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Capability of Energy Efficient Ships for Winter Operations in the Bothnian Bay

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ABSTRACT

The Energy Efficiency Design Index (EEDI) is mandatory for new ships, including ice classed ships governed by the Finnish-Swedish Ice Class Rules (FSICR). The EEDI requirements will affect the transportation regime in the Bothnian Bay in the Baltic Sea, where high ice class ships are the basis for year-round operation. This paper describes a study where ice-going capabilities of an EEDI type ship were evaluated. The study includes development of an ice classed EEDI optimized hull form, ice model tests and an observation voyage with an existing ice classed ship.

The model tests were done with two different ship models having same main dimensions: one with EEDI optimized hull form and a reference ship with hull form optimized for winter operations. Tests were done in various ice conditions that can be expected in the Bothnian Bay. The observation voyage to the Bothnian Bay was done with a typical ice class IA Super ship during severest part of the winter. Ice conditions, power usage and need for icebreaker assistance were recorded during the voyage.

The model test results show that the ship with EEDI hull form performed equally well or better than the reference ship in almost all tested conditions. However, performance of the EEDI hull form was sensitive to different icebreaking modes observed in the tests. In one condition, outbreaking of channel, the EEDI hull form did not perform well.

The main result of the observation voyage was the actual engine power used in various conditions which is compared to EEDI and FSICR requirements. In general, the used power levels were low. Power levels of more than 60% of maximum power were needed only in the most difficult ice conditions during the voyage.

KEY WORDS: Energy efficiency design index; Ice-going capability; Ice model tests;

INTRODUCTION

The Energy Efficiency Design Index (EEDI) is mandatory for new ships, including ice classed ships governed by the Finnish-Swedish Ice Class Rules (FSICR). The EEDI requirements will tighten in three phases: Phase 1 from January 2015, Phase 2 from January 2020 and Phase 3 from January 2025 and onward. The EEDI requirements will affect the transport regime in the Bothnian Bay in the northern Baltic Sea, where high ice classes are the basis for year-round operation. Typically, ice class of IA or higher is required in mid-winter when sailing to ports in the Bothnian Bay due to traffic restrictions set by the Finnish and Swedish maritime authorities. The maximum allowed power will be dropped substantially due to EEDI requirements. This will have significant effects on the ice-going capabilities of ice classed ships and, in practice, EEDI optimized ships do not consider the needs of ice operations. However, according to the EEDI regulations correction factors for ice classed ships can be used which allow an increased engine power.

The implementation of EEDI has raised concerns on how the requirements will affect ice classed ships and the winter navigation in the northern Baltic Sea and to study these issues a number of EEDI related research projects, funded by the Finnish-Swedish Winter Navigation Research Board, have been carried out. These include statistical studies on the effect of ice class correction factors for various ship types (Westerberg 2014, Mattsson 2018) and a statistical study on the effect of EEDI on the need for icebreaker assistance (Heinonen 2018). Some results from these projects have been implemented in new IMO (International Maritime Organization) guidelines for calculation of EEDI (IMO 2018).

For new, energy efficient ships, novel bow forms have been developed, which fulfil the minimum engine power requirements of ice class IA. The design requirement for ice-going capability defined by the FSICR for IA ice class ships is 1 m thick brash ice channel at a minimum speed of 5 knots (Trafi 2016). However, when a ship is operating in ice in the Bothnian Bay the conditions might change rapidly. For example, a consolidated layer in the brash ice channel may develop in few hours to an ice class IA Super type channel, and after one day the situation can be even worse. Safe and efficient winter operation in the Bothnian Bay requires also ability to pass other ships and break out from the channel if needed. Thus, from an operating point of view it is not enough for an ice-going ship to be only able to use IA type brash ice channels and withstand IA ice class compression forces.

A research project, named BowForm, was carried out to study the ice-going capabilities and possible problems that EEDI optimized hull forms have in actual winter operations. The study was carried out during 2017 and 2018 and it was funded by the Finnish-Swedish Winter Navigation Research Board. The study includes development of an ice classed EEDI optimized hull form, an observation voyage with an existing ice classed ship and comparative ice model tests with the developed EEDI optimized hull form and an existing hull form optimized for winter operations. The ship type selected for the study is a small product tanker with size of about 15000 DWT.

HULL FORM DEVELOPMENT

Typical EEDI optimized bow forms have vertical or almost vertical stem and bow buttock lines. The bow is sharp, and the bow waterlines have small entrance angles and the bulbous part extends forward only slightly. The bulbous part is often quite slim and narrow and integrated to bow part. Some EEDI bow forms are shown in Figure 1.

Figure 1. Novel bow forms of EEDI time

The hull form of an existing product tanker optimized for winter operation was used as a reference when developing the new EEDI optimized hull form. The selected reference ship, product tanker MT Suula, is shown in Figure 2. The ship is a typical FSICR ice class IA Super vessel with single screw propulsion and bulbous bow. The engine power (MCR – maximum continuous rating) of the ship is 8450 kW. She operates in the Baltic Sea and visits the ports in the Bothnian Bay on a frequent basis year-round. Also, it was possible to do observations onboard this ship during a voyage to the Bothnian Bay.

Figure 2. The reference ship (Photo: Neste Oil)

The objectives when developing the new EEDI bow form was to follow the bow shapes of the above-mentioned novel ships and minimize the open water resistance of the vessel. The reference ship hull form was used for the mid and stern parts, while the bow part was designed close to the shape used in ice class IA tankers that fulfil at least EEDI Phase 1 requirements. The displacement, breadth, draught and length of the reference ship were used as limiting factors for the new hull design. When these constraints were applied, there was only about 30% share of the total open water resistance which could be optimized from a wave making resistance point of view.

During the bow form development several optimization rounds were done in order to get the open water performance to a level that fulfils EEDI requirements. During each step the open water resistance was evaluated using a CFD tool, which includes free-surface capturing and viscosity, and simultaneously the ice performance was evaluated with a semi-empirical method keeping in mind that the ship needs to be capable to operate in an ice class IA brash ice channel. The final EEDI hull form and the reference ship hull form are shown in Figure 3. The main dimensions are shown in Table 1.

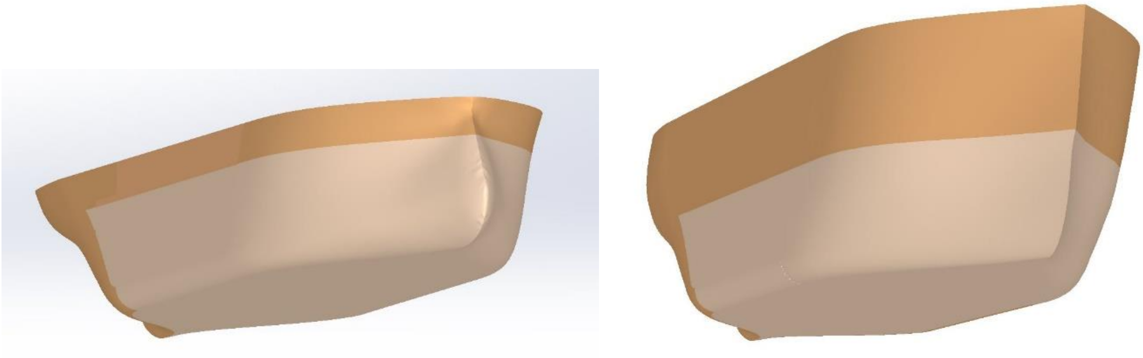

Figure 3. Underwater shape of the reference ship hull (left) and EEDI optimized hull (right)

Table 1. Main dimensions of the ships

		Reference ship	EEDI hull form
Length overall	L_{OA} [m]	139.75	140.87
Length at design waterline	L_{DWL} [m]	135.0	140.34
Breadth at design waterline	B_{DWL} [m]	21.70	21.70
Draft at design waterline	T_{DWL} [m]	8.70	8.70
Propeller diameter	D_P [m]	5.1	5.1

OBSERVATION VOYAGE

An observation voyage to the Bothnian Bay with an existing ice classed ship was made as a part of the study. The purpose of the voyage was to observe the ship's capability to operate and get icebreaker assistance in different ice conditions. The observation voyage was done with the reference ship during the severest part of winter in March 2017. The voyage was divided in two legs: from Porvoo to Oulu with almost full load (draft close to design waterline) during 12 to 14 March and from Oulu to Vaasa with partial load (draft between design and ballast waterlines) during 15-16 March. The route of the voyage is shown in Figure 4.

Ice conditions

In general, the ice winter 2016-2017 in the Baltic Sea was mild. The ice conditions in mid-March 2017 are shown in Figure 4. Practically, only Bothnian Bay and eastern part of Gulf of Finland were covered by ice at the time of the observation voyage in mid-March. During the voyage ice was encountered in the Bothnian Bay while other areas were ice free except for a narrow fast ice zone off Porvoo and Vaasa. The Bothnian Bay was mainly covered with 15 to 40 cm thick very close drift ice. During the voyage ice compression was experienced at times due to strong southerly to westerly wind with speed ranging from 10 to 15 m/s. A jammed brash ice barrier was encountered at the landfast ice edge, close to Oulu 1 lighthouse. The Oulu fairway was covered by a brash ice channel surrounded by landfast ice 45 to 70 cm thick.

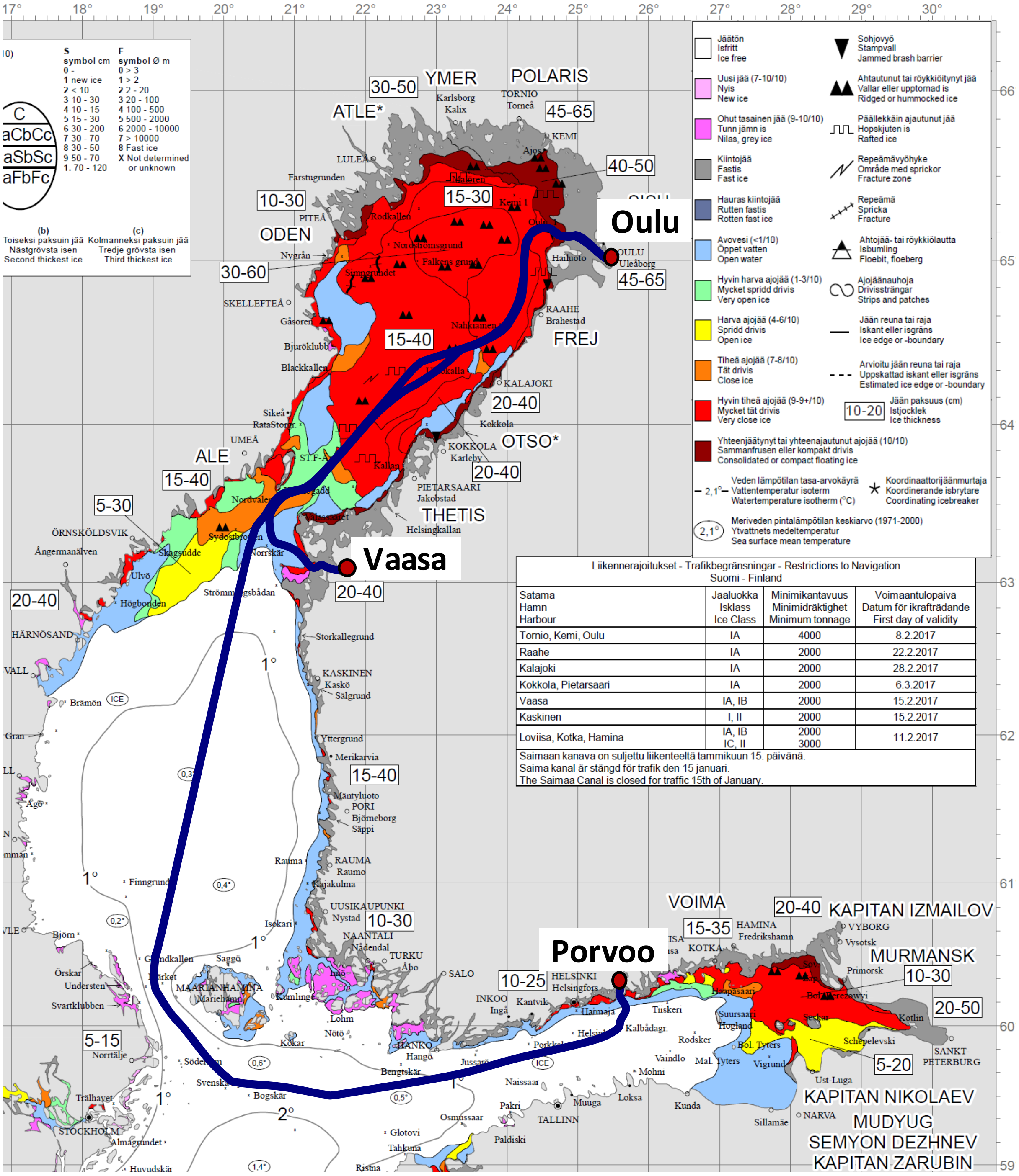

Figure 4. Extract of Baltic Sea Ice chart on 14 March 2017 (Source: Finnish Meteorological Institute). The observation voyage route is shown as a dark blue line.

Onboard Observations

During the voyage the ship encountered ice, from a practical point of view, only in the Bothnian Bay. Therefore, major part of the Porvoo-Oulu leg was sailed in open water, where the average ship speed was 13.5 to 14 knots with an engine power of 3600 to 3900 kW. In the Bothnian Bay the ship encountered a variety of ice conditions: level ice fields, areas of broken ice as well as channels broken by other ships. The ship speed in these conditions was 12 to 13 knots while engine power was gradually increased from about 4000 to 6000 kW when moving northwards. Ice compression was experienced in the area west of Hailuoto island which significantly slowed down the ship although a high engine power was used. The ice compression in this area was strong during the Oulu-Vaasa leg and the ship got stuck even it was following an icebreaker as the channel made by the icebreaker closed quickly. In the brash ice channel in the Oulu fairway the ship was assisted by an icebreaker. In the heavy part of the brash ice channel the ship was able to follow the icebreaker at a speed of about 10 knots with an engine power of 6400 to 6800 kW. The ship got stuck at the jammed brash ice barrier at the landfast ice edge despite of icebreaker assistance and the icebreaker had to cut her loose. Different conditions encountered during the voyage are shown in Figure 5.

Figure 5. Typical conditions encountered during the observation voyage: Open water (top left), Closed channel (top mid), Pack ice (top right), Level ice (bottom left), Stuck at jammed brash ice barrier and cut loose by icebreaker (bottom mid), Assisted by icebreaker in heavy brash ice channel (bottom right)

According to ship crew the performed observation voyage was a typical voyage to the northern part of the Bothnian Bay during a mild winter. However, significant ice compression is not normally experienced. During mild winters the ship typically operates independently in the Bothnian Bay and icebreaker assistance is only needed in brash ice channels in fairways leading to the northernmost harbours in the area. In severe winters the ship may need icebreaker assistance in the entire Bothnian Bay.

Ship Performance

Ship performance during the voyage was evaluated based on visual observations and data obtained from ship's own data recording system. The following quantities were recorded at 7 to 8 minutes intervals:

- Speed
- Heading
- Main engine power
- Wind speed and direction

The recorded data was combined with ship position and visual observations and then divided in legs which represent relatively constant conditions. A summary of the ship performance in representative conditions is shown in Table 2 and Table 3

Table 2. Performance of the reference ship during voyage from Porvoo to Oulu

Date	Area	Condition	Wind speed [m/s]	Wind direction	Average ship speed [kn]	Heading [deg]	Engine power [kW]
12.03.-13.03.2017	Gulf of Finland, Åland Sea, Bothnian Sea	Open water	8.5-14	SW	13.5-14	260-015	3600-3900
14.03.2017	Bothnian Bay	Thin level ice	10-13	S	13	040	3800
14.03.2017	Bothnian Bay	Pack ice	11.5-13	S	12.5	070	4100-4600
14.03.2017	Bothnian Bay	Pack ice	11.5-13	S	13.5	010-065	5000-6000
14.03.2017	Bothnian Bay	Level ice, ice compression	11.5-15.5	SW	7-10	025	6000-6900
14.03.2017	Bothnian Bay	Newly broken channel, following an icebreaker	12-13	S	11.5	060	4600
14.03.2017	Oulu fairway	Heavy brash ice channel, assisted by an icebreaker	9.5-12	S	10	060-115	6750
14.03.2017	Oulu fairway	Brash ice channel	10-12.5	S	13	115-140	6200

Table 3. Performance of the reference ship during voyage from Oulu to Vaasa

Date	Area	Condition	Wind speed [m/s]	Wind direction	Average ship speed [kn]	Heading [deg]	Engine power [kW]
15.03.2017	Oulu fairway	Brash ice channel, assisted by an icebreaker	12.5-14.5	SW	13.5	320-340	5600
15.03.2017	Oulu fairway	Heavy brash ice channel, assisted by an icebreaker	12.5-14.5	SW	10	240-295	6400
15.03.2017	Bothnian Bay	Pack ice, ice compression assisted by an icebreaker	11-16.5	SW	10-14	185-250	5000-6700
15.03.2017	Bothnian Bay	Open water	10-12.5	W	16	230	5000
16.03.2017	Quark, Bothnian Sea	Open water	8.5-14.5	W	15	120-250	4200-4400

ICE MODEL TESTS

Ice model tests were performed with both the reference ship hull form and the EEDI optimized hull form in similar test conditions at design draft. The tested ship models are shown in Figure 6. The main objective of the model tests was to investigate the ice performance of the EEDI optimized hull form and compare it with the reference ship. The model test results, together with the observations onboard the reference ship, are used to draw conclusions on the possibilities of an EEDI type bow to operate in ice.

Figure 6. Models of the reference ship (left) and EEDI hull form (right)

Model Test Program

The model tests were made in various ice conditions, partly representing the ice conditions observed during the voyage with the reference ship. The tests were made in the following conditions:

- Level ice, thickness 0.35 m and 0.5 m
- Brash ice channel, thickness 1.3 m
- Heavily consolidated brash ice channel, thickness 1.3 m
- Pack ice, floe size 50 m, ice thickness 0.35 m and 0.5 m
- Small triangular ice ridge, thickness 5 m
- Outbreaking from own channel

The brash ice channels were made according to the Guidelines for the application of the 2017 Finnish-Swedish Ice Class Rules (Trafi 2017). The thickness for the model test channels was defined based on these guidelines for ice class IA. Tested ice conditions are shown in Figure 7.

Figure 7. Ice conditions in model tests: brash ice channel (left), pack ice (mid), triangular ridge in level ice field (right)

Model Test Results

In general, the EEDI hull form performed in the model tests equally well or even better than the reference ship. This is, most probably, due to the hull design with a small icebreaking edge at the waterline. On the other hand, tests showed that the EEDI hull form is sensitive to the icebreaking mode. Sometimes the EEDI bow breaks the ice by bending, resulting in relatively low ice resistance, while sometimes the icebreaking occurs by crushing and cutting, resulting in high ice resistance. The crushing and cutting mode might be more representative for bow shapes with a vertical stem.

The results of level ice tests are shown in Figure 8. The net thrust curves for the ships are presented for engine power levels corresponding to 50%, 75% and 100% of maximum power (MCR) of the reference ship. The icebreaking cycle of the EEDI hull form is instable and therefore the icebreaking capability is strongly dependent on the icebreaking mode. The EEDI hull form can reach a clearly higher speed when ice is broken in bending mode than when the ice is broken by crushing and cutting. In crushing and cutting mode the performance of the EEDI hull form is close to the reference ship which breaks the ice by bending upwards with the bulbous bow. The differences in the icebreaking modes are shown in Figure 9.

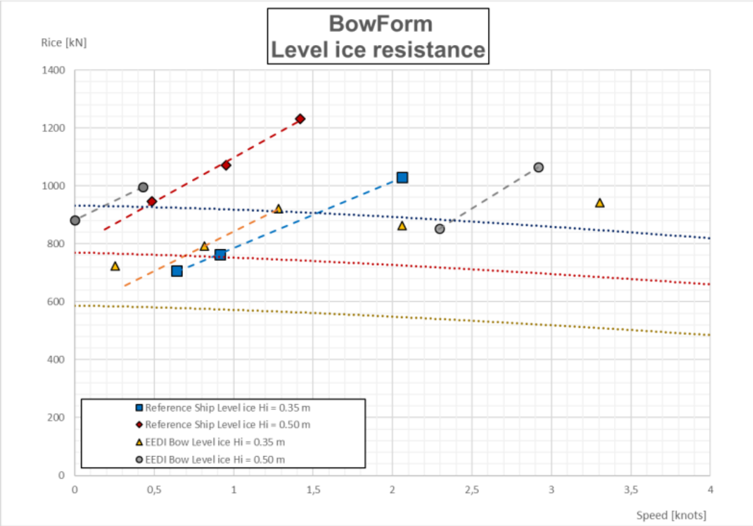

Figure 8. Ice resistance in level ice

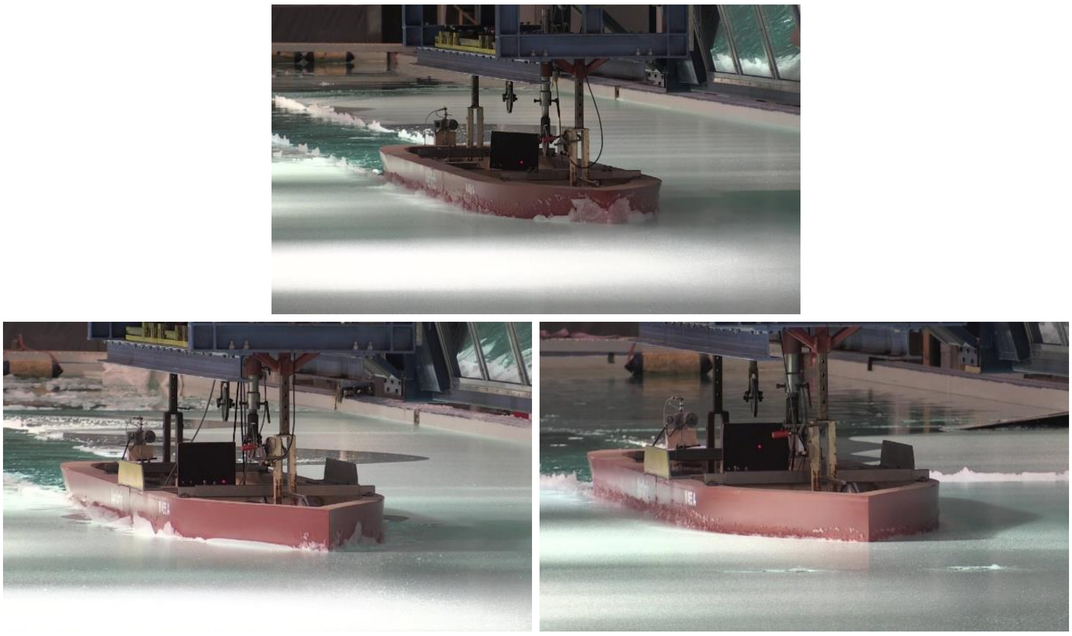

Figure 9. Level ice tests: Reference ship breaking ice by bending upwards (top), EEDI bow form breaking ice by bending (bottom left) and by crushing and cutting (bottom right)

In the brash ice channel corresponding to FSICR ice class IA requirements both hull forms fulfil the speed requirement of 5 knots set by the rules even with a power level corresponding to about 4200 kW (about 50% of reference ship MCR). This is a lower value than the power requirement calculated according to the equation defined in the FSICR for the reference ship (about 5500 kW for ice class IA). the EEDI hull form performed somewhat better than the reference ship in the tested brash ice channels. The results of brash ice channel tests are shown in Figure 10. Pictures from the tests are shown in Figure 11.

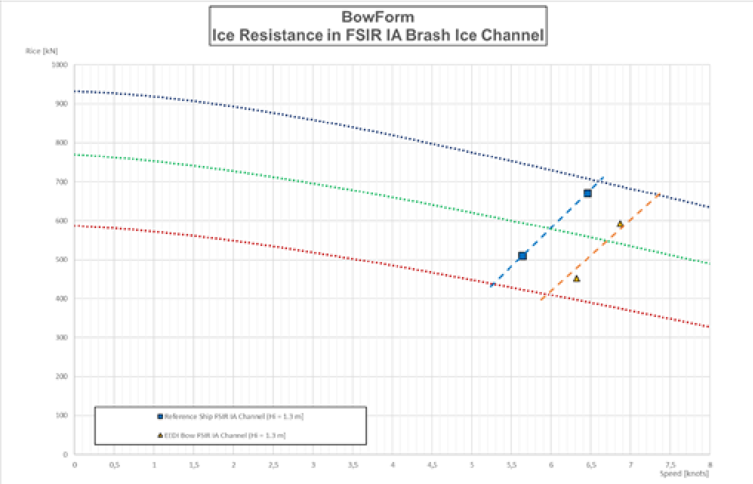

Figure 10. Ice resistance in brash ice channel for FSICR ice class IA

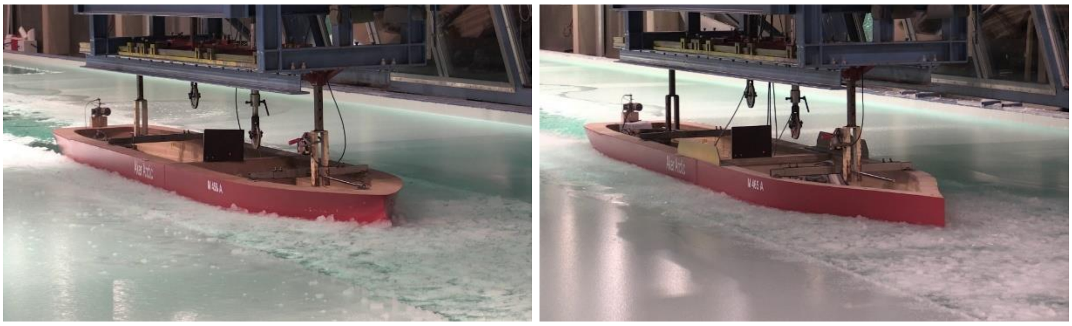

Figure 11. Tests in FSICR IA brash ice channel, Reference ship (left) and EEDI bow (right)

The ice resistance in pack ice is clearly lower than in level ice. In pack ice the EEDI hull form performed clearly better than the reference ship, because the EEDI hull form was splitting the ice floes more effectively. Pictures from the pack ice tests are shown in Figure 12.

Figure 12. Pack ice tests, Reference ship (left) and EEDI bow (right)

In ridge tests both hull forms performed equally well by crossing the ridge with a steady speed of 0.7 to 0.8 knots with a power level corresponding to about reference ship MCR. The achieved speed while crossing the ridge was almost the same as in the surrounding level ice and only a small speed reduction was observed. Pictures from the pack ice tests are shown in Figure 13.

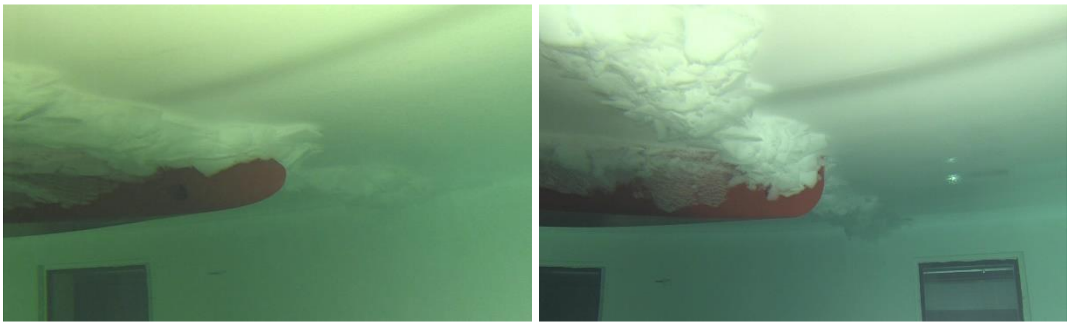

Figure 13. Reference ship (left) and EEDI bow (right) penetrating through a small ridge

In the outbreaking tests neither of the ships was able to break out of the channel within the test distance corresponding to about 500 m in full scale. A rudder angle of 45 degrees was used. However, the ships behaved differently in the tests. The reference ship was breaking a steadily widening channel and would have eventually broken out at some point. However, this couldn't be confirmed in the model tests due to limited test distance. The EEDI hull form was not able to widen the channel and when turning towards the channel edge the model bounced to the opposite side of the channel and was not able to break out. Pictures from the outbreaking tests are shown in Figure 14.

Figure 14. Attempt to break out from channel with Reference ship (left) and EEDI bow (right)

DISCUSSION AND CONCLUSIONS

The target of this study was to investigate the operability in ice of EEDI type hull forms that are typically equipped with a vertical stem. The research started with an observation voyage through ice in the Bothnian Bay onboard an existing vessel, the reference ship. During the voyage the ship performance was observed in different encountered ice conditions. The experiences from this voyage were used as a basis for developing the ice model test program. The ice model tests were performed both with the reference ship and a ship with an EEDI type bow form which was developed as part of the study.

The observation voyage with the Reference ship to the Bothnian Bay was done in March 2017. The winter 2017 was mild and most of the voyage was done in open water or light ice conditions. More severe ice conditions occurred only in the northern part of the Bothnian Bay. One of the most important findings of the voyage is that the used power levels were less than or about half of the installed power most of time i.e. in open water and light ice conditions. High power levels were used in the most severe ice conditions only. The speed of the ship was mostly more than 10 knots when moving both independently and in icebreaker assistance.

The ice model tests were intended to be done in similar ice conditions as those experienced during the observation voyage. However, it was not possible to model these conditions precisely due to restrictions in model ice properties. The model tests represent an estimate of the ice performance of EEDI type hull forms, which can be used to assess the operability in real ice conditions by comparing the results of the EEDI hull form and the reference ship to each other.

Based on the model test the EEDI bow is performing equally well as or even better than the reference ship in almost all tested conditions. In one condition, namely outbreaking from channel, the EEDI bow performs much worse than the reference ship. This might be a safety issue during operation when encountering another ship in a channel.

Although the results of this study are promising, the ice operability of the tested EEDI hull form should not be generalized. The tested hull form was not optimized only for open water and ice-going capability was also taken in consideration when optimizing the hull shape. The test results indicate that the ice performance of an EEDI hull form is sensitive to the icebreaking mode and how the bow pushes brash ice in channels.

ACKNOWLEDGEMENTS

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