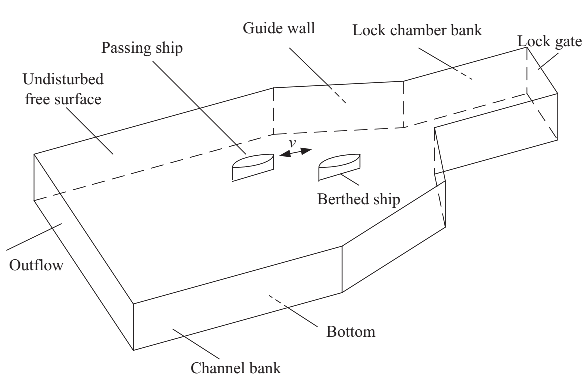

Fig. 2. Computational domain and its boundaries.

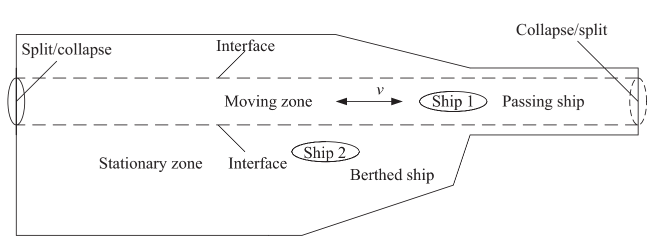

Fig. 3. Definition of moving zone.

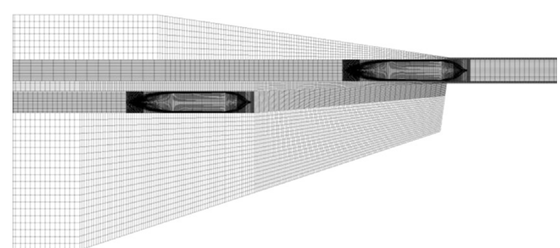

Fig. 4. Sketch of grid distribution.

Table 1
Ship characteristics, bulk carrier.

	Full scale	Model
L_{OA} (m)	265.0	3.533
L_{PP} (m)	259.2	3.456
B (m)	43.0	0.573
T (m)	17.342	0.231
C_B	0.854	0.854

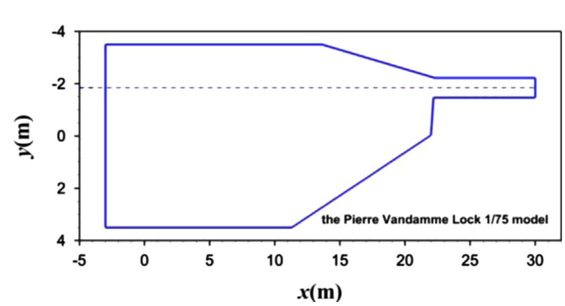

Fig. 5. Lock configuration in towing tank for captive model tests.

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