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Ice forces acting on towed ship in level ice with straight drift. Part I: Analysis of model test data

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Abstract

A series of tests in an ice tank was carried out using a model-scale ship to investigate the ice loading process. The ship model Uikku was mounted on a rigid carriage and towed through a level ice field in the ice tank of the Marine Technology Group at Aalto University. The carriage speed and ice thickness were varied. In this paper, ice loading process was described and the corresponding ice forces on the horizontal plane were analysed. A new method is proposed to decompose different ice force components from the total ice forces measured in the model tests. This analysis method is beneficial to understanding contributions of each force component and modelling of ice loading on hulls. The analysed experimental results could be used for comparison with further numerical simulations.

Keywords: Ice model test; Ice forces; Level ice; Ice failure mode

1. Introduction

Due to the increased hydrocarbon exploration and exploitation in ice-covered waters, ship transports and operations under ice impact are becoming more and more concerned. It is important to study ice loads acting on ice-going vessels under design conditions in order to select appropriate propeller and propulsion system which meet power requirement of the ship.

The interaction between ship and level ice has studied ice resistance since 1970. Enkvist et al. (1979) discussed the main phenomena in the level ice-breaking process. Lewis and Edwards (1970) and Kotras et al. (1983) observed the level ice–hull interaction and divided the whole process into several phases, including ice breaking, rotating, sliding and clearing. Lindqvist (1989), Keinonen et al. (1996) and Riska et al. (1997) proposed some formulas to calculate ice resistance based on massive full scale measurements on icebreakers.

Zhou et al. (2013a) carried out a series of ice model tests to investigate the key ice load issues on an ice breaking tanker. A ship model of the ice going tanker Uikku was towed through the unbroken ice sheet to simulate the interaction process in the ice tank of the Aalto University. The aim was to measure the level ice loads and investigate the corresponding phenomena during the loading process at different constant ice drift directions and speeds. Zhou et al. (2013b) used a numerical model to simulate the dynamic ice loads acting on the ice breaking 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 in the model tests as shown in Zhou et al. (2013a). Good agreement was achieved in terms of mean value, standard deviation, maximum and extreme force distributions, though there are some deviations between predicted and measured results for some cases. Later, several popular empirical and analytical formulas were tried to calculate ice resistance for head on scenarios by Hu and Zhou (2015). It was found that the empirical methods could predict ice resistance at different

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accuracy, but none of them could give a good estimation for all cases. In order to further study ice resistance, second round of model tests has been performed using the same ship model (Hu and Zhou, 2016). Based on the model test results, the relationships between mean, maximum, minimum and standard deviation regarding ice resistance were summarized and highlighted.

In this paper, the measured data of the second round model tests in an ice tank were presented. A new method to analyse the measured ice forces from the model test is proposed. The aim is to decompose the total ice forces measured from the model tests into different ice force components. The contributions from different components are described and compared. This analyse method could be used for comparison with further numerical simulations.

2. Experimental setup

The second round of model tests was also carried out in the multifunctional ice basin of the Marine Technology Group at Aalto University. The ice breaking tanker model Uikku was used in the model test. The dimensions of the tanker were reduced to the model scale with a geometric scale factor of $\lambda = 31.6$. The particulars of the model and the full-scale vessels are given in Table 1.

The model ship was constrained so that the six force components could be measured. An upper frame with a stiff tube and long beam was used to connect the towing carriage, where the load measurement units were attached to the ship model (Fig. 1). The instrumentation applied for the model test includes an LFX_A_3 KN compact 6-component force transducer, a one-directional load cell and two cameras. A Dynamic Measurement Unit (DMU) was applied to measure the liner accelerations of the model ship. Six fully conditioned analogue signals were output by the DMU, which was connected directly to a data acquisition device without further buffering.

Some impact tests were conducted in open water to define the dynamic characteristics of the model ship. Frequency analysis was performed on the decay of the time series from the results of the free vibration test. The calculated natural frequency of the model setup was obtained and used to filter the measured ice forces.

The ice sheet was made by cooling, spraying, freezing and tempering. Two ice sheets were generated for these tests. The properties of the ice were measured according to the recommended procedures of the ITTC at three locations along each test lane. The average values of the ice thickness, h_i, the ice drift speed, v_i, the bending strength, σ_b, the compressive strength, σ_c, and the elastic modulus, E_i are given in Table 2. All data shown in the present paper are in full scale if not specified otherwise.

Table 1
Primary dimensions of MT Uikku.

Item	Full scale	Model scale
Length [m]	150	4.75
Breadth molded [m]	21	0.67
Tested draft [m]	9.5	0.30
Bow waterline angle [deg]	21	
Bow stem angle [deg]	30	
Block coefficient	0.72	

In the model tests, dynamic ice forces acting on the ship model were measured in six degrees of freedom with assistance of load cells as shown in Fig. 1. When the ship model was towed forwards during the tests, the ice failure modes and ice breaking process were observed and recorded by the videos. The typical ice breaking lengths were measured after the test stopped. One scope of the model test is to find the relationships between longitudinal ice force and transverse ice force by analysing model test results. In total, there are six tests performed in two different ice sheets with thickness of 1.03 and 0.63 m. The drift speeds that were used to tow the ship model are 0.2, 0.5, 1.0 m/s.

3. Ice loading process

The ship model was towed through ice field straight forward at different speed by the main carriage. During the model tests, bending failure was observed to be the most predominant failure mode. As the model ship interacted with the intact ice sheet, ice crushed at its very bow stem. Ice failed by progressively bending downwards around either side of the bow. Ice breaking was initiated with a circumferential crack which was propagated by arcing circumferentially toward the bow stem and shoulder. Then, a radial crack occurred after the circumferential crack formed as the bow advanced. The radial crack resulted in the re-breaking of ice floes. The ice breaking pattern is shown in Fig. 2.

Once the circumferential crack developed at the shoulder area, the edge of the cusp was crushed with another end supported by the surrounding intact ice sheet. This loading process is similar to a hinge being pressed in the axial direction. The typical ice pieces at the shoulder were larger than those formed at the bow. Normally, the duration of the rotation process lasted much longer than that of the cusps broken at the bow. After the first piece formed in a breaking sequence, more followed the same breaking pattern while the first one rotated until the open channel was wide enough for the model ship to move through the ice sheet. This process gives rise to added resistance in the longitudinal direction. This added resistance is the frictional force arising from the crushing and rotation at the mid-body area. Figs. 3 and 4 show ice breaking scenarios on the port and starboard side of the hull respectively. It is found that ice breaking process is not always simultaneous at both sides, which may lead to large transverse ice force.

Field observations have shown similar trend of the interaction process at the parallel mid-body of vessel. Very large ice pieces with a curved edge were bent down from the intact ice cover, after which the piece would rotate and submerge against the hull as shown in Fig. 5.

Ice transport underwater, which is related to ice submersion force, was also observed according to the videos made by two cameras underwater. There was no ice accumulation or ice pile

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