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A prediction method of ice breaking resistance using a multiple regression analysis

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ABSTRACT: *The two most important tasks of icebreakers are first to secure a sailing route by breaking the thick sea ice and second to sail efficiently herself for purposes of exploration and transportation in the polar seas. The resistance of icebreakers is a priority factor at the preliminary design stage; not only must their sailing efficiency be satisfied, but the design of the propulsion system will be directly affected. Therefore, the performance of icebreakers must be accurately calculated and evaluated through the use of model tests in an ice tank before construction starts. In this paper, a new procedure is developed, based on model tests, to estimate a ship's ice breaking resistance during continuous ice-breaking in ice. Some of the factors associated with crushing failures are systematically considered in order to correctly estimate her ice-breaking resistance. This study is intended to contribute to the improvement of the techniques for ice resistance prediction with ice breaking ships.*

***KEY WORDS**:* Ice breaking ships; Multiple regression analysis; Ice model test; Ice resistance; Crushing failure.

NOMENCLATURES

α	Waterline angle (*Deg.*)	E	Elastic modulus (*Pa*)
μ	Frictional coefficient (-)	h	Ice thickness (*m*)
σ_f	Flexural strength (*Pa*)	L	Ship's length (*m*)
φ	Stem angle (*Deg.*)	R_{BR}	Ice breaking resistance (*N*)
B	Beam (*m*)	T	Draft (*m*)
C_{BR}	Coefficient of ice breaking resistance (-)	v	Ship's velocity (*m/s*)

INTRODUCTION

The hull and propulsion system of ice breaking ships used to be designed and constructed largely on the basis of sailing experience in the Baltic and Norwegian Seas, or else by making adaptations to existing vessels designed for the open-water. Then, in the early 1960s, a design for an ice-breaker was tested in model ice (Corlett and Snaith, 1964). This was the Polish ice-

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breaker, the Perkun, launched in 1964. To meet their particular requirements, the bow of ice breaking ships needs to be sharp, with a small stem angle, so as to break the ice sheets easily, while her propulsion system needs to be 2~3 times stronger than that of an open-water vessel.

By the late 1960's, many studies had been conducted with model tests in ice and new hull types for breaking sea ice efficiently (Kashteljan et al., 1968; Lewis and Edwards, 1970; Edwards et al., 1972; Enkvist, 1972; Vance, 1975). These model tests were followed by ice trial tests. By this time, the purpose of ice breaking ships was changing from pure research to exploration and transportation, due to the discovery of crude oil in Alaska (White, 1970). This discovery prompted an important leap forward in the study of polar engineering.

In the 1980's, it was reported that enormous oil and natural gas resources were lying under the area above the Arctic Circle. However, arctic platforms that could endure ice loads would be required for the oil drilling, and many strong icebreakers and expensive ice-strengthened vessels would be needed for the safe transportation of the oil. Furthermore, the price of oil was only gradually stabilizing across the globe. For these reasons, there was very little activity in arctic development projects at that time.

Since the 2000's the economic efficiency of the Northern Sea Route (NSR) has improved, due to a decrease in the extent of the sea ice in the Arctic; consequently research into the development of the Arctic is steadily moving forward, and the value of the area's natural resources becomes increasingly significant. Therefore, large ice-breaking merchant vessels that can make their own way through ice, and arctic platforms for the drilling and production of oil are now under construction (Niini et al., 2007; Clarke et al., 2005). In addition, more reliable testing techniques for using ships in ice have been developed through improvements in the measurement techniques used with ice model tests, and with new model test methods and the further development of sea ice trials (Cho et al., 2011; 2013; Kim et al., 2014).

In this paper, some major studies on ice resistance done in the 1970's are briefly reviewed and analyzed, and the merits and demerits of each study are identified. We have also developed a new procedure for estimating ice breaking resistance, based on model tests with three medium ice breaking ships, which were built recently and exhibit good ice breaking performances. Through dimensional and regression analysis, an equation that includes various influencing factors and a logical procedure for deciding on weights is proposed. The equation is compared with previous studies, and is evaluated against the results of the model test.

Previous studies

Much literature related to ice resistance has been published since 1960, however Kashteljan et al. (1968) proposed the first detailed equation to analyze the level of ice resistance by breaking it down into its components. They divided total ice resistance into the resistance due to breaking the ice, the resistance due to forces connected with weight, and the resistance due to passage through broken ice, but omitted the open-water resistance, as shown in Table 1. Their equation was developed from a model and then full-scale tests were done with the Ermak.

Table 1 Various equations used for the estimation of ice breaking resistance in previous studies.

Published by	Year	Ice-breaking resistance
Kashteljan et al.	1968	$C_{BR}\sigma_f Bh\mu_o$
Lewis et al.	1970	$C_{BR}\sigma_f h^2$
Edwards et al.	1972	$C_{BR}\sigma_f Bh$
Enkvist	1972	$C_{BR}\frac{\sigma_f}{E}Bh\sigma_f$
Vance	1975	$C_{BR}\sigma_f Bh$

In North America, many strong icebreakers and ice-strengthened vessels were needed for transportation once crude oil was discovered at North Slope in Alaska. Lewis and Edwards (1970) published a technique using regression methods whereby the icebreaking resistance was formulated and a final regression equation was created using data from several different model tests and from full-scale data (Table 1). In 1972, Edwards et al. proposed a prediction technique, once again based on regression analysis; however, some changes were made to their previous equation, as is shown in Table 1.