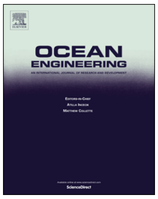
Ocean Engineering 119 (2016) 217–232

Contents lists available at ScienceDirect

Ocean Engineering

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



Influence of bow design on ice breaking resistance

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ARTICLE INFO

Article history:
Received 11 March 2015
Accepted 6 February 2016
Available online 22 February 2016

Keywords:
Ice breaking resistance
Resistance prediction method
Bow shape
Ice breaking ships
Level ice

ABSTRACT

One of the main contributions to the resistance in level ice is the breaking force which is mainly influenced by the bow shape, beside ice properties and the ship's speed. Understanding the influence of the bow shape on the ice breaking resistance is essential for the assessment of the hull form in an early design stage. However, at a first glance the bow shapes of modern ice breaking vessels seem to be quite similar. Thus, a need exists to evaluate the contribution of the ice breaking force to the resistance in ice methodically for different bow shapes. Since model tests are still the most reliable resistance prediction method, they form the basis for the analysis of the ice breaking process at the bow. Specifically, breaking patterns and geometric bow parameters are investigated. The findings are compared with the selected semi-empirical method of Lindqvist. On this basis the Lindqvist approach is evaluated with further model test results and theoretical considerations. Finally, refinements of the Lindqvist formula are suggested where appropriate based on the analysis.

1. Introduction

The major requirement for ice breaking ships is a good performance in level ice. Good performance means low ice resistance, high propulsive efficiency and guaranteed continuity in ice breaking. This paper focuses on the resistance in ice, which can be subdivided into the following categories according to the different forces acting on the ship hull: Breaking, rotary, submersion and sliding forces (Puntigliano, 2003). This subdivision of the resistance in ice is the result of creation and advance of ice floes caused by the ship hull proceeding through the ice.

In practical ship design empirical or semi-empirical formulas are used to approximate the resistance in the early design stage. After one or more promising designs have developed, a numerical resistance prediction method based on Computational Fluid Dynamics (CFD) or other advanced numerical methods may be used. But up to now the available CFD-methods for ice resistance prediction are not sufficiently reliable to give a valuable contribution to the design process. Thus, in a later design stage model tests have to be used to evaluate one or few specific designs.

One of the main contributions to the resistance in level ice is the breaking force (Puntigliano, 2003; Riska, 2006; Valanto, 2001), which is mainly influenced by the bow shape, beside ice properties and the ship's speed. Although the bow shapes of modern ice breaking vessels seem to be quite similar at a first glance the breaking resistance may show significant differences. In order to save costs and time during the design process it is of great advantage to be able to evaluate the ice breaking resistance of a vessel in an early design stage as precisely as possible. However, there may be constraints for the bow geometry due to ice class requirements. Important ice class rules are given by the Finnish Transport Safety Agency, TraFi (TraFi, 2010), and the Russian classification society RMRS (Russian Maritime Register of Shipping, 2013). Specifically, TraFi requires a certain engine power depending on the ice class resulting from an approximation formula. The formula is based on the bow geometry and the main dimensions of the ship. The Russian rules require certain angles of the bow depending on the ice class. Beside the existing regulations, a need exists to evaluate the contribution of the ice breaking force to the total resistance methodically for different bow shapes.

As a consequence, a detailed analysis of different bow shapes based on ice model test results from HSVA's database from 1996 to 2014 is carried out. The analysis is based on current ice breaking ships such as Ice Breaking Supply Vessels, Anchor Handling Tugs as well as Salvage or Rescue Vessels. Especially in recent years the demand for such ice breaking ships increased strongly, which is why the majority of the available test data originates from this group of ships. The analysis focuses in particular on the breaking patterns formed in level ice (Fig. A15) with regard to relevant hull shape parameters as identified by Myland and Ehlers (2014). The main hull data of the ships are presented in Table A1. The ship models chosen for test analysis have similar scaling factors leading to model ice conditions, model speed values and ship model dimensions in the same range. In order to

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http://dx.doi.org/10.1016/j.oceaneng.2016.02.021

Nomenclature

B	ship breadth
E	modulus of elasticity
FP	pull force
g	gravitational acceleration
h_{ice}	level ice thickness
l	length of cusp
l_c	characteristic length of ice
L, L_{pp}	ship length between perpendiculars
L_{bow}	ship bow length
n	number of cusps
n_{idling}	rate of revolution at idling condition
n_{max}	maximum rate of revolution
R_B	bending resistance
R_{B1}	bending resistance at 1/8 B
R_{B2}	bending resistance at 2/8 B
R_{B3}	bending resistance at 3/8 B
R_{B4}	bending resistance at 4/8 B
R_{BR}	breaking resistance
R_C	crushing resistance
R_{ice}	ice resistance
R_{OW}	open water resistance
R_S	submersion resistance
RIT, R_{tot}	total resistance
T	ship draught
THDF	trust deduction fraction
TT	thrust
v	ship velocity
α	waterline (entrance) angle
α_{avg}	average waterline angle at center line of hull
$\alpha 1$	waterline angle at 1/8 B
$\alpha 2$	waterline angle at 2/8 B
$\alpha 3$	waterline angle at 3/8 B
$\alpha 4$	waterline angle at 4/8 B
$\Delta\rho$, ρ_g	density difference
μ	friction coefficient between ship hull and ice
ν	Poisson's ratio
ρ_w	density of water
σ_f, σ_{flex}	flexural strength
φ	buttock angle
ϕ	stem angle
ψ	normal angle – angle between normal to the bow plate and vertical
ψ_{avg}	average normal angle

obtain a certain friction coefficient between ice and hull ($\mu=0.1$) the tested ship models were painted with a special paint composition.

The actual ice and ship property values of the selected ice model tests were measured during the testing and extrapolated to their target values in full scale as listed in Table A2. The extrapolation was done according to HSVA's standard correction methods (Appendix C – Data Analysis). The methods were set up in the past by comparison of full scale trials with corresponding model test results. These correction methods have been validated against full scale data several times. Using the target ice and ship property values improves the precision of the analysis since the range of considered ice properties is reduced. Thus, the ice and ship property values as listed in Table A2 can be kept almost constant throughout the analysis. As a consequence the analysis can be mainly focused on the bow shape. Due to the fact that the selected model tests were carried out as towed propulsion tests the target value of the ship speed is equal to the measured value. The model test conditions of ice and investigated ships correspond to typical design values of the chosen group of ships.

Understanding the influence of the bow shape on the total resistance is essential for the assessment of the hull form in an early design stage. Several theoretical ice prediction methods may be applied here, e.g. Su et al. (2010), Sawamura (2012), Lindström (1990), Valanto (2001) and Lindqvist (1989), which take into account the physical effects of the ice breaking process by different approaches. In Table A3 a systematic comparison of the mentioned methods is given.

Another issue, which has a large influence on the prediction of the resistance in ice, is the precision with which the hull shape of the ship is considered. Provided that the hull shape is taken into account, only a limited number of characteristic values are used for its description. The same applies for the ice conditions. Thus, from comparison of the presented theoretical ice prediction methods it can be concluded that the relevant resistance contributions are considered differently for each method by means of generalizing assumptions, strong simplifications, or are even neglected in the existing approaches. Thus, further research is required to predict the resistance and its components more precisely as stated in Myland and Ehlers (2014).

From theoretical considerations the obvious difference between model tests and all presented methods in Table A3 is that model tests seek to cover major physical effects of full scale ship-ice interaction, whereas almost every analytical or empirical method is the result of the author's judgment about the significance and influence of each physical effect by setting up equations to describe them. However, some of the formulas include physical effects of full scale ship-ice interaction by taking into account model test results. Nevertheless, also these methods lead to only rough estimations of the resistance, since the present ship design, i.e. the bow shape, is not fully considered in the applied prediction method. Consequently, the aim of this paper is to analyze the ice breaking process at the bow in more detail, compare the findings with a selected semi-empirical method, evaluate the semi-empirical method with further model test results and theoretical considerations and finally suggest adjustments where appropriate based on the analysis. The prediction method is chosen on the basis of Table A3 with the objective to identify the influence of geometric changes on the resistance rapidly in the conceptual design phase. Table A3 reveals that the Lindqvist method is the most advanced empirical prediction method for calculation of the ship`s resistance in level ice by taking into account the most hull shape and ice parameters.

2. Presentation of applied methods

Brief descriptions of two resistance prediction methods are given in this chapter – Lindqvist approach and ice model tests.

Since model tests are still the most reliable resistance prediction method, they form the basis for the analysis of the ice breaking process at the bow. The findings are finally used to suggest adjustments for the semi-empirical method of Lindqvist where appropriate. Table A3 reveals that the approach of Lindqvist forms a valuable basis for revision, because it takes into account most relevant hull shape and ice parameters.

2.1. Lindqvist approach

Lindqvist (1989) approximated the ice resistance by simple but physically sound formulas. The considered hull parameters are presented in Fig. A7.