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Experimental and numerical study on ice resistance for icebreaking vessels

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ABSTRACT: *Ice resistance is defined as the time average of all longitudinal forces due to ice acting on the ship. Estimation of ship's resistance in ice-covered waters is very important to both designers and shipbuilders since it is closely related to propulsion of a ship and it determines the engine power of the ship. Good ice performance requires ice resistance should be as low as possible to allow different manoeuvres. In this paper, different numerical methods are presented to calculate ice resistance, including semi-analytical method and empirical methods. A model test of an icebreaking vessel that was done in an ice basin has been introduced for going straight ahead in level ice at low speed. Then the comparison between model test results and numerical results are made. Some discussions and suggestions are presented as well to provide an insight into icebreaking vessel design at early stage.*

KEY WORDS: Ice resistance; Ice resistance formulas; Model test data; Icebreaking vessels.

INTRODUCTION

Growing interest in shipping and drilling operations in ice-covered waters has triggered more investigation on ice loads estimation. Understanding and calculating ice loads form the basis of ship design for ice. For icebreakers and icebreaking vessels, ice resistance estimation is a key mission in preliminary stage of design process and highly related to ship's global performance. Once a certain hull is determined, it is important for designers to have insight into ice loads in order to select propeller and propulsion system which meet power requirement of the ship. The hull designed is expected to undertake low ice resistance and have good performance in ice under certain ice conditions.

Many researchers has done research on ice resistance and thus developed a lot of empirical and analytical formulas since 1970. Enkvist et al. (1979) discussed the main phenomena in the level ice-breaking process. Keinonen et al. (1996) presented equations to calculate ice resistance for a ship traveling at low velocity in level ice based on massive full scale measurements on icebreakers. Riska et al. (1997) proposed a formula to calculate ice resistance. In particular, some researchers divided level ice-hull interaction process into several phases, including ice breaking, rotating, sliding and clearing (Lewis and Edwards, 1970; Kotras et al., 1983; Lindqvist, 1989; Spencer et al., 2001; Valanto, 2001; Jeong, 2010).

More recently, some researchers began to develop numerical simulation in time domain. Wang (2001) initialized a method

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for simulating the interaction between moving level ice and a fixed conical structure. Based on the ice failure model derived by Wang (2001), Su et al. (2010) refined the ice-ship contact procedure to simulate ship manoeuvres in level ice. The numerical analysis was validated by comparing simulations with ship performance data of icebreaker Tor Viking II.

However, no single and exact method to calculate ice resistance exists. In this paper, a numerical method in time domain and several typical ice resistance formulas often used are described. The calculated results are compared with those from the model tests. Some discussions and suggestions on selections of formulas and how to make a reasonable prediction on ice resistance are made. This might provide help to icebreaker designers to some extent.

METHOD OF NUMERICAL SIMULATION IN TIME DOMAIN

In the present simulation, there are two reference frames used, see Fig. 1.

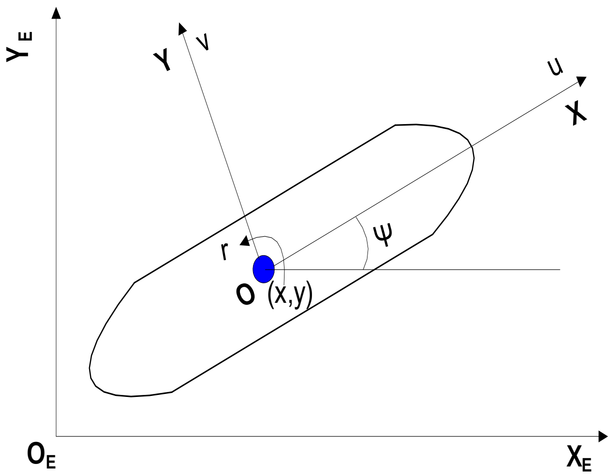

Fig. 1 Earth-fixed ($X_EY_EZ_E$) and body-fixed (XYZ) reference frames in the horizontal plane.

- The Earth-fixed frame, denoted as $X_EY_EZ_E$, is placed so that the X_EY_E plane coincides with the water surface, and the Z_E axis is positive downwards.
- The body-fixed frame, denoted as XYZ, is fixed to the vessel in such a way that the origin coincides with the centre of gravity, the X-axis is directed from aft to fore along the longitudinal axis of the hull, and the Y-axis is directed to the starboard.

The horizontal position and orientation of the vessel in the Earth-fixed coordinate system are defined by $\boldsymbol{\eta} = [x, y, \psi]$, where the first two variables describe the position and the last variable describes the heading angle. Correspondingly, the translational and rotational body-fixed velocities are defined by $\mathbf{V} = [u, v, r]$. The body-fixed general velocities are transformed to the Earth-fixed frame by

$$\dot{\boldsymbol{\eta}} = \mathbf{J}(\boldsymbol{\eta})\mathbf{v} \tag{1}$$

$$\mathbf{J}(\boldsymbol{\eta}) = \begin{bmatrix} c\psi & -s\psi & 0 \\ s\psi & c\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

where c, s are compact notations for cosine and sine, respectively.

The equation of motion is first expressed in the Earth-fixed coordinate system and then converted to the body-fixed coordinate system. Based on Newton's second law, the linear coupled differential equations of motion in the body-fixed coordinate can be written in the following form: