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Ice forces acting on towed ship in level ice with straight drift. Part II: Numerical simulation

Li Zhou [a,*], Zhenju Chuang [b], Xu Bai [a]

[a] School of Naval Architecture and Ocean Engineering, Jiangsu University of Science and Technology, Zhenjiang, 212003 China
[b] DNV GL, Høvik, Norway

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Abstract

A numerical method is proposed to simulate level ice interaction with ship in transverse and longitudinal directions in time domain. A novel method is proposed to simulate non-symmetric transverse force in a stochastic way. On the basis of observations from the model tests, the simulation of longitudinal force combines the ice bending force acting on the waterline, submersion force below the waterline and ice friction forces caused by transverse force and ice floes rotation amidships. In the simulations the ship was fixed and towed through an intact ice sheet at a certain speed. The setup of the numerical simulation is similar to the ice tank setup as much as possible. The simulated results are compared with model tests data and the results show good agreement with the measurement.

Keywords: Numerical simulation; Level ice; Ice force; Comparison

1. Introduction

It is import to give a reasonable prediction of ice load on structures operating in ice covered waters. For safe design of marine structures, level ice load is often studied. A lot of researchers have applied different ways to study level ice interaction with marine structures. Lewis and Edwards (1970), Enkvist et al. (1979), Kotras et al. (1983) observed the main phenomena in the process of level ice breaking against the icebreakers and divided the whole process into several phases, including ice breaking, rotating, sliding and clearing. Sanderson (1988) separated the failure process into failure of the ice sheet through upward bending, and ride-up of the ice along the structure to calculate the ice load on sloping structures. Later, Lindqvist (1989), Keinonen et al. (1996) and Riska et al. (1997) developed some analytical and empirical formulas to calculate ice resistance based on massive full scale measurements on icebreakers. Hu and Zhou (2015) tried several popular empirical and analytical formulas to calculate ice resistance for head on scenarios.

Recent research on the numerical modeling of ice—hull interaction and ship maneuvering in level ice can be found for example in Valanto (2001), Liu et al. (2006), Martio (2007), Sawamura et al. (2010) and Lubbad and Løset (2011). For the simulation of full scale icebreaking runs, a more integrated model was developed and improved by Su et al. (2010). By modifying the model, Zhou et al. (2012) presented a 2D method for simulating level ice interaction with moored ship to investigate the station keeping problem and used a conical structure called the Kulluk to validate the simplified numerical model. Zhou et al. (2013a) performed a series of ice model tests to investigate the ice load experienced by an icebreaking tanker. The tanker was towed through the unbroken ice sheet to simulate the interaction process. Then the ice loads were measured. . Zhou et al. (2013b) applied a numerical model to simulate the dynamic ice loads acting on the icebreaking

* Corresponding author.
E-mail address: zhouli209@hotmail.com (L. Zhou).
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tanker Uikku in level ice, considering the action of ice in the vicinity of the waterline caused by breaking of intact ice and the effect of submersion of broken ice floes. The numerical simulations were also compared with the measured data as given in Zhou et al. (2013a). Good agreement was achieved though there are some deviations between predicted and measured results for some cases. However, the transverse force simulated is very small with the method when the ship is head on.

According to the model tests by Zhou (2016), the mean transverse forces are 1.2—5 times the mean longitudinal forces and the maximal transverse forces are 1.8—7 times the maximal longitudinal forces. The transverse force may make non-trivial contribution to the ice resistance. Therefore, a new method to simulate transverse force and longitudinal force is proposed based on observation from model tests and field. This is totally different from previous ideas on ice force components. In this paper, the transverse force will be simulated in a nondeterministic way. The contribution from the transverse force to the longitudinal force is included. A simple ice bending simulation method will be introduced. Moreover, ice submersion force and ice friction due to the rotation of ice floes at the middle part of the ship will be taken into account. Finally, the calculate results will be compared with model test results.

2. Numerical model

2.1. Transverse force model

Minor study has been done on the transverse ice force when ships travel ahead. The transverse ice force may give a large contribution to the ice resistance which need to be overcome by ships. Therefore, it is also import to do research on the transverse force in ice.

Løset (1998) performed a number of model-scale tests at a scale of 1:36 in the Hamburgische Schiffbau-Versuch-sanstalt GmbH (HSVA) ice tank in Hamburg. The aim is to study the feasibility of the Submerged Turret Loading (STL) concept in level ice, broken ice, and pressure ridges. The model of the STL ship was connected to the underwater platform by 8 mooring lines that were fixed to the turret. The ship model was driven straight ahead at 0.3, 0.4, and 0.75 m/s respectively in ice sheets with thicknesses of 1.1, 1.5, 1.6, 1.7 m by a carriage. A triaxial cell measured the forces in the x-, y- and z-directions at the turret. All measured longitudinal forces in x-direction are positive, but the measured transverse forces vary from negative to positive. The ratios of mean transverse force to longitudinal force for each test range from −70% to 110%, which shows that the transverse ice force should be taken into account.

In present study, the open water tests have been carried out when the ship model was towed forward with straight drift at speed 0.05, 0.5 and 1.0 m/s in full scale. The corresponding time series of transverse forces at steady state are now presented in Fig. 1. Some fluctuations could be found from the time series due to the vibration of the system. This is as

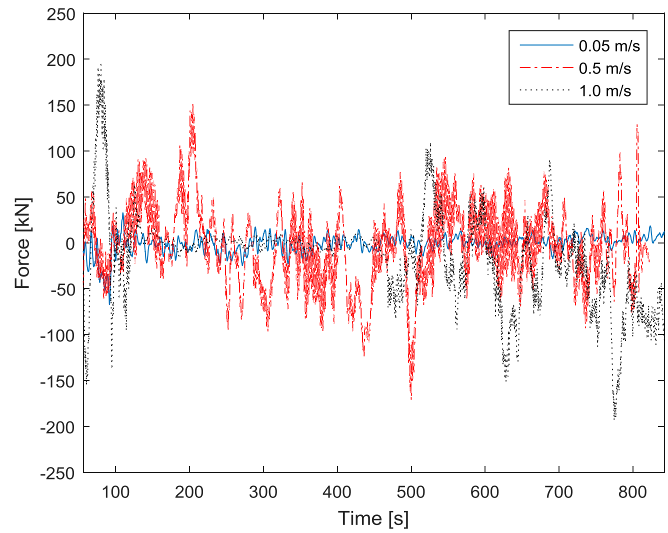

Fig. 1. Time history of measured transverse forces in open water.

expected. The mean transverse forces are 1, 7 and 24 kN respectively. According to the model tests done by Zhou (2016), the magnitude of the transverse ice force is much large than the longitudinal force in straight head on tests, ranging from 650 to 2710 kN for mean force. Compared to the mean transverse forces in ice, these measured forces in open water are trivial and could be neglected, which verifies that there is no significant problem with measurement systems and the measurements made by the system are reasonable. The measured data for the tests in ice are also valid. There exists non-symmetric transverse force which could not be neglected in amplitude indeed.

When the ship model advances in the ice sheet, the ice crack initiates at the shoulder area. The ice cusp will continue to crush against the mid hull area as it moves forward. In most occasions, ice impact at either side of the hull is not always simultaneous. The icebreaking pattern and resulting ice forces in the transverse direction is not symmetric along the longitudinal direction. A photograph of ice breaking pattern made in a test is given in Fig. 2. The ice cusp formed at the left side of the ice channel experienced re-broken in radial direction

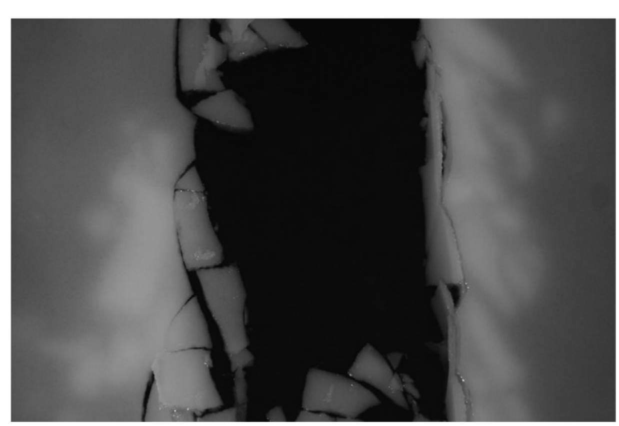

Fig. 2. Ice breaking pattern after the ship model was towed through.

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