Behaviours of a Ship Passing through a Lock under the Influence of a Berthed Ship

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***Abstract* - In this paper, a numerical study on the behaviours of a ship passing through a lock under the influence of a berthed ship is carried out. The viscous flow and hydrodynamic forces are calculated by applying an unsteady RANS code with a RNG k-ε turbulence model. UDF is compiled to define the ship motion. The numerical results are obtained and analyzed for the cases of the berthed ship at different longitudinal and transverse position in the approaching channel to investigate the influences of the berthed ship's postion on the ship-ship and ship-lock hydrodynamic interaction.**

Keywords - ship behaviours in lock; berthed ship; hydrodynamic interaction; numerical simulation

INTRODUCTION

The continuous development of water transportation has lead to a high density of ships in waterways and made the ship-ship hydrodynamic interaction a prominent problem. When navigating in restricted waterways, such as passing through a lock, the ship hydrodynamic behaviours are quite different from those in unrestricted waters due to the ship-ship and ship-waterways interaction. Nowadays, a large number of locks have been or are being designed and constructed all over the world. For ships moving relatively in a lock, they will experience a particular force and moment caused by the hydrodynamic interaction between ships. It is important to study this hydrodynamic interaction in lock to provide certain guidance on design of approach lanes to the lock and safe operation of passing through a lock.

The ship-ship hydrodynamic interaction has received great attention for a long time. During the last decades, many researches were conducted to study the hydrodynamic interaction between ships. The overtaking results of two ship models in deep water are presented (Newton 1960). Two ships meeting and overtaking in a narrow channel are investigated (Müller 1967). The mooring forces induced by passing ships are investigated (Remery 1974). The method of matched asymptotic expansions based on slender-body theory is used to calculate the hydrodynamic forces between two ships in deep water (Tuck and Newman 1974). The problem of two ships interaction in shallow water is solved by using a similar approach (Yeung 1978).

Some studies also have been conducted to study ship behaviour in lock. The wave height and ship speed are calculated when entering a lock (Vrijburcht 1988). Mooring forces and ship behaviour in navigation locks are investigated (Mülder 2009). 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 by Vantorre et al (2012).

In this paper, the commercial CFD code FLUENT is used to simulate the unsteady viscous flow around a ship passing through the Pierre Vandamme Lock when there is a berthed ship in the approaching channel. By using the numerical method, quantitative predictions of the most interesting hydrodynamic quantities, such as the lateral force and yaw moment at different lateral distance and longitudinal position of berthed ship are achieved. Numerical results are compared to investigate the effects of these factors on hydrodynamic interaction..

PROBLEM FORMULATION

As shown in Fig. 1, the interaction between a ship (ship1) passing through a lock and a berthed ship (ship2) is considered. A space-fixed right-handed coordinate system, *o-xyz*, is adopted to describe the problem, with *x*-axis pointing to the moving direction of the ship entering lock, *y*-axis directing towards starboard and *z*-axis pointing downward. The passing ship speed is U which is assumed to be constant and small. *Sp* is transverse distance between two ships.

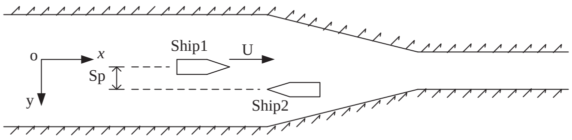

Fig. 1: Ship-ship interaction between a ship entering the lock and a berthed ship

Under the assumption of low ship speed, the elevation of free surface is negligible. The fluid around the ship is single phase, viscous and incompressible. Using Reynolds-Averaged method, the governing equations for this flow problem are:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\rho \frac{\partial u_i}{\partial t} + \rho u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}(\mu \frac{\partial u_i}{\partial x_j} - \rho \overline{u_i' u_j'}) \tag{2}$$

where x_i (i=1, 2, 3) is the ith component of the fixed coordinate system, ρ is the density of fluid, ui is the mean velocity component, p is the mean pressure, μ is the viscosity and $-\rho \overline{u_i' u_j'}$ is the Reynolds stress. The RNG $k-\varepsilon$ turbulence model is adopted to solve the Reynolds stress.

NUMERICAL METHOD

Computational Domain and Boundary Conditions

The computational domain and boundary conditions of passing ship affected by berthed ship in a lock are shown in Fig. 2. The computational domain is bounded by the ship hulls, the water bottom, the undisturbed free surface, channel bank, cofferdam and lock chamber, the lock gate and a fictitious outflow boundary downstream. Considering that the free surface is assumed to be rigid in the analysis, the top surface of the domain is set as symmetry. On the ship hull, the water bottom, the lock gate, cofferdam and lock chamber, wall boundary condition is imposed. On the outflow boundary, pressure outlet condition is imposed.

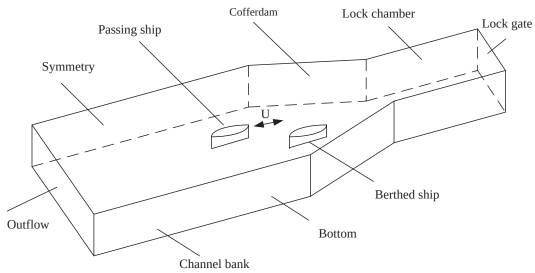

Fig. 2: Computational domain and boundary conditions

Units Dynamic Mesh Method

In this paper, dynamic mesh method is used to simulate the relative motion between ships and lock. The layering method is chosen to update the mesh. The basic principle of layering is to split or collapse cells near the moving boundary with defined movement. When using the layering method, boundaries between moving zone and stationary zone are set as interface. Interface is usually used when calculating non-conformal grid of two zones. It uses interpolation method to calculate the flux cross two faces. As shown in Fig. 3, the zone containing the passing ship is set as moving zone which moves with the ship speed, and the dashed line indicates the interface. Boundaries indicated by solid ellipse and dashed ellipse are places where grids split and collapse.

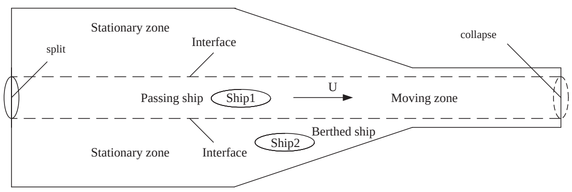

Fig. 3: Definition of moving zone

Solution Settings

User-defined function (UDF) is a function programmed by the user that can be dynamically linked with the FLUENT solver to enhance the standard features of the code. In this paper, UDF is used to set the speed of ship, to define the gravity center of each ship and to calculate the force and moment acting on each ship. UDF is also used to output the results as text file to edit.

The unsteady part in governing equations is discretized by the first-order implicit scheme. The algorithm SIMPLE is chosen to solve the velocity-pressure coupling problem. Momentum, turbulent kinetic energy, turbulent dissipation rate are discretized by second-order upwind scheme. Time step is set as 0.1s to make sure that the product of the time step times velocity is smaller than the mesh size in moving zone.

NUMERICAL RESULTS AND DISCUSSION

Ship and Lock Model

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The Pierre Vandamme Lock has a length of 500m, a width of 57m and a depth of 18.5m. The model scale ratio is 1/75. As shown in Fig. 4, the lock shape is asymmetry. The dashed line stands for the center line of lock chamber. To compare with the available model test results, a bulk carrier ship model is chosen as the passing ship and berthed ship for the numerical study. The main dimensions of the ship and the model are listed in Table 1.

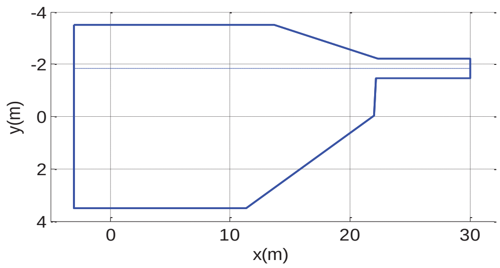


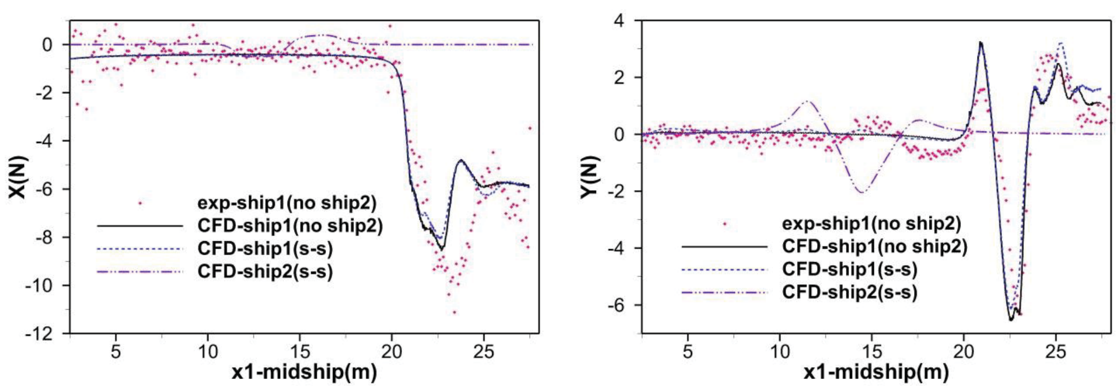
Fig. 4: Lock configuration in towing tank for captive model tests.

Table 1- Ship characteristics: bulk carrier

	Full scale	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

Comparison Between Numerical and Test Results

Under test condition, the ratio of water depth to draft (*h/T*) is 1.2, the model speed is 0.15m/s (*Fn*=0.0258, *Rn*=4.55×105), the ship model navigates forward along the center line of lock chamber (the dashed line in Fig. 4). Besides, there is no berthed ship in test. In this numerical study, a berthed ship is added to investigate the hydrodynamic interaction between berthed ship and ship passing through a lock. The berthed ship's midship section x_2=14.58m, transverse distance Sp=5/3B. As shown in Fig. 5, the time histories of numerical results of passing ship and berthed ship are plotted to compare with the experimental and numerical results of ship passing through the lock without berthed ship. All results are plotted as a function of the longitudinal position of the passing ship model's midship section x_1.



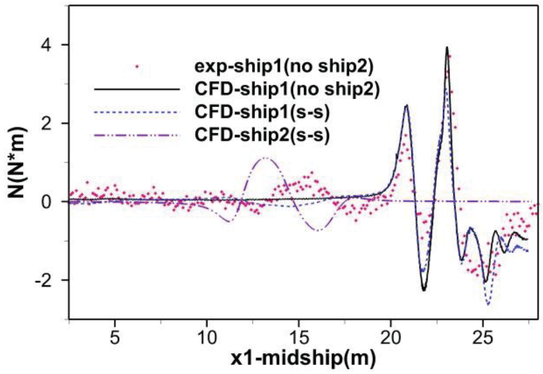
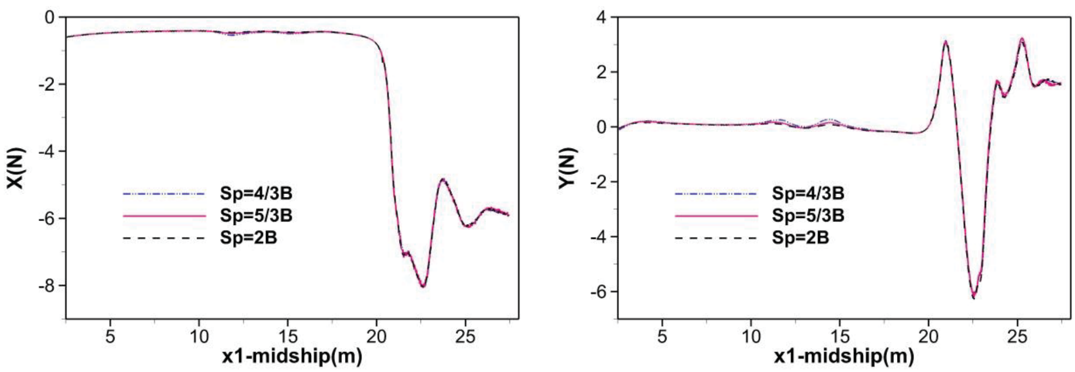


Fig. 5: Calculated hydrodynamic forces compared with the model test results

From Fig. 5, we can see that the present prediction results of hydrodynamic lateral force and yawing moment are in good agreement with the experimental data, while the longitudinal force is underestimated because of increasing blockage in navigation lock under test conditions. Because the shape of the lock is asymmetrical, the values of lateral force and yaw moment are large. For passing ship, the hydrodynamic longitudinal force, lateral force and yaw moment induced by ship-ship interaction is much smaller than the hydrodynamic forces acting on berthed ship. It is more dangerous for berthed ship than passing ship under ship-ship interaction. Besides, the hydrodynamic forces of passing ship induced by ship-lock interaction are much larger than the hydrodynamic forces of passing ship and berthed ship induced by ship-ship interaction. More attention should be paid to the process of ship entering the lock chamber.

Effect of Transverse Distance

Due to the ship-ship interaction, a longitudinal force, a lateral force and a yawing moment will act on the ship when it sails closed to another ship. In this section, the effect of transverse distance on the hydrodynamic interaction between two ships is investigated. Fig. 6 shows the longitudinal force, lateral force, yaw moment acting on two ships for different transverse distance Sp between two ships, where Fig. 6b shows the magnified part in Fig. 6a when the ship1 is passing by ship2. It can be seen that with the decrease of transverse distance, the hydrodynamic forces increase.



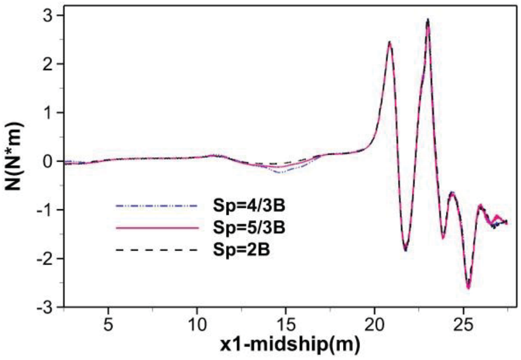


Fig. 6a: Hydrodynamic forces of passing ship changing with transverse distance in the whole process

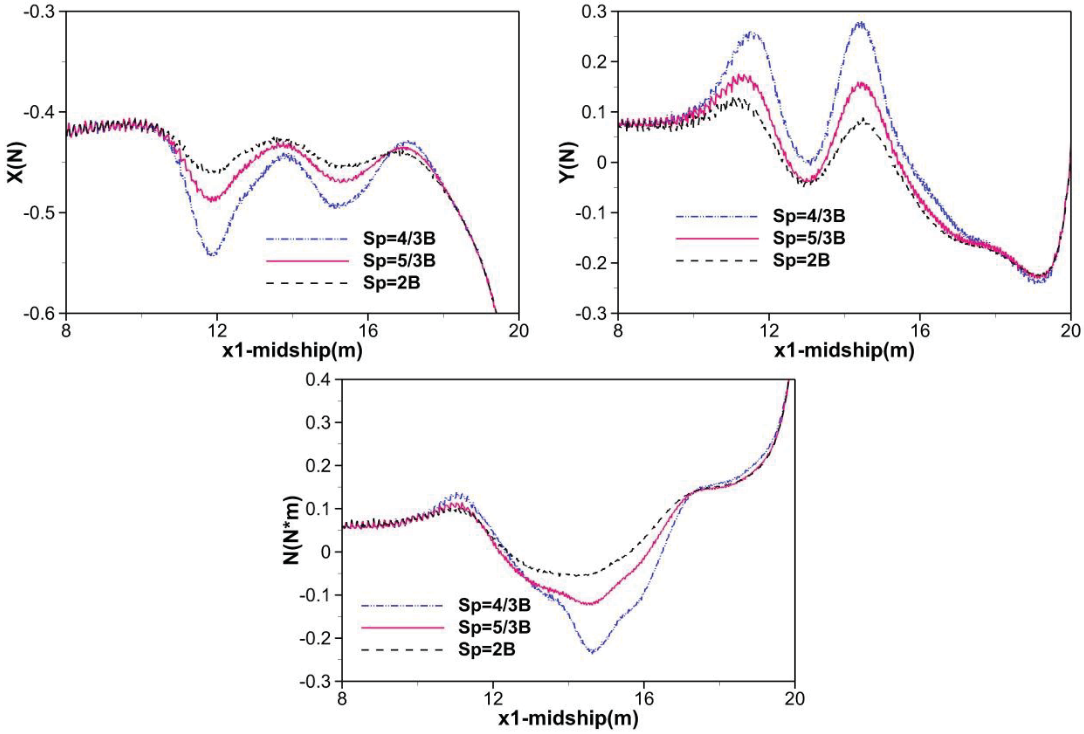
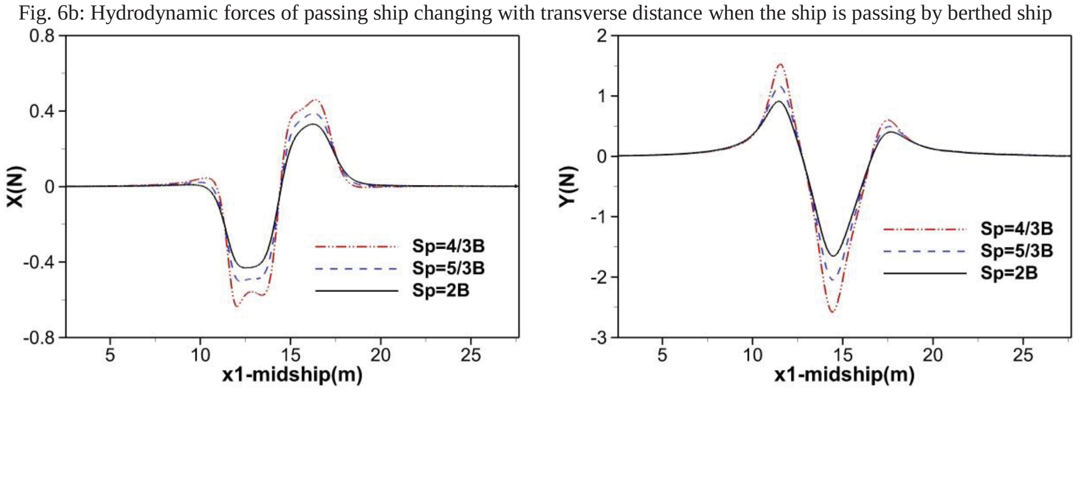


Fig. 6b: Hydrodynamic forces of passing ship changing with transverse distance when the ship is passing by berthed ship



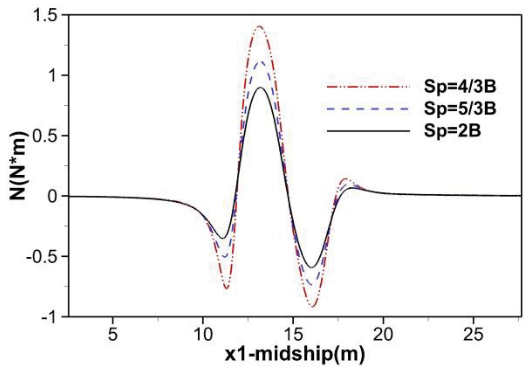


FIG. 6C: HYDRODYNAMIC FORCES OF BERTHED SHIP CHANGING WITH TRANSVERSE DISTANCE IN THE WHOLE PROCESS

Effect of Longitudinal Position of Berthed Ship

Fig. 7 shows the effect of longitudinal position of berthed ship x_2 on the hydrodynamic forces. It can be seen that the effect of longitudinal position of berthed ship on the the maximal forces and moments of the passing ship is small. However, the berthed ship closed to the lock entry will experience a larger force and moment when the passing ship is entering the lock chamber.

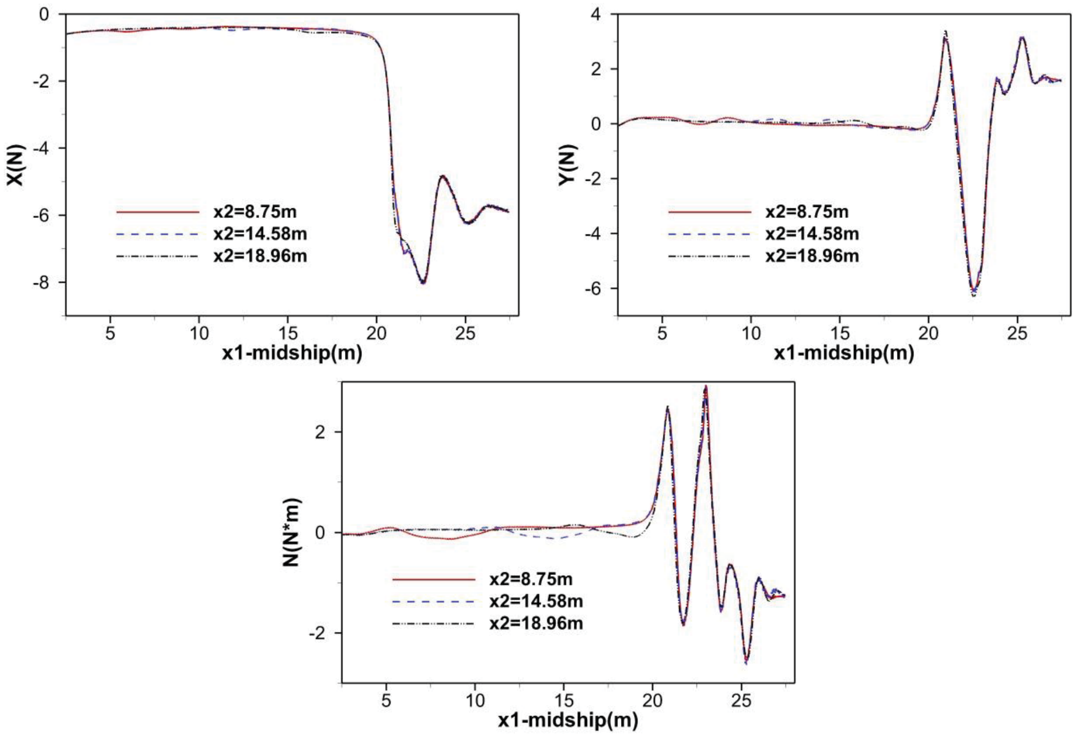


Fig. 7a: Hydrodynamic forces of passing ship changing with longitudinal position of berthed ship in the whole process

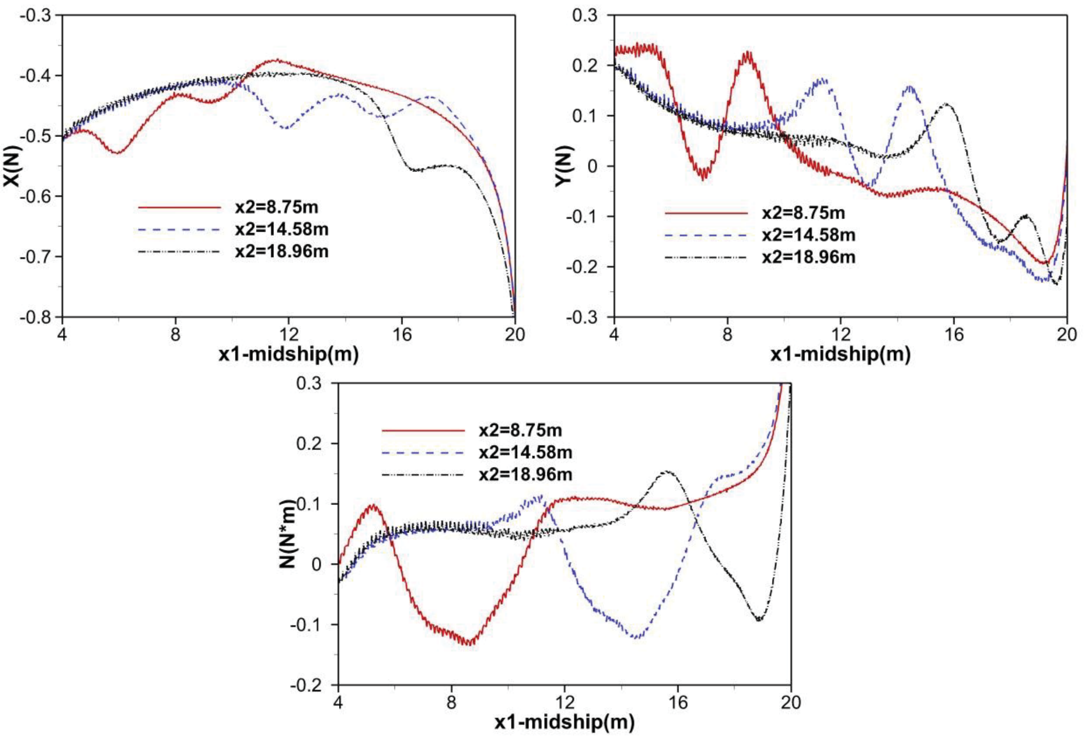


Fig. 7b: Hydrodynamic forces of passing ship changing with longitudinal position of berthed ship when the ship is passing by berthed ship

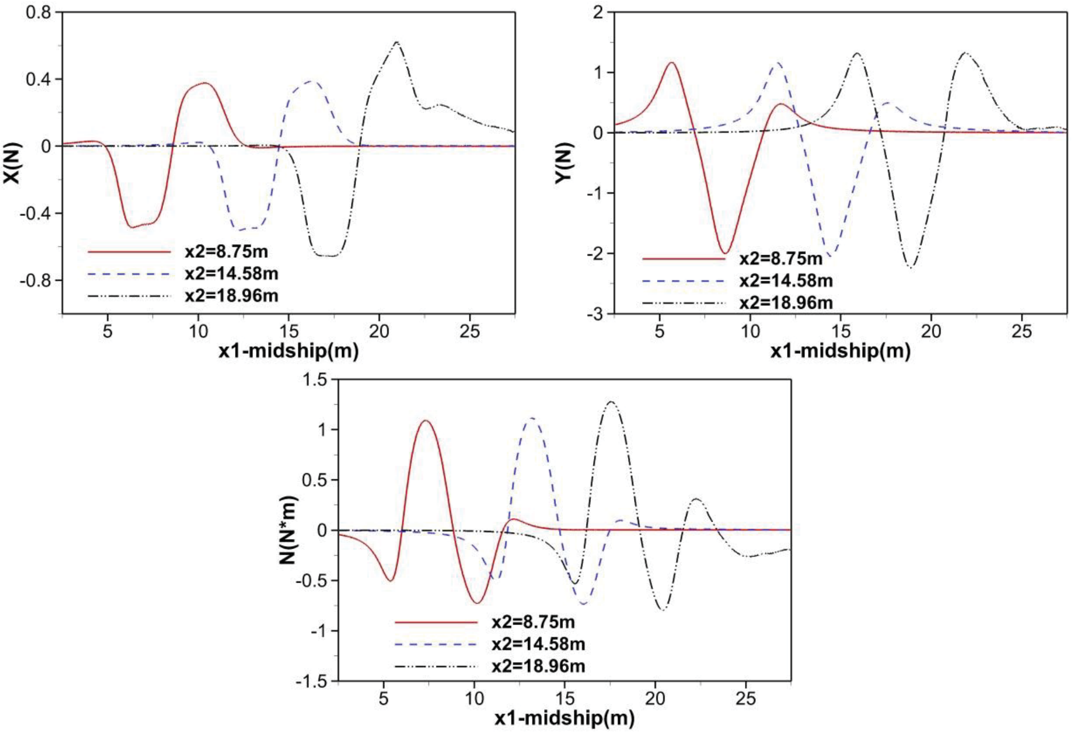


Fig. 7c: Hydrodynamic forces of berthed ship changing with longitudinal position of berthed ship in the whole process

CONCLUSIONS

A numerical study on the hydrodynamic interaction between a ship passing through a lock and a berthed ship is carried out by using an unsteady RANS solver. Hydrodynamic forces acting on passing ship and berthed ship are calculated. The lateral force and yaw moment acting on the passing ship are evaluated with good accuracy in comparison with the experimental data when there is no berthed ship. The hydrodynamic forces of passing ship induced by ship-lock interaction are much larger than the hydrodynamic forces of passing ship and berthed ship induced by ship-ship interaction. Meanwhile, the hydrodynamic forces acting on passing ship induced by ship-ship interaction are much smaller than the hydrodynamic forces acting on berthed ship. The effects of different transverse distance and longitudinal position of berthed ship on the hydrodynamic force and moment are investigated. The magnitude of hydrodynamic forces increases as the transverse distance decreases. Whatever the longitudinal position of berthed ship is, its effect on the maximal hydrodynamic forces acting on passing ship is small. However, the berthed ship closed to the lock entry will experience a larger force and moment when passing ship is entering the lock chamber. The present numerical method can qualitatively estimate the ship behaviour affected by a berthed ship when passing through a lock

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