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MODEL TEST PROCEDURE UPDATE

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FOREWORD

In this report no 136, the Winter Navigation Research Board presents the results of Model test procedure update. Project goal was to identify parts of the model testing guidance which should be updated to match latest research.

The Winter Navigation Research Board warmly thanks the author for this report.

Helsinki

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AKER ARCTIC TECHNOLOGY INC REPORT

**MODEL TEST PROCEDURE UPDATE
FOR
FINNISH TRANSPORT AND
COMMUNICATIONS AGENCY**

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<p>Summary:</p> <p>The purpose of this report is to propose modifications to the model testing guidelines for determining the minimum power requirements for Finnish-Swedish ice classes. The new environmental standards impose strict emission restrictions on merchant ships, necessitating novel hull shape optimizations. Recently introduced hull forms often feature vertical or near-vertical stem angles to enhance open water performance, unlike the small stem angles of traditional ice-going ships. The current guidelines, effective for traditional ice-going merchant ships, are suboptimal for modern, open-water optimized designs. The modifications introduced in this report are driven by the need to equally consider the modern bow shapes, and the need for a better-standardized testing conditions that reflect representative natural conditions. Key updates include incorporating requirements for realistic simulation of interactions between ice fragments, setting a target speed for a model test experiment, and considering the thickness of the surrounding ice field for wide ships. It is also proposed to change to the friction coefficient correction formula. In addition to these improvements on the simulation of brash ice around ships with different shapes, a significant update in channel width and average thickness of brash ice mass in model test is proposed because of emergence of significantly wide ships.</p> <p>The goal is to ensure consistent and accurate performance predictions across different ship models and test facilities, ultimately leading to more equal and functional determination of required minimum power for ice-classed ships.</p>			
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ABBREVIATIONS

FSICR.....Finnish Swedish Ice Class Rules

IMO The International Maritime Organization

SDG..... Goals to promote Sustainable Development

B Ship’s beam

D_{channel}..... The width of brash ice channel

H_{ave} Thickness of brash ice channel in a model test experiment

H_{mid} Thickness of the mid part of an old brash ice channel

H_{surrounding ice} Thickness of ice field surrounding the channel

L_{channel} Length of the brash ice channel

m_{brash ice} Mass of brash ice

μ_{actual}..... Measured friction coefficient between ship model and model ice

μ_{target}..... Targeted friction coefficient between ship model and model ice

ρ_{brash ice} Porosity of brash ice

R_{ch} Ship’s resistance in an ice channel

ρ_{ice} Density of ice fragments

V_{brash ice}..... Volume of brash ice

1 INTRODUCTION

This work relates to this year's Specific research topic 1:

“Development of model tests for determining minimum power requirement for Finnish-Swedish ice classes

Since the 2003 FSICR it has been possible to determine the minimum engine power requirement for Finnish-Swedish ice classes by using model tests. However, no clear requirements for the model tests exist. The guidance given in the Guidelines to the Application of the Finnish-Swedish Ice Class Rules should be updated especially to consider larger ships and different model ice types and it should be considered whether the text should be included in the FSICR.”

Ice Class Regulations and the Application Thereof (Traficom 2021) item 3.2.5 allows determination of ship's resistance in a brash ice channel for ice class granting by model scale tests in ice. The Guidelines for the application of the Finnish-Swedish Ice Class Rules (Traficom, 2018) describe the permitted procedures to perform the model test experiment.

The model test guideline for determining the minimum required power needs revision to better reflect the current situation. Our earlier research indicates that the existing procedure is effective for traditional ice-going merchant ships but suboptimal for modern, open-water optimized bow forms. Furthermore, the current procedure does not differentiate adequately between ships with significantly large beams and those with conventional beams, even though in practice, channels are relatively wider for smaller ships.

A realistic assessment of a ship's resistance at the specified performance point – 5 knots in a channel of certain midpart thickness – is crucial for an equitable and functional determination of the required minimum power. To ensure standardized and accurate performance predictions in realistic channels for all bow forms, the model test procedures need updating to account for all relevant forces and processes influencing channel resistance.

Aker Arctic has advanced the methodology for predicting ship channel resistance through model scale tests, based on research conducted since 2016. This research, supported by the Winter Navigation Research Board projects W16-6 Model Channel and W18-8 FSC Channel Resistance, has been extensively documented in several peer-reviewed journal papers and a publicly examined doctoral thesis. The objective of this report is to translate the theoretical insights gained through the research into practical guidelines.

The proposed modifications to the current Guidelines are intended to predict channel resistance, representing a ship's performance under targeted operational conditions. This approach aims to ensure consistency across different ship models and test facilities. It is though acknowledged that old, unconsolidated brash ice channels in nature can be quite diverse, influenced by factors such as long-term weather patterns, short-term temperature fluctuations, snow cover, and traffic frequency; thus, the natural sea environment remains largely unpredictable and uncontrollable. In the FSICR, each ice

class (IA-IC) is described by frequently operated old channels with specified midpart thickness and transverse profiles. As noted, brash ice channels of similar geometrical dimensions can cause varying resistance for the same ship due to the prevailing properties of the brash ice. Therefore, to gain insight into a merchant ship's performance in typical winter navigation ice conditions, it is necessary to standardize the testing conditions to reflect representative natural conditions. In other words, the standardized testing condition proposed in the new guidelines might not correlate perfectly with all unconsolidated old brash ice channels in nature.

It is emphasized that the interpretation of the research results reflects the opinion of a research engineer with focus on performance prediction methodology, while the authorities with a wider perspective might have reasons to choose prioritizing different aspects.

2 REASONS FOR MODIFICATIONS

The International Maritime Organization (IMO) has established development goals to promote sustainable development (SDG). As a result, higher standards for sustainable shipping have led to stricter emission controls and a call for careful resistance-optimization of hull shapes. This has resulted in ship designs that are notably different from traditional merchant vessel designs, particularly from traditional ice-going merchant vessel designs. Many recently built merchant ships feature vertical or nearly vertical stem angles to enhance open water performance, whereas traditional ice-going ships have smaller stem angles. These recent changes in the merchant fleet necessitate reconsideration of the suitability of current FSICR ice class granting procedures for all hull shapes, including modern, open-water-optimized designs, which were not previously in existence or considered during the original development of the regulations.

In addition to the modifications in the bow designs of modern merchant fleets, new emission regulations coupled with rising fuel prices are driving a trend towards limiting engine power in newly built ships. These new vessels, which replace those reaching the end of their lifecycle, often have significantly reduced engine power compared to their predecessors. This reduction is partly due to the elimination of all performance margins exceeding the requirements, as these ships are optimized for good open water performance — a condition that typically prevails for the majority of operational time for a typical ice-classed merchant ship. As a consequent, the newly launched ice-classed merchant ships have generally lower ice performance when compared fleet launched 30 years ago.

An additional reason for the development of model testing guidelines is to address the emergence of significantly wide ships. It is expected that the presence of panamax-sized ships will increase in future at the Baltic Sea. Some newly launched merchant ships have a beam up to 35 m, which is significantly wider than the beam of any Baltic icebreaker. While the width of a typical old brash ice channel develops wider than icebreaker beam, the significantly wide ships still experience higher resistance compared to the channel resistance determined by the current FSICR model-testing procedures applied for granting certain ice class. This is because the current procedure assumes that the channel is always twice as wide as the ship's beam, which is not a reasonable assumption for a wide ship.

3 MODIFICATIONS

3.1 INCLUDE A REQUIREMENT FOR ICE STRENGTH

Our earlier research (Matala & Skogström 2017; Matala, 2018; Matala, 2023) shows that simulating the interaction between a merchant ship and brash ice in an old unconsolidated brash ice channel requires accurately replicating the processes and forces affecting a ship's ice resistance. Modern ships with high stem angles face primarily displacement and friction resistance, while traditional ice-going ships with low stem angles also experience significant submerging resistance.

Accurate modeling of the submerging resistance component necessitates accounting for gravitational forces. The gravity remains constant both in model scale and full scale, with approximately identical density differences between water and ice in both scales. Consequently, the current model ice effectively simulates the submerging resistance component, provided that the geometric similarity of the brash ice mass dimensions and the size distribution of brash ice fragments are adequately considered.

Unlike submerging forces, the forces associated with displacement resistance and friction are not effectively scaled in current model test practices. This discrepancy arises because scaling down flexural strength significantly alters fragment interactions: the model ice deforms more easily, increasing ice-ice friction, and ice fragments may coalesce into a non-granular mass with properties different from full-scale granular brash ice. Accurately simulating the forces involved in displacing ice fragments laterally necessitates a realistic simulation of force chains and interactions between the ice fragments. Replicating the contact forces between brash ice fragments in physical model tests depends on the internal friction angle and cohesion of the brash ice. While flexural strength is crucial for accurately mimicking an icebreaker breaking level ice in physical model tests, it is irrelevant in brash ice scenarios where no bending failure occurs. Instead of focusing on the realistic breaking of level ice, the emphasis should be on the accurate failure of the brash ice column. Therefore, to satisfactorily simulate a ship navigating through brash ice, prioritizing the simulation of interactions between ice fragments over simulation of bending failure of individual ice fragments is essential. Theoretical and experimental evidence suggests that the model test-based resistance prediction has been proven to be conservative when a brash ice test is performed in model ice with scaled-down flexural strength. Therefore, scaling down the flexural strength should be discontinued in model scale tests involving broken ice, such as brash ice, where no breaking is expected. If brash ice mass is formed of solid ice cubes, flexural strength is not scaled down.

Thus, it is proposed that the brash ice mass for the model test experiment is formed of solid ice cubes with strength properties corresponding to nature sea ice or fresh water ice. The shape of the fragments should at some level correlate to nature brash ice fragments with round shapes, avoiding angular shapes. The solid ice cubes function for all bow forms, but the traditional soft model ice can be used for traditional bow shapes, i.e. low bow angles.

3.2 INCLUDE A REQUIREMENT FOR A TARGET SPEED

In ice model testing procedures, it is generally assumed that the open water resistance is negligible compared to ice resistance, and that it can be excluded from the total resistance using the superposition principle. This assumption is particularly valid for level ice conditions where the vessel typically advances at relatively low speeds. However, this may not hold true for channel conditions, where the vessel can progress at relatively high speeds, resulting in a proportionally higher open water resistance. Additionally, at high speeds, wave-making effects within the channel and beneath the surrounding level ice further complicate matters. To standardize test conditions and outcomes, the test speed should be regulated in the guidelines, proposing either setting a target speed of 5 knots \pm 1 knot (the criterion point) or by setting an upper limit (e.g. 7 kn). It is noted that in self-propulsion test in which the model is running free, exactly reaching a set target speed is practically challenging.

3.3 INCLUDE A REQUIREMENT FOR THICKNESS OF SURROUNDING ICE FIELD

The current regulation does not provide target value for the thickness of the level ice field, which surrounds the brash ice channel. However, in Guidelines for the application of the Finnish-Swedish Ice Class Rules Appendix 4 Annex "Required Information in a Model Test Report" it is requested to report the thickness of parental ice, which is practically the thickness of the surrounding ice field. In current regulation the width of the brash ice channel is set to $2 \times B$ (B is the beam of the tested ship), which means that the channel edges have no impact on channel resistance. This can be visually verified by observing either a ship in real old brash ice channel or in a brash ice model test experiment, as the ice fragments are not moving close to the channel edges, given that the channel is wide as $2 \times B$. However, as proposed later in Chapter 3.8, in real operations the channel edges impact on the ship's channel resistance if the ship is significantly wide. When the ice fragments start moving close to the channel edges, the surrounding ice field thickness impacts how easily the ice fragments flow below the ice field. Therefore, if the width of the channel is less than $2 \times B$, a target value should be given to the surrounding ice field.

One simple and reasonable suggestion is to apply typical thickness of ice field in the Baltic sea, e.g. $H_{\text{surrounding ice}} = 0.5 \text{ m}$ in full scale. However, when the ship's beam is close to the channel width, the interaction between piled-up brash ice and channel edge becomes more complicated than this. The issue is further considered in Chapter 3.8.

3.4 MODIFY REQUIREMENT OF TWO LAYERS OF ICE FRAGMENTS

In Guidelines for the application of the Finnish-Swedish Ice Class Rules Appendix 4 Chapter 3 it is stated:

"The channel should be 100% covered with ice, so that there are around two layers of ice fragments on top of each other."

Depending on practical aspects such as the scale of the experiment, average thickness of the rule channel, and availability of brash ice fragments of certain dimensions, it might be challenging to guarantee two layers of ice fragments on top of each other. However, requesting 100% coverage is crucial for a realistic simulation. Thus, it is proposed that the wording is modified so that 100% coverage is guaranteed without requesting two layers of fragments.

Sufficient coverage can be secured by requesting the test channel contain sufficient volume of brash ice mass. The brash ice volume in a channel with width of $D_{channel}$, length of $L_{channel}$, and thickness of H_{ave} is filled with brash ice with porosity of $p_{brash\ ice}$ and density of ice fragments ρ_{ice} , the volume $V_{brash\ ice}$ of brash ice mass should be

$$V_{brash\ ice} = D_{channel} \cdot L_{channel} \cdot H_{ave} \quad [\text{Eq. 1}]$$

The volume of brash ice is believed to be the correct approach to reach targeted brash ice thickness and coverage simultaneously.

From *Eq 1*, it follows that the mass $m_{brash\ ice}$ of brash ice

$$m_{brash\ ice} = V_{brash\ ice} \cdot (1 - p_{brash\ ice}) \cdot \rho_{ice} \quad [\text{Eq. 2}]$$

This approach may be useful when acquiring ice cubes.

3.5 MODIFY FRICTION COEFFICIENT CORRECTION FORMULA

The current FSICR Guidelines (Traficom, 2018) include a correction method for the friction coefficient $C\mu$ between the ship model and ice. The purpose of this is to ensure the certain ice performance of the ship hull also with a slightly corroded, not-freshly painted ship hull. In practice, this is implemented by correcting the friction coefficient between the ship model and ice into target value. The target value μ_{target} is set to be 0.10, which means that the measured resistance of the ship is corrected upwards as a typically lower coefficient (0.05 – 0.10) is targeted in ship models to represent a freshly-painted coating. The correction formula is presented in the FSICR Guidelines (Traficom, 2018) Appendix 4, Chapter 4, and it is based on empirical regression analysis of an icebreaking ship hull.

This issue has recently been further investigated by Suominen (2023) in a Winter Navigation Research Board Report 130, and the results are further analysed in Suominen & Puolakka (2024). Suominen & Puolakka's experimental research concludes that a friction correction presented in *Eq. 3* would normalize the model test results for all bow forms when the tests are performed in solid ice cubes. The boundary condition for applying this formula is that the measured friction coefficient between the ship model and ice μ_{actual} is between 0.1 ± 0.05 . The formula presented in *Eq. 3* is believed to be currently the best estimate to harmonise test results between different experiments. The formula has been defined between model-ice friction coefficient varying between 0.05 – 0.15. It needs to be clearly indicated, whether the same formula can be extended to cover 0.03 – 0.017.

$$R_{ch\ (with\ \mu_{target})} = \frac{0.4+6 \cdot \mu_{target}}{0.4+6 \cdot \mu_{actual}} \cdot R_{ch\ (with\ \mu_{actual})}, \quad 0.05 \leq \mu_{actual} \leq 0.15 \quad [\text{Eq. 3}]$$

3.6 CONSIDER REASSESSING THE TARGET VALUE FOR FRICTION COEFFICIENT BETWEEN BRASH ICE AND SHIP MODEL

The target friction coefficient between model ice and ship model is set to be 0.10, which intends to represent a not recently painted ship hull. Typically, the measured resistance of the ship is corrected upwards if a lower coefficient (0.05 – 0.10) is targeted in ship models to represent a freshly-painted coating. However, this target value represents the contact between unbroken ice and ship hull, while the surface properties of brash ice might significantly differ from surface properties of level ice. It is acknowledged that the friction characteristics of brash ice in nature appear in a wide range, as they are impacted by the number of ship passages in the channel, the air temperature, snow properties, earlier consolidation etc., meaning that no target value would function for every old brash ice channel in nature. Moreover, the aim of the tests is to harmonise the test results between different experiments, and harmonising the test result to a reasonably good estimate of the friction coefficient is sufficient. Still, more research on the friction coefficient between a non-freshly-painted ship hull and typical brash ice inside an old unconsolidated brash ice channel would improve the resistance prediction correlation to ship's actual performance in ice.

3.7 MODIFY TEXT PART OF REPORTING OPEN WATER RESISTANCE

Generally, the current guidelines assume that the ship's total resistance in a brash ice channel is the sum of ship's ice resistance and open water resistance. Thus, in Guidelines Appendix 4 Annex, item 7.1 requires reporting estimate of the resistance of the model in open water. It is noted that the open water resistance is considered directly in analysis process, if the ice resistance is determined using open water overload tests. Therefore, it is proposed to modify item 7.1 to cover this option, e.g.

"7.1 Estimate of the resistance of the model in open water if the value is used in deriving ice resistance".

3.8 MODIFY RULE CHANNEL'S TARGET WIDTH AND TARGET AVERAGE THICKNESS IN MODEL SCALE EXPERIMENTS

Some newly launched merchant ships have a beam that is wider than the width of a typical old brash ice channel, which is created by icebreakers leading convoys through same channels. Significantly wide ships experience higher resistance in real operations compared to the channel resistance determined by the current FSICR model-testing procedures, applied for granting certain ice class. Higher resistance is caused by at least three factors. Firstly, the adjacent channel edges limit the movement of unconsolidated brash ice fragments. Secondly, the brash ice close to the channel edges consolidates more often even in a frequently operated channel, because the traffic limits the consolidation mainly in the channel's midpart. Thirdly, frequent ship passages result in the development of a brash ice channel's thickness profile towards the profile typical to an old brash ice channel. This profile is characterized by the greatest thickness near the channel edges and the least thickness at the center. Consequently, wide ships may

encounter significantly thick brush ice masses near the channel edges. To demonstrate this, Figure 3-1 illustrates two different-sized ships inside a channel of the same width.

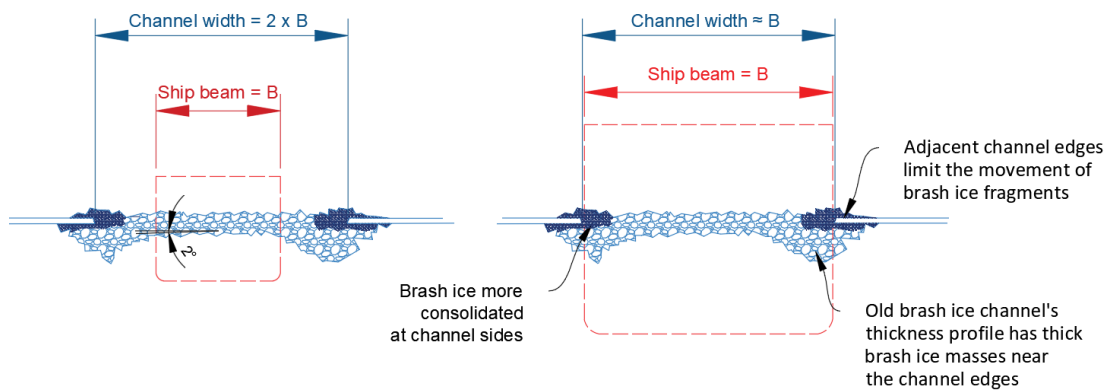


Figure 3-1: The channel width relation to ship beam impacts the channel resistance of the ship. This illustration demonstrates the reasons why a wide ship encounters higher resistance in a typical brush ice channel in relation to a narrow ship.

The current model test procedure for verifying ship's performance for an ice class granting process assumes that the channel is always twice as wide as the ship's beam, which is not a reasonable assumption for a wide ship. Therefore, it is suggested to modify the required width of the test channel in the current Guidelines for the application of the Finnish-Swedish Ice Class Rules.

It is beneficial to keep the testing method relatively simple. Also, from the operational point of view, it is reasonable to assume that icebreaker escort services ensure widening the existing channels to have minimum width equal to assisted ship's beam. This means that an ice-classed ship should not need to break intact ice at the shoulder areas. Still, when the ship's beam is close to the channel width, the interaction between piled-up brush ice and channel edge becomes more complicated than in situations in which the ice fragments are practically not moving close to the channel edges.

It is also noted that in those situations the assumption of performing tests in an even average brush ice thickness (presented in Guidelines for the application of the Finnish-Swedish Ice Class Rules Appendix 4, Chapter 3) might not perfectly simulate the situation in real life. The average thickness in the rules is developed to represent situation, in which the ship is advancing at the midpart of the old brush ice thickness, assuming that the brush ice profile thickens towards the edges by a gradient of 2° . Close to the channel edges, the channel edges are steeper as outlined in Figure 3-1.

As mentioned in Chapter 3.3, it is safe to assume that if the width of the brush ice channel is $2 \times B$ (B is the beam of the tested ship) the channel edges have no impact on channel resistance (Figure 3-2). The limit width of channel, at which the channel edges start impacting the movement of brush ice is dependent on hull form and cannot be universally determined. Based on Aker Arctic's experience (e.g. model scale experiments in Voutilainen, 2023; full scale expedition related to Matala & Skogström, 2017), the ice fragments seem to move in relation to each other at approximately 5 m from the ship's side (Figure 3-3). This is assumed to be approximately a constant, independent from ship's beam. To simulate a situation of a wide ship in a tight channel, the channel width should be less than $B + 10$ m. As we simultaneously assume that the assisting icebreakers

widen the channels at least to the width of the ice-classed ships, the average width of the channel would correspond to $B + 5$ m.

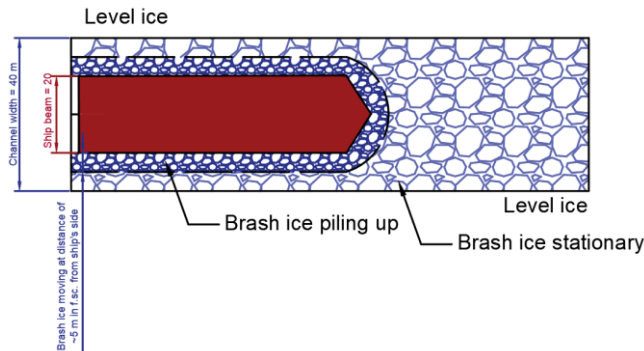


Figure 3-2: Brash ice movement around a ship in a model test simulating FSICR ice class IA channel with channel width equal to $2B$.

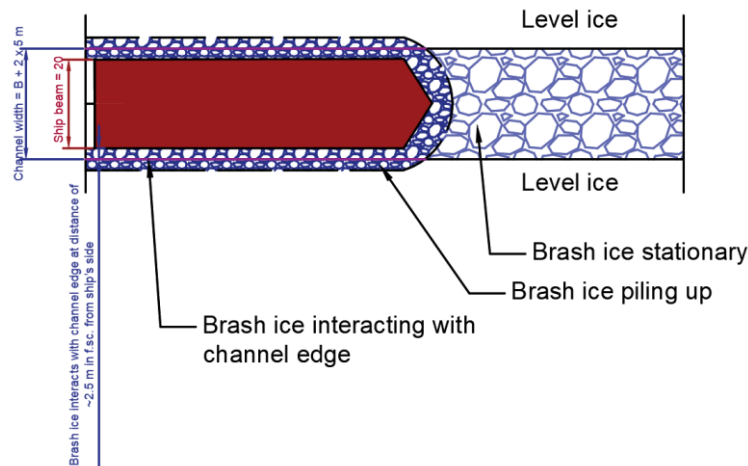


Figure 3-3: An outline of a situation, in which the channel width limits the brash ice movement at the channel sides. The channel width is set to the middle of the distance, at which the brash ice is moving.

Prioritising the aim of keeping the model testing procedures simple as possible, however fair, it is proposed that the target width of the channel would be changed from $2 \times B$ to be e.g. wider of the following two measures:

- 35 m in full scale independent from tested ship's beam,
- $B + 5$ m

In addition, the formula for average thickness of the model scale channel should be developed further so that the average thickness in model test experiment increases with the ship's beam. When the ship's sides reach the steep side edges of pre-determined representative old channel, the average model scale thickness should increase so that the average thickness considers the increasing thickness profile gradient.

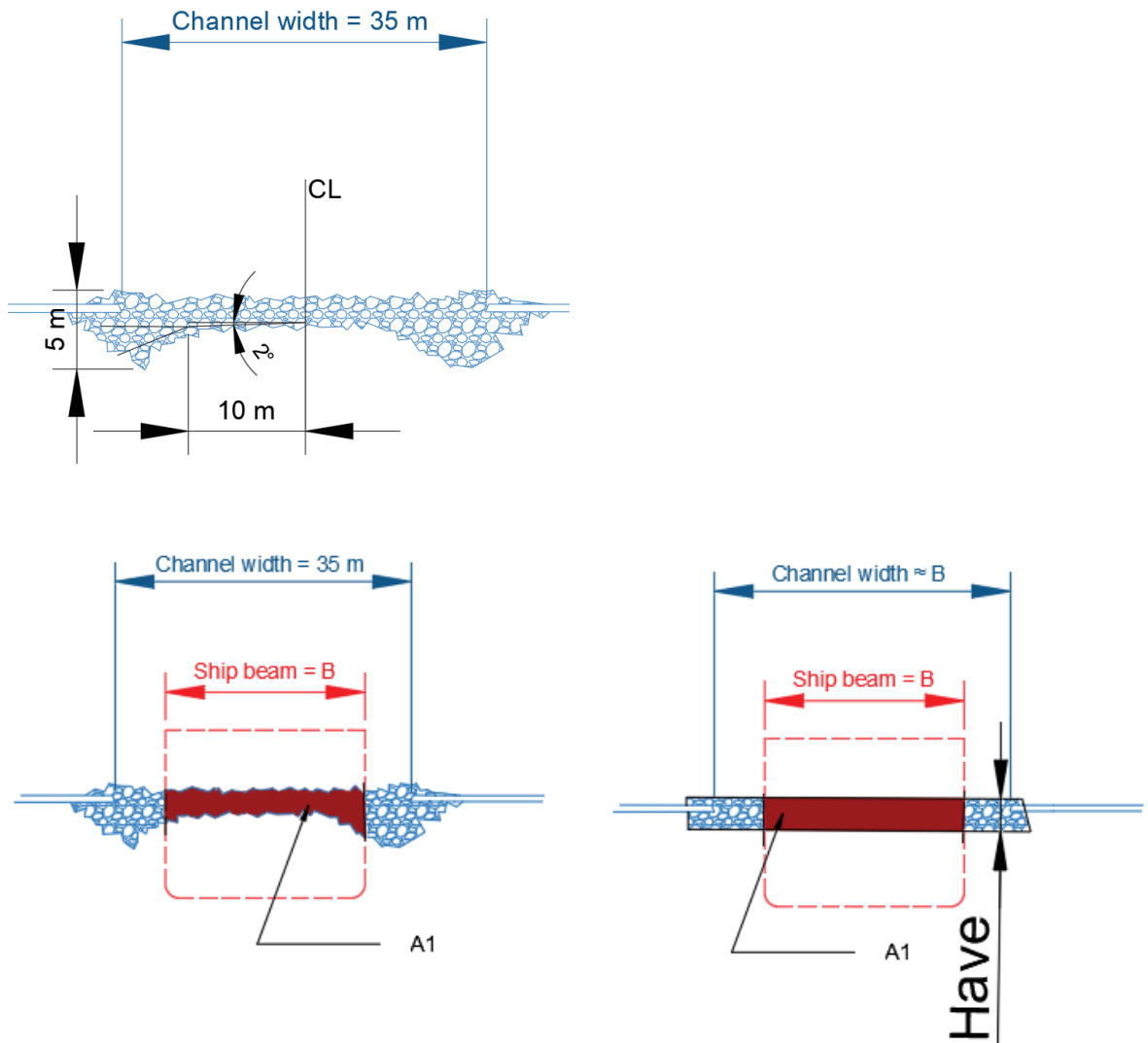


Figure 3-4: The average thickness in a model test could correspond to the brash ice mass replaced by the ship. The illustration on the left represents the channel in real life, the illustration on the right represents the model test experiment with even brash ice layer.

In case of ships wider than $B > 20$ m, we propose the formula for average thickness to be different with gradually increasing thickness. As an example, [Eq. 4] is derived from channel profile (0 m = channel midpart, 17.5 m = channel side) shown in Figure 3-5. It is noted that Eq. 4 might be unnecessarily complicated, and the phenomenon of increasing thickness close to the channel edges could probably be caught well enough using a lower degree equation.

$$H_{ave} = H_{mid} \cdot \left(0.0003 \cdot \left(\frac{B}{2} \right)^4 - 0.003 \cdot \left(\frac{B}{2} \right)^3 + 0.011 \cdot \left(\frac{B}{2} \right)^2 + 1.094 \cdot B + 1 \right) / \left(\frac{B}{2} \right) \quad [\text{Eq.4}]$$

For ships less than 20 m, the old formula is sufficient. Figure 3-6 presents a graph of average channel thickness for Ice Class 1A test as a function of ship's beam using the old formula for ships less than 20 m wide and the new formula for ships more than 20 m

wide. The curve representing the new formula is drawn with a dashed line to underline the possibility of replacing the formula with a simpler approach.

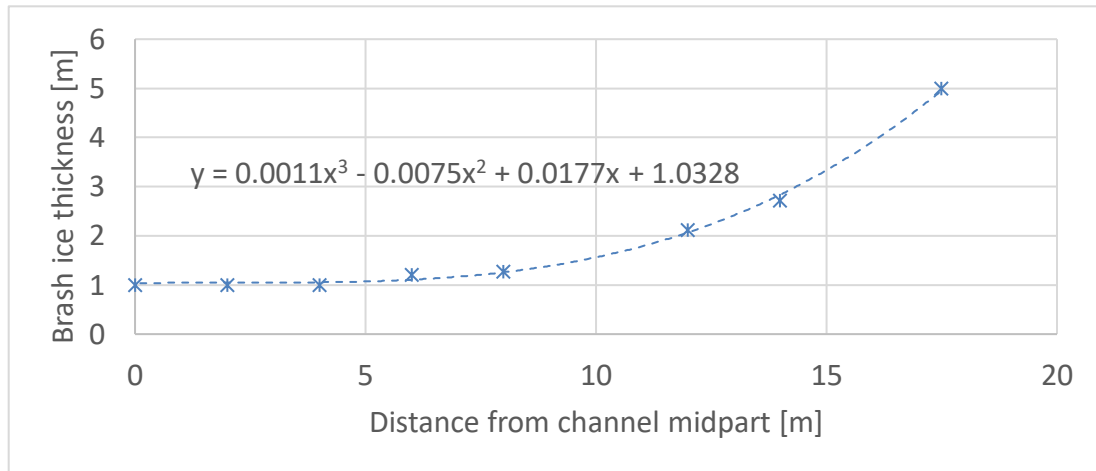


Figure 3-5: Channel profile of a typical old brash ice channel with midpart thickness of 1.0 m and width of 35 m.

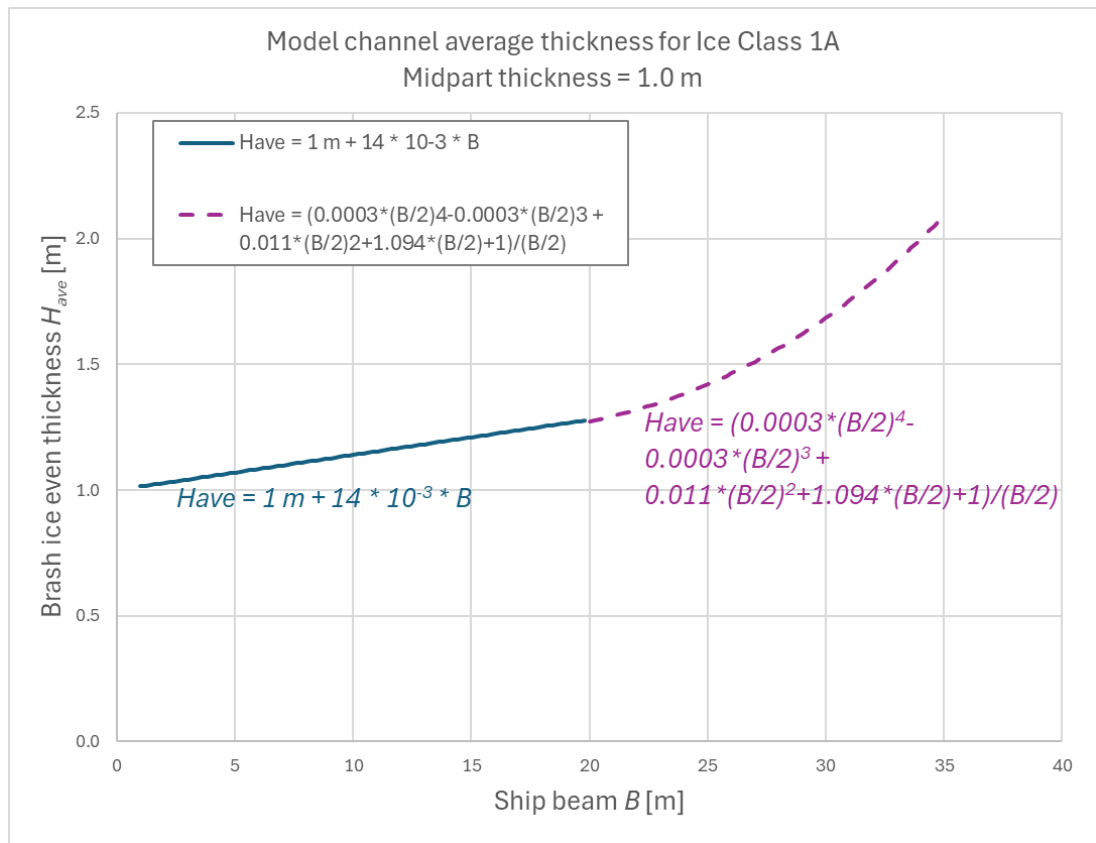


Figure 3-6: Average thickness of channel for Ice Class 1A according to new proposed procedure.

This approach increases the resistance of wide ships in a model test experiment; however, the impact might be milder than it is in real life, due to possible consolidation of brash ice close to channel sides. However, it is reasonable to assume that the presented simplified approach is sufficient.

The exact impact of channel width into the ship's resistance in the channel can be experimentally investigated further in the future.

3.9 CONSIDER RE-EVALUATING THE CRITERIA POINT

The performance requirement for FSIC in Guidelines for the application of the Finnish-Swedish Ice Class Rules is described as follows: "Ships must be able to follow icebreakers at a reasonable speed and proceed independently in old brash ice channels at reasonable speeds." The design point is set so that for certain ice class IA – IC, the ship must make at least 5 knots in an unconsolidated brash ice channel with certain midpart thickness. For ice class IA Super, the ship must make at least 5 knots in a consolidated brash ice channel with certain thickness.

Setting the performance point in a design condition, which represents the expected operation of the ice-classed ships is assuredly the optimal way to keep the procedures practical. However, regarding the purpose of this report, the design point itself might need re-evaluation. The improved methodology for predicting ship's resistance in unconsolidated brash ice channels is believed to treat the different bow shapes equally in the design condition. The modern bow shapes operate typically quite well in this particular condition. However, in real operations, the ships temporarily encounter conditions different to design condition, such as slightly consolidated channels. There is a risk that the bow shapes with vertical stem angles face more challenges in such conditions compared to traditional ice-classed merchant ships. Whether this concern is worth further consideration needs to be assessed by the authorities.

4 OTHER MODIFICATION TO FSICR APPENDIX 4

4.1 VERBAL MODIFICATIONS

- 1) Chapter 1, use “self-propulsion tests” instead of propulsion tests
- 2) Chapter 2: a possibility to clarify the text.
- 3) Chapter 3: replaced with new pictures and formula. The measurement intervals are considered in Chapter 4.2 point 5.4, which will be the updated Appendix 4 Annex.

4.2 REQUIRED INFORMATION IN A MODEL TEST REPORT

Guidelines for the application of the Finnish-Swedish Ice Class Rules TRAFI/708629/03.04.01.01/2018 Appendix 4 provide a list “Required Information in a Model Test Report”. The current list includes useful information related to a well-reported ice model test. It is proposed that the list is reduced to contain sufficient details to assess rule fulfillment. The proposed items to be removed are indicated with ~~strike through~~ in the list below. Proposed additions are indicated with **blue**.

“The following information should be included in a model test report submitted in order to have the engine power accepted in accordance with section 3.2.5 of the Finnish-Swedish Ice Class Rules, 2017.

1. General description of the ice model basin and the model ice
2. Ship model
 - 2.1 Main particulars of the ship, including displacement and deadweight
 - 2.2 Main particulars of the model
 - 2.3 Description of the ship geometry, with hull lines drawing
 - 2.4 Model scale
3. Propulsion
 - 3.1 Description of the ship propulsion system, including the net thrust and bollard pull curves
 - 3.2 Description of the model propellers
 - 3.3 The bollard pull versus the RPM curve of the ship model
4. Test program and procedures
 - 4.1 Model test program
 - 4.2 Hull friction coefficient measurement procedure
 - 4.3 Description of the measurement system for propulsion values
 - 4.4 Description of the measurement system in resistance and/or propulsion tests
 - 4.5 Analysis procedures
5. Model ice
 - 5.1 Thickness and description of the surrounding ice field
 - 5.2 Description of applied model ice and brash ice piece size and form
 - 5.1 Data on the parent level ice thickness

~~— 5.2 Parent level ice strength (bending strength and also, preferably, compressive strength)~~

~~5.3 Description of the method for producing the channel~~

~~5.4 Measurement of the channel profile, cross-sectional profile with 5 measures at the full channel width with longitudinal interval of 2 m at most. Measurement of the channel profile at sufficiently small intervals (intervals of around 10 ... 20cm) to allow the accurate determination of the cross-sectional area of the channel. In a longitudinal direction, the cross-sectional profiling interval should be 2m at most. The methods used in this measurement should be described.~~

~~— 5.5 From each cross section, an average channel thickness should be computed based on a channel width which is the breadth of the ship and 1.6 times the ship's breadth.~~

~~5.6 Description of the porosity of the brash ice. Photographs from above the channel to provide a picture of the brash ice coverage along the entire length of the channel.~~

~~5.7 For the ice class IA Super, it is assumed that a consolidated layer 10 cm in thickness (full scale) is lying on top of the brash ice. If this layer is modelled, the modelling procedure should be described, including the manner in which it was produced and how its thickness and strength were measured.~~

6. Test results

~~6.1 Measurements of the hull coefficient for friction with ice~~

~~6.2 The time histories of the model speed, propeller thrust, torque and RPM derived from each test. Indication of the part of the time history based on which the final values were calculated.~~

~~6.3 Description of the behaviour of the brash ice in the channel. A measurement of the cohesion and internal friction angle or some other parameters describing the strength of the brash ice should be performed, or an earlier result for these quantities should be produced in a similar manner based on a brash ice channel.~~

~~6.4 Photographs of the channel made by the vessel immediately after the tests, from above.~~

~~6.5 The deduced (from time histories referred to in section 6.2 above) and calculated model propulsion, total model resistance and ice resistance values~~

~~6.6 Full-scale resistance and engine power prediction, including a description of the extrapolation method. An estimate must be given of the accuracy of the result obtained by extrapolation.~~

7. Other information

~~7.1 Estimate of the resistance of the model in open water.~~

~~7.2 Calculation of the required engine power according to the Finnish Swedish Ice Class Rules, 2010, with input data.”~~

5 CONCLUSION

This report lists suggestions of modifications for the model testing guidelines for determining the minimum power requirements for Finnish-Swedish ice classes to better address the evolving merchant fleet. The current guidelines, while effective for traditional ice-going vessels, are not suitable to predict performance of all modern ice-classed merchant ship bow designs, which are optimized for open water performance. These modifications aim to enhance the accuracy and relevance of the guidelines, ensuring that they reflect the realities of modern maritime operations.

The suggested modifications aim to consider all factors which need to be carefully defined in the test conditions, and list all parameters and property measurements, which need to be recorded and reported. One of the key updates is the incorporation of requirements for ice strength, target speed, and in some cases the thickness of the surrounding ice field. The report also proposes changes to the friction coefficient correction formula. These factors are crucial for a realistic simulation of a ship's resistance in brash ice channels. Additionally, it is proposed to modify current guidelines to address the operational discrepancy between ships with significantly large beams and those with typical beams. The proposed modifications aim to provide a more equitable and functional determination of the required minimum power for ice-classed ships in condition representing an old brash ice channel in the Baltic Sea.

The modifications emphasize the need for realistic simulation of interactions between ice fragments. This approach is particularly important for modern ships with high stem angles, because a significant share of their resistance is induced by the brash ice piling-up to the sides. Thus, accurate modeling of the forces between the brash ice fragments is essential for predicting a ship's performance in brash ice channels. The proposed guidelines suggest abandoning the scaling down of flexural strength in model scale tests involving brash ice and instead forming the brash ice mass of solid ice fragments.

Additionally, to develop further the simulation of brash ice behaviour around any merchant ship form, a new approach is proposed regarding the width of the physical channel in model test experiment. This is due to the recent emergence of significantly wide ships. Some modern ice-classed merchant ships operating in the Baltic Sea have beams up to 35 meters, which is significantly wider than the beams of traditional ice-classed ships in the area. The current model testing procedures assume that the channel is always twice as wide as the ship's beam, from which it follows that the channel edge has no impact on brash ice behaviour inside the channel. This is not a realistic assumption for a 35-meter-wide ship due to the typical width of an old brash ice channels at the Baltic Sea. The proposed modifications suggest changing the required width and the definition of average brash ice thickness of the test channel to better reflect the reality of an old brash ice channel at the Baltic Sea.

In conclusion, the proposed modifications to the model testing guidelines are driven by the need to ensure accurate performance predictions in brash ice channels equally for all shapes and sizes of merchant ships applying for Finnish-Swedish ice classes. The suggested modifications in guidelines aim to provide a more equitable and functional determination of the required minimum power for ice-classed ships. These updates are

essential for ensuring that the guidelines remain effective to equally determine ship's ice resistance in evolving maritime environment and environmental standards.

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