Ocean Engineering 140 (2017) 57–65

Contents lists available at ScienceDirect

Ocean Engineering

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

Implementation of ship performance test in brash ice channel

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ARTICLE INFO

Keywords:
Baltic Sea
Finnish Swedish Ice Class Rules (FSICR)
Brash ice channel
Ship performance test
Ice classes 1A and 1B

ABSTRACT

Vessels operating in the Baltic Sea and northern regions should satisfy the ice class rules for safe navigation; thus, shipyards should determine the most effective propulsion capacity and hull form during the design stage of a vessel. This can be done using a model test in an ice model basin and/or Finnish Swedish Ice Class Rules (FSICR) formulas. This study focused on brash ice testing and analysis methodology using a square-type ice model basin. The model ice preparation and property measurement procedures were introduced, and the preparation procedures for the brash ice channels were developed based on the guidelines of the Finnish Transport Safety Agency (Trafi) and Swedish Transport Agency (2011). The analysis methodology for the towed propulsion condition was described as well. Ship performance tests for the model ship have been carried out at ballast/scantling drafts in two different brash ice thicknesses for Ice Classes 1A and 1B in the ice model basin of the Korea Research Institute of Ships and Ocean Engineering (KRISO). Model test results were then compared with the results derived from the FSICR formulas and the ice operating condition by the installed engine was verified to evaluate the ship's performance in a brash ice channel.

1. Introduction

In the Baltic Sea, the ice channel is covered by broken ice pieces due to ship navigation and repeated traffic, which makes the sizes of the ice pieces smaller. The typical size of the broken ice pieces is less than about 2.0 m in diameter, and the upper part of the channel can be refrozen, forming a consolidated layer. This channel may be regarded as a brash ice channel. The vessels operated in a brash ice channel should be constructed to overcome the navigation restrictions, and these vessels should satisfy the ice class rules for the safety of navigation. When a ship navigates in ice, the vessel can be assisted by an icebreaker, because a ship's speed will substantially decrease due to the ice condition. Normally, a ship is assisted to the harbor entrance, and after that the ship should be able to sail to the port on its own, although the icebreaker must often escort small ships in particular up to the port. The Finnish and Swedish administrations provide icebreaker assistance to ships bound for ports in these two countries in the winter season (Finnish Maritime Administration and Swedish Maritime Administration, 2005). The greatest thickness of the level ice at sea during an average winter is about 50 cm in the eastern Gulf of Finland and 70 cm in the Bothnian Bay. The corresponding average maximum thicknesses of deformed ice are 10 cm and 30 cm in the eastern Gulf of Finland and the Bothnian Bay, respectively. During a severe winter, the greatest level ice thicknesses are 70 cm and 100 cm, and the deformed ice thickness is 70 cm for these sea areas (Juva and Riska, 2002).

In the design stage of a vessel, the minimum engine power and ice resistance should be determined to ensure a ship's navigation in the Baltic Sea. The Finnish Swedish Ice Class Rules (FSICR) is the accepted rule used for vessel trading in the Northern Baltic Sea in the winter season. This rule primarily addresses matters directly relevant to the capability of ships to advance in ice. Herein, ships are required to maintain a minimum speed (i.e., 5 knots) in a brash ice channel to ensure the smooth progress of traffic in ice conditions. The required engine output and ship resistance in a brash ice channel can be determined by FSICR formulas, but a model test in an ice model basin will be required to confirm a ship's performance in some cases. As mentioned above, FSICR formulas are widely used to determine the minimum engine output and ship resistance in brash ice. By evaluating a ship's performance in a brash ice channel using the model test results, shipyards can determine the effective propulsion capacity and hull form in the design stage of a vessel that operates in the Baltic Sea and higher northern regions.

The objective of this study was to develop the model test and analysis methodology in a square-type ice model basin. The model ice preparation and property measurement procedures were introduced, and then preparation procedures for generating a brash ice channel were developed. In addition, a model test and an analysis methodology

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http://dx.doi.org/10.1016/j.oceaneng.2017.05.008
Received 15 September 2015; Received in revised form 11 May 2017; Accepted 12 May 2017

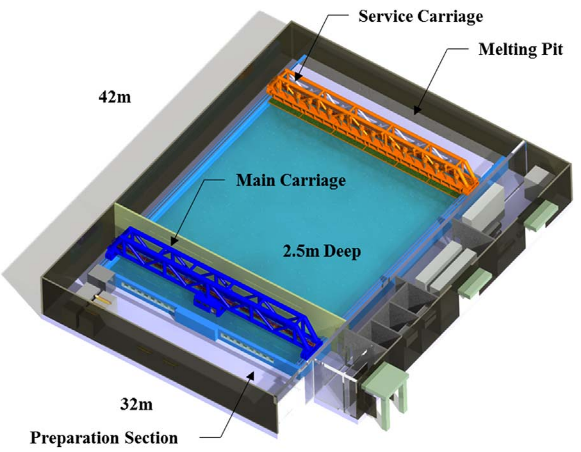

Fig. 1. Layout of the KRISO ice model basin.

were developed. Towed propulsion tests were carried out at ballast and scantling drafts in the ice model basin of the Korea Research Institute of Ships and Ocean Engineering (KRISO) to establish the minimum engine power and ship resistance in a brash ice channel for Ice Classes 1A and 1B. Model test results were then compared with the calculated results derived from the FSICR formulas and the capability of ice operating for the design propeller by the installed engine was verified to evaluate the ship's performance in a brash ice channel.

2. Model ice preparation and property measurement

Fig. 1 shows the layout of the KRISO ice model basin. The dimensions of the ice model basin are as follows: 42 m (length)×32 m (width)×2.5 m (depth). The KRISO ice model basin permits a model ship to complete a full-turning circle test. In a typical ship resistance and/or propulsion test, the 32 m of available ice width allows more than five or six parallel test channels within one ice sheet. The KRISO ice model basin uses EG/AD-CD model ice, where EG, AD, and CD denote the ethylene glycol, aliphatic detergent, and controlled density, respectively (Kim and Choi, 2011). The crystal structure of the model ice is a columnar type. The model ice is a dilute aqueous solution of EG and AD in approximate ratios of 0.39% and 0.036%, respectively. The preparation of the model ice sheet will begin with a wet-seeding procedure. The model ice will be grown at a temperature of −18 ± 0.5 °C. The growth rate during this period is expected to be approximately 2.1 mm/h. During the latter part of ice growth, the air temperature will be raised to +2 °C to control the strength of the ice. To control the air temperature, heating systems were attached to the front of the unit cooler, which was located in the ceiling of the ice model basin. These systems were automatically controlled during the tempering phase, but there was still a small difference in ice strength because of the width of the KRISO ice model basin. The target ice strength will be achieved via a tempering process. The properties of the model ice will be routinely measured for each ice sheet, and a database of ice properties will be maintained for quality control and prediction. Microbubbles will be uniformly discharged from the bottom of the ice model basin over the full ice-grown area during the entire freezing and tempering processes to adjust the model ice density to simulate that of the arctic sea ice range. After the level ice thickness reaches the target value, the ambient air temperature of the ice model basin will be raised up to −1 °C. Fig. 2 shows the preparation procedures for the KRISO ice model basin.

Generally, most of the ice model basin is a rectangular-type ice model basin and it has a long longitudinal length, but the KRISO ice model basin is a square-type ice model basin. In that case, the longitudinal length is not very long, but it has a greater width than other rectangular-type ice model basins. Thus, a model test can be conducted in many channels that run side by side in the ice basin. In this study, two brash ice channels were prepared in one ice sheet; thus, a total of four model test runs were conducted in two ice sheets. For the brash ice channel preparation, the ice sheets between the two brash ice channels were similar to a large cantilever beam. If the distance between two brash ice channels is not enough, then the root point of the cantilever beam can be broken in process of brash ice channel production. Thus, in this study, each channel was separated by about 15–20 m to prevent the root point from cracking (see Fig. 3). Test conditions are summarized in Table 1. Model tests in ballast and scantling drafts for each Ice Class were conducted in identical ice sheets. In addition, Tests 1B/Ballast and 1A/Scantling were conducted in identical testing channels and Tests 1B/Scantling and 1A/Ballast were also conducted in identical testing channels.

Short preparation time for the brash ice channel is very important. When preparing the brash ice channel, two methods were adopted in this study. In Method 1, the parental level ice sheet was broken by a manual-type ice pusher with about 10 cm in diameter. The dummy model ship enters a broken ice sheet to scatter the broken ice pieces. After running the dummy model ship, the small ice sheet pieces are inserted into the center of the running channel and then the inserted ice sheets are broken in the same manner. The cumulated ice pieces were rearranged and the broken ice pieces will be small ice pieces of 3.0 cm in diameter during this process. It will be repeated until reaching the target brash ice thickness. This rearrangement process required much time; therefore, it does not seem to be an appropriate method because the properties of model ice can be changed during the process. In addition, the thickness profile using Method 1 showed a striped line running in the longitudinal direction, and the brash ice channel was a bit thicker around this line (see Fig. 4d) because the broken ice pieces that were pushed by the dummy hull accumulated along the edge of the dummy hull beam, making the rearrangement process more difficult because of the adhesive force between the broken ice pieces. Therefore, another preparation method was considered. Method 2 is based on the ice volume calculation. To calculate the needed ice volume, the average channel thickness concept was adopted. An average channel thickness, H_{av}, may thus be used, which is affected by the breadth of the ship (Finnish Transport Safety Agency (Trafi) and Swedish Transport Agency, 2011).

$$\mathrm{H}_{av} = H_M + 14.0\cdot 10^{-3}B, \tag{1}$$

where B is the beam of the vessel, and H_M=1.0 m for 1A, 0.8 m for 1B, and 0.6 m for 1C.

First, the parental level ice thickness was grown until reaching the target value, and the needed ice volume was calculated; then, technicians broke the parental level ice using three manual-type ice pushers at the service carriage along the horizontal direction. The broken ice pieces are then also broken along the vertical direction in the same manner. In those channels, the broken small ice pieces have a regular distribution. After the level ice is broken, the broken ice pieces are scattered irregularly using the ice pusher to achieve a realistic brash ice channel. The broken ice pieces are then compressed using the ice pusher, and the needed ice volumes were inserted into the broken ice channel to achieve the target brash ice thickness. The required time in Method 2 was less than that of Method 1. In addition, no line of thicker ice formed in Method 2; thus, Method 2 is a more suitable methodology when generating a brash ice channel. The preparation procedures for the brash ice channel are presented in Fig. 4, and the size and shape of the ice pieces, as well as the underwater features, from Method 2 are presented in Fig. 5.

To measure the brash ice channels, special vernier calipers with two parallel flat plates that moved up and down were used. This device could easily measure the thickness profiles of the brash ice channels. Before the model tests were begun, the thickness of the brash ice channels was measured at seven points in the horizontal direction in order to obtain cross-sectional profiles of the brash ice channels. The