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Numerical study on the structural response of energy-saving device of ice-class vessel due to impact of ice block

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A B S T R A C T

The present paper considers the contact between energy-saving device of ice-class vessel and ice block. The main objective of this study is to clarify the tendency of the ice impact force and the structural response as well as interaction effects of them. The contact analysis is performed by using LS-DYNA finite element code. The main collision scenario is based on Finnish-Swedish ice class rules and a stern duct model is used as an energy-saving device. For the contact force, two modelling approaches are adopted. One is dynamic indentation model of ice block based on the pressure-area curve. The other is numerical material modelling by LS-DYNA. The authors investigated the sensitivity of the structural response against the ice contact pressure, the interaction effect between structure and ice block, and the influence of eccentric collision. The results of these simulations are presented and discussed with respect to structural safety.

1. Introduction

An energy-saving device is one of the most effective measures to improve propulsive efficiency in ice-free water. It is expected to be effective for ice-class vessels. However, its strength due to ice contact should be carefully considered in its design, and it is a significant technological issue to evaluate structural response due to impact of ice. Since some types of energy-saving devices are protuberant structure, they are strongly affected by dynamic factor such as oscillation. Therefore, “Time-domain” analysis is necessary instead of conventional “Static” estimation based on energy theory. Kinnunen et al. (2013, 2015) implemented the contact analysis between ice and the azimuthing thruster. They indicated that the dynamic behavior of the structure affected the impact load significantly.

The purpose of the present study is to investigate the tendency of ice contact load and the structural response of the stern duct equipped for ice-class vessels. The main contact scenario is based on Finnish-Swedish Ice Class Rules (TRAFI, 2010), and the used stern duct structure is Weather Adapted Duct (Kawashima et al., 2014) developed in National Maritime Research Institute, Japan. In this study, the authors carried out a series of non-linear dynamic finite element simulations to evaluate the structural safety and estimate the ice contact load, including the effect of ice–structure interaction. For the ice contact load, two modelling approaches are adopted. One is dynamic indentation model of an ice block based on the pressure-area curve. The other is numerical material modelling by LS-DYNA to consider ice–structure interaction. For the evaluation of structural safety, the sensitivity analysis against the ice contact pressure was performed. In addition to the structural response, the ice contact load was investigated in detail such as the effect of the structural interaction and the influence of eccentric collision.

2. Ice load scenarios

It is assumed that the ice block contacts to the front end of stern duct as shown in Fig. 1. According to Finnish-Swedish Ice Class Rules (2010), the maximum design ice block entering the propeller is a rectangular ice block with the dimensions of $H_{ice} \cdot 2H_{ice} \cdot 3H_{ice}$. The thickness of the ice block H_{ice} is given as 1.5 m for ice-class 1A. The density of ice block ρ_{ice} was assumed to be 880 kg/m^3, and the added mass was given as the following equation (Karasuno et al., 1998).

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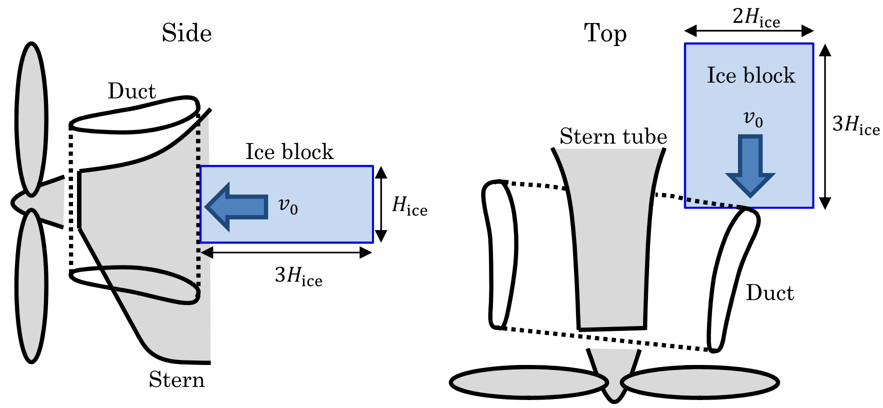

Fig. 1. Contact between stern duct and ice block.

$$M_a = 1.82\rho_{ice}H_{ice}^3 \quad (1)$$

Only the added mass was considered as the fluid force effect. The initial velocity of the ice block is assumed to be 5 knot that is required as a vessel speed in the brash ice channels for the powering requirement of Finnish-Swedish Ice Class Rules. These values are summarized in Table 1.

3. Ice modelling

To perform safety evaluation, it is one of the most important processes to estimate an ice contact load. In this study, two load modelling approaches are adopted. One is the simple estimation model based on pressure-area curve (Daley, 1999). The ice load for structural requirement in UR-I (IACS, 2007) is based on this model. The other is FEM modelling. In order to validate the applicability, the dynamic contact simulation between ice block and rigid cylinder was carried out.

Table 1
Ice block basic parameter.

Ice thickness H_{ice}	1.5[m]
Ice mass M_{ice}	17,820[kg]
Ice added mass M_a	6296[kg]
Initial velocity v_0	2.572[m/s]

3.1. Load model based on pressure-area curve

The general principles of the model are shown in Fig. 2. In this analysis, it is assumed that the ship speed is constant while collision of ice block. The fore part of the stern duct is modelled to be a rigid cylinder, and the indentation depth ζ_n can be obtained by the motion equation of an ice block.

$$(M_{ice} + M_a)\ddot{\zeta}_n = -F_n \quad (2)$$

Here, the ice contact force F_n is expressed as a product of average contact pressure P and nominal contact area A:

$$F_n = PA \quad (3)$$

Here, P is expressed as a function of A:

$$P(A) = P_0 A^{ex} \quad (4)$$

Here, P_0 is average contact pressure at $A = 1$ m^2, and *ex* is an exponent constant. In this paper, the following equations are mainly used.

$$P(A) = 2.2A^{-1/3} \quad (5)$$

$$P(A) = 7.4A^{-0.7} \quad (6)$$

The Eq. (5) is proposed by Frederking and Ritch (2009) based on impact tests of bergy bit and ship. The Eq. (6) is proposed by Masterson (Palmer et al., 2009) for isolated small areas (<10[m^2]), which is also recommended by the ISO code (ISO, 19906, 2010).

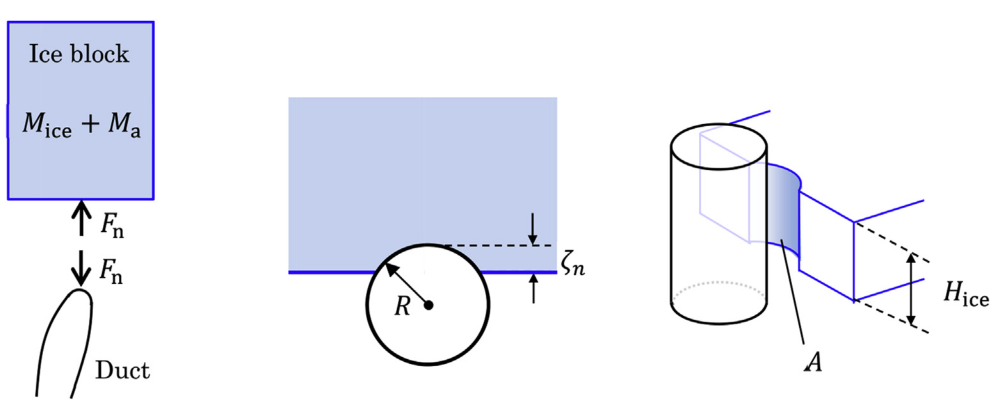

Fig. 2. Indentation of vertical cylinder.

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