Cold Regions Science and Technology 106–107 (2014) 96–109

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Numerical assessment of a double-acting offshore vessel's performance in level ice with experimental comparison

Biao Su [a,*], Roger Skjetne [a], Tor Einar Berg [b]

[a] Department of Marine Technology, NTNU, Trondheim, Norway
[b] MARINTEK, Trondheim, Norway

ARTICLE INFO

Article history:
Received 13 March 2014
Accepted 25 June 2014
Available online 1 July 2014

Keywords:
Double-acting vessel
Numerical model
Icebreaking capability
Ship maneuverability
Ice model test

ABSTRACT

In this paper a numerical model is used to investigate the level ice performance of a double-acting intervention vessel, and the results are compared with a limited set of experimental data. The icebreaking capability and maneuverability in level ice are analyzed by evaluating the behavior of the vessel when it is running both ahead and astern. The simulated icebreaking patterns, h–v curves, and turning circles in different modes of operation are discussed and compared partly with the corresponding ice model tests. The simulation results can supplement the experimental data by providing more information about the vessel's maneuverability in level ice and identifying the physical foundation for the exhibited performance of the vessel. The paper also presents the implementation of a random crack size model for more realistic icebreaking behavior, giving more consistent evaluation of the ship's performance in various ice conditions.

1. Introduction

Since the beginning of the 1990s, the major development of ice-going ships has been the use of podded propellers in ice with double-acting vessels (Jones, 2004). The idea is to design an efficient icebreaking stern for the vessel while keeping an efficient open-water bow. During these years a number of vessels have been designed and built according to the double-acting principle. Vocke et al. (2011) presented a recent review of the experiences gained from realized projects where the most relevant milestones in double-acting vessel developments were summarized. These vessels were first tested and studied in the ice model basin to get the best possible design features. Many operational experiences have also been gained through full-scale ice trials and practical operations of the vessels.

The double-acting principle is of interest to the offshore industry as the oil and gas explorations are moving further north. In collaboration with several research institutes and companies, MARINTEK recently completed a project to develop a vessel (the CIVArctic vessel) for all-year intervention work on subsea oil and gas installations in the north-eastern part of the Barents Sea. As the vessel will be operating and transiting in open waters for most of its working time, the design focus was initially on open-water performance. An efficient icebreaking stern was then designed for operation in moderate first-year level ice. A series of open-water and ice model tests have been carried out to verify this design (Berg et al., 2013).

In the present paper a numerical model is applied to evaluate the level ice performance of the CIVArctic vessel. In general it should be mentioned that level ice breaking takes only a small fraction of the total operating time of the vessel. The reason why the level ice is often considered is that the design ice conditions are defined in most ice class rules (e.g. Finish–Swedish Ice Class Rules) by using the equivalent level ice thickness. Analysis of the hull damages caused by ice shows that this definition gives a reasonable estimate of the severity of ice conditions (Riska, 2007). For a more robust design, the CIVArctic vessel was also tested in floe ice and ice ridges; however, this paper only focuses on the level-ice performance and mainly describes the numerical studies with a comparison to experimental test results. The icebreaking capability and maneuverability in level ice are analyzed by evaluating the behavior of the vessel when it is running both ahead and astern. The results of the comparison also identify the physical foundation for the exhibited performance. Another contribution of this paper is the implementation of a random crack size in the modeling of icebreaking. This will give a more consistent evaluation of the ship's performance in various ice conditions.

2. Numerical model

As shown by the illustration in Fig. 1, the ice forces encountered by a ship transiting level ice depend primarily on the icebreaking and displacement processes. First the ice sheet touches the hull, and crushing occurs. This load will increase with the contact area until the ice sheet fails some distance away from the interaction zone. The failure mechanisms are mainly governed by the interaction geometry and ice

* Corresponding author. Tel.: +47 73551113; fax: +47 73595697.
E-mail address: biao@ntnu.no (B. Su).

http://dx.doi.org/10.1016/j.coldregions.2014.06.012
0165-232X/

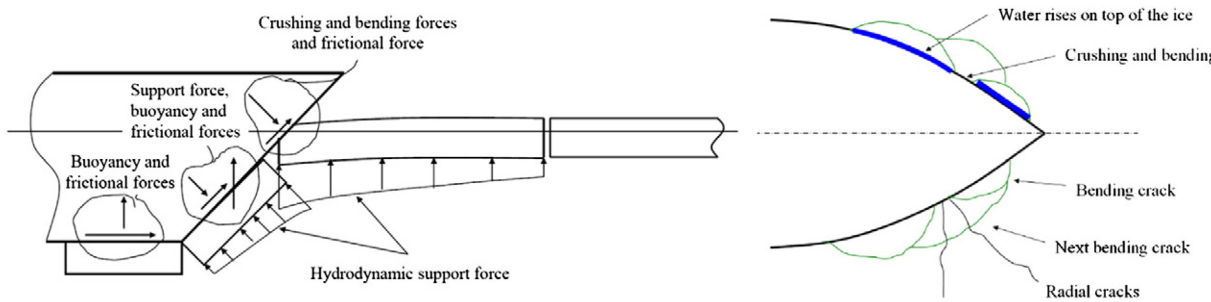

Fig. 1. Illustration of the ice–hull interaction process.
Source: Riska (2010).

material properties involved. For inclined planes, this usually means a bending failure. After the ice floe has been broken from the ice sheet, the advancing ship forces it to rotate, submerge, and slide along the hull. In some hull zones, typically at the shoulders and midship with large slope angles, crushing may be the only failure mode. A relative heading toward the ice sheet heavily exposing these hull sections will cause enlarged resistance.

Relevant examples of research on numerical modeling of ice–hull interaction and ship maneuvering in level ice can be found in Liu et al. (2006), Martio (2007), Nguyen et al. (2009), Sawamura et al. (2010), Lubbad and Løset (2011) Metrikin et al. (2013), and Tan et al. (2013), Valanto (2001). In this paper, the validated partly empirical numerical model presented in Su et al. (2010a) is applied to investigate the icebreaking capability and maneuverability of the CIVArctic vessel in level ice. A 2D simulation program has been developed to reproduce the observed icebreaking patterns and the continuous icebreaking forces imposed by a level ice sheet, where the ice has uniform or randomly varying thickness and strength properties. The numerical method for the realization of the physical process of icebreaking can be found in Su et al. (2010a, 2011), while the simulation of ship maneuvering is mainly described herein.

2.1. Equations of ship's motion

Fig. 2 illustrates the numerical ice–hull interaction model, which enables simulations of ice maneuvering by solving the three-degree-of-freedom differential motion equations for surge, sway, and yaw:

$$(\mathbf{M}+\mathbf{A})\cdot\ddot{\mathbf{x}}(t)+\mathbf{B}\cdot\dot{\mathbf{x}}(t)+\mathbf{C}\cdot\mathbf{x}(t)=\mathbf{F}(t) \quad (1)$$

where **M**, **A**, **B**, and **C** are the rigid body mass, added mass, damping, and restoring force matrices, $\mathbf{x}=[x \quad y \quad \psi]^{\mathrm{T}}$ is the displacement vector (surge, sway, and yaw) expressed as a function of time t, $\dot{\mathbf{x}}$ and $\ddot{\mathbf{x}}$ are, respectively, the first and second time derivatives of **x** (velocity and acceleration), and $\mathbf{F}=\left[F_x \quad F_y \quad M_z\right]^{\mathrm{T}}$ is the force/moment vector.

The added mass and damping matrices are calculated in open water without considering the effect of ice. The contributions from wind and waves are neglected as minor forces to the ice load.

2.2. Force decomposition

In order to evaluate the forces encountered by a ship transiting in level ice, one of the basic assumptions that have commonly been accepted is that the total ice resistance can be taken as the superposition of several force components, that is, icebreaking force, ice floe rotation and submergence force, and friction force associated with ice contact. However, this assumption is questionable since the force components could be "complicatedly entangled in each other" (Enkvist et al., 1979; see also Kjerstad et al., 2014, where these phenomena are discussed further, especially the interaction between the vessel and the accumulated ice masses, which effectively increases the total mass of the affected system). Moreover, since open-water resistance is usually very small compared to ice resistance at icebreaking speeds, the coupling between them could be neglected without causing significant errors. Thus, we assume that the open-water resistance and the pure ice resistance are also separable (as described in Riska et al., 1997).

Based on this superposition principle, the force/moment vector is then decomposed as:

$$\mathbf{F}=\mathbf{F}_p+\mathbf{F}_{brk}+\mathbf{F}_{sbmg}+\mathbf{F}_{ow}+\mathbf{F}_{Euler} \quad (2)$$

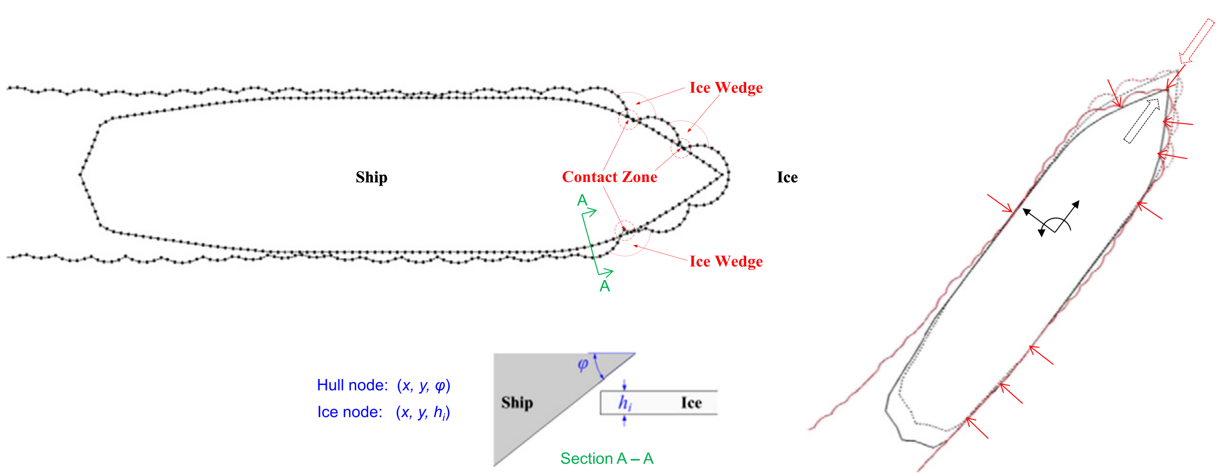

Fig. 2. Illustration of the numerical ice–hull interaction model.
Su et al. (2010a).