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Scaling principles for model testing in old brash ice channel

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ABSTRACT

Climate warming sets higher requirements for sustainability in ship industry, which fuels the introduction of stricter power restrictions and new types of ship hull design. The new designs invite us to reconsider the principles in model scale testing in ice, which is the state-of-the-art method to predict vessel's ice performance prior to its construction. Ice model testing principles were originally developed for the evaluation of performance in level ice at slow speed, but currently those principles are widely applied for ice model testing in other ice conditions as well.

The forces forming the vessel resistance in a brash ice channel are different compared to forces forming the vessel resistance in level ice. In consequence, the current model scale testing principles are suboptimal when predicting vessel's performance in an old, frequently operated brash ice channel, as our earlier research indicates that the prediction is conservative especially for modern merchant ship bow shapes with high stem angles. An old brash ice channel is especially interesting, as it is the determining ice condition in Finnish-Swedish Ice Class Rules ice class granting process.

This paper addresses the problem by introducing a new similitude number – a Channel number – to be applied alongside the currently applied Froude and Cauchy similitudes. The Channel number aims to realistically scale the dominating forces that form the resistance of the vessel in an old brash ice channel by developing further the modelling of the resistance component induced by displacing the ice fragments. This necessitates considering the brash ice fragment interaction and inertia forces. The new scaling principle, which supplements the currently applied Froude-Cauchy scaling principle by the Channel number, is considered more accurate for brash ice conditions. It is designed to predict fairly and uniformly the ship resistance for all bow shapes avoiding potential overpowering of the modern bow types with a high stem angle. This would contribute to providing a good harmonization of ships' expected ice performance with ice classes, and, further, improve the fleet schedule predictability that the logistic chains demand from the transportation.

1. Introduction

The new sustainable development goals within the seafaring generate new requirements for the merchant fleet. These new requirements encourage developing new designs for merchant vessels, which occasionally operate in ice conditions. As the ice-strengthened merchant fleet is an inseparable part of the current winter navigation system in the Baltic Sea, accounting the changes in the fleet and whole system is important on both economic and environmental grounds. Our earlier research on ship's resistance in an old channel (Matala and Suominen, 2022) indicates that the currently applied methods provide conservative predictions of channel resistance for certain types of modern hull shapes, which might result in unnecessary high requirements for the ship's minimum engine power. This research will contribute to a deeper understanding of the current model-test-based performance prediction practices suitability for all hull shapes.

The current winter navigation system in the Baltic Sea employs assisting icebreakers and state authorities controlling the regulations and traffic restrictions in addition to the merchant fleet. The Finnish-Swedish Ice Class Rules (FSICR) are developed to govern the ice class granting process (Trafi, 2017). The FSICR Ice Class is the basis for the determination of the ship fairway due and the availability of the icebreaker assistance in the Baltic Sea. As a result of the provided icebreaker assistance, an old brash ice channel (Fig. 1) is the most common operational ice condition for the merchant vessels. Therefore, FSICR considers an old brash ice channel as the design ice condition. Old

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brash ice channel forms when multiple vessels are piloted through the same channel. Frequent passages of ships re-shape the brash ice mass in the channel to a profile, which is typically thinnest in the centre and thickest at the channel edges. With time the ice fragments in the brash ice channel become rounder and more solid because of the repeated freezing cycles.

To acquire an ice class, the vessel needs to fulfil the requirements for the minimum engine power and hull strengthening set by FSICR. This article focuses on the FSICR requirement for the minimum engine power required for ice classes, and therefore our focus is on old brash ice channels. FSICR provide two alternative methods to determine the minimum required engine power for a vessel: 1) based on a calculation formula presented in FSICR (Trafi, 2021) and 2) based on physical model scale testing in ice in accordance with the FSICR guidelines (Trafi, 2017). The ice class is granted based on the predicted ice performance, and no full-scale verification is required. Because of the vital role of the merchant vessel ice class in the current winter navigation system, it is important that the ice class granting process is up-to-date and uniformly considers all hull shapes.

Ice model testing is the state-of-the-art method to evaluate ice performance of a vessel prior building a prototype. The currently applied model ice and the model scale testing methods were originally developed for predicting limiting ice conditions for a vessel in level ice. The first ice model tests were performed by Arctic and Antarctic Research Institute (AARI) that initiated the development of ice model scale testing methods and principles in the 1950s (Kashtelyan et al., 1968; Sahari and Matala, 2021). Later, new facilities were formed that developed their own model ice, procedures, and methods (ITTC, 2014). Today, the model test procedures are discussed on regular basis at International Towing Tank Conference (ITTC) Specialist Committee on Ice to harmonize the testing principles. However, none of the prevailing model ice types can scale all natural ice features accurately simultaneously (ITTC, 2014). The central scaling principles are well established and generally agreed, but have developed only incrementally over years (e.g. Schwarz, 1977; von Bock und Polach and Ehlers, 2015). It is recognized that alternative scaling methods for model scale testing in ice has been suggested, but those have not been applied in common practice nor validated with full scale tests. Atkins (1975) has proposed an idea of a special ice-number, which would involve correctly scaling the fracture toughness. Palmer and Dempsey (2009) have criticized applying Froude similitude in slow-speed structure tests. von Bock und Polach et al. (2021) have proposed an approach of using Virtual Equivalent Thickness in tests modelling wave-ice interaction. Universally, von Bock und Polach and Malyneux (2017) have proposed a case-based scaling, which would abandon the idea of a general scaling method but develop an improved method for different test scenarios.

The central theoretical approach in model scale testing is the similitude theory. The theories have been utilized for a wide range of diverse engineering applications to enable the studies on the behaviour of massive prototypes with reduced scale models. In addition to geometrical similitude, similitude theory aims to establish "the necessary and sufficient conditions of similarity among phenomena" as stated by Coutinho et al. (2015). In model scale tests in ice, this would require similarity of phenomena, which are present when an actual vessel is operating in ice. Vance (1974) reasoned respectively that such requires the modelling of geometric, kinematic, and dynamic similarity between the prototype and the model. The total dynamic similarity therefore requires retaining the relationship between gravitational, inertia, elastic, and frictional forces.

The relationships between these forces have been traditionally established by satisfying Froude and Cauchy similitudes. Froude similitude considers the ratio between inertia and gravitational forces, while Cauchy similitude considers the ratio between inertia and elastic forces of the ice (e.g. von Bock und Polach and Ehlers, 2015). Accounting the frictional forces would require maintaining the Reynolds similitude, i.e. the ratio between water inertia forces and viscous forces. However, maintaining Reynolds and Froude similitudes simultaneously would require altering the viscosity of the water that is not easily achieved (Vance, 1974). As the inertial and gravitational forces (Froude) are assumed to influence more in the icebreaking process than viscous forces at low speeds (Reynolds), commonly Froude similitude is modelled correctly (Vance, 1974).

Despite the design conditions and requirements for vessels vary e.g. from the slow speed level ice breaking to operations in brash ice

Fig. 1. An icebreaker assisting a merchant ship in an old brash ice channel at the Baltic Sea.

channels at 5–10 knots, the same scaling principles are applied for both conditions (ITTC, 2021), although the forces acting in these two conditions are different. As an example, because brash ice mainly consists of broken ice, the forces related to breaking the ice are insignificant when compared to level ice. Therefore, there is a need to reconsider the suitability of the currently applied similitude methods in brash ice testing and develop it further.

The ice resistance prediction from model scale tests to full scale has traditionally been verified by correlation tests. The results are convincing and the methodology in level ice is widely approved (ITTC, 2021; Myland, 2019). Nevertheless, there is a limited number of equivalent correlation tests in brash ice channel, while it is notified that conducting a correlation resistance test in brash ice is challenging, as the brash ice channel can appear in many forms in nature, the properties are difficult to measure, and the properties may change within short time periods and with temperature. Our earlier research on the resistance of the vessel in brash ice channels (Matala, 2021; Matala and Suominen, 2022) demonstrates that the brash ice fragment interaction might be a central factor in the brash ice resistance. In our earlier research (Matala and Suominen, 2022), we introduced channel closing as a visual indicator of evaluating if the applied model scale ice behaves realistically inside the channel, see Fig. 2. While being qualitative nature, this observation motivates to investigate the differences between the applied model ice types. This helps to understand which brash ice properties are the most significant ones in the vessel-brash ice interaction process, and which properties therefore should be carefully considered when developing the scaling law further for model scale tests in an old brash ice channel. The reasoning of this insight is outlined in detail in Matala and Suominen, 2022 together with the potential uncertainties involved to the currently applied model scale test procedures. To ensure the scale model functionality, the processes and forces need to be equivalent in full scale and in model scale, which is not fulfilled with the current model scale test procedures. Because the currently applied ice model test scaling principle fails to model the fragment interaction realistically, the correlation in old brash ice channel needs to be subjected to scientific scrutiny.

Our earlier research on vessel resistance in old brash ice channel has systematically investigated the brash ice properties (Matala, 2021; Matala and Gong, 2021) and model scale tests correlation to full scale (Matala and Suominen, 2022). This paper aims to improve the representation of brash ice behaviour and resistance prediction in model scale testing in ice by investigating the topic theoretically. This study focuses on the currently applied scaling principles and their application in old brash ice channel. The paper summarizes which of the currently applied scaling principles are relevant for a model scale test in an old brash ice channel, and which important phenomenon and forces of brash ice are not satisfactory modelled using the currently applied scaling laws. Based on the understanding of the most significant forces in ship's resistance in brash ice, we introduce an improved scaling procedure which involves applying a new similitude number – the Channel number – alongside Froude and Cauchy similitudes, which would provide standardized and realistic circumstances for model scale testing in an unconsolidated old brash ice channel by improving the modelling of the ship's resistance component, which is induced by displacing the ice fragments. Finally, the proposed scaling procedure is verified by reflecting the findings to the earlier correlation brash ice channel tests in full scale and in model scale.

Our research focuses on unconsolidated old brash ice channels, but the same principles are applicable on any unconsolidated brash ice tests. The most important difference between a brash ice field and brash ice in an old brash ice channel is that the brash ice in an old brash ice channel is constrained by the surrounding level ice outside the channel edges. This difference is not seen to limit the application of the new principles to only channels, because the old brash ice channel described in FSICR has the width corresponding to 2 × ship beam, and in full scale tests no brash ice movement was observed in channel edges with corresponding channel width. The consolidated layer, which is considered for Ice Class 1A Super is not typically modelled in model scale tests, because freezing the model ice produces a consolidated layer corresponding to ice with full-scale properties. Instead, the resistance of a model in a consolidated brash ice channel can be determined for example utilizing superposition principle and determining separately the resistance of the unconsolidated brash ice channel by model test and the resistance from the consolidated layer using calculation methods.

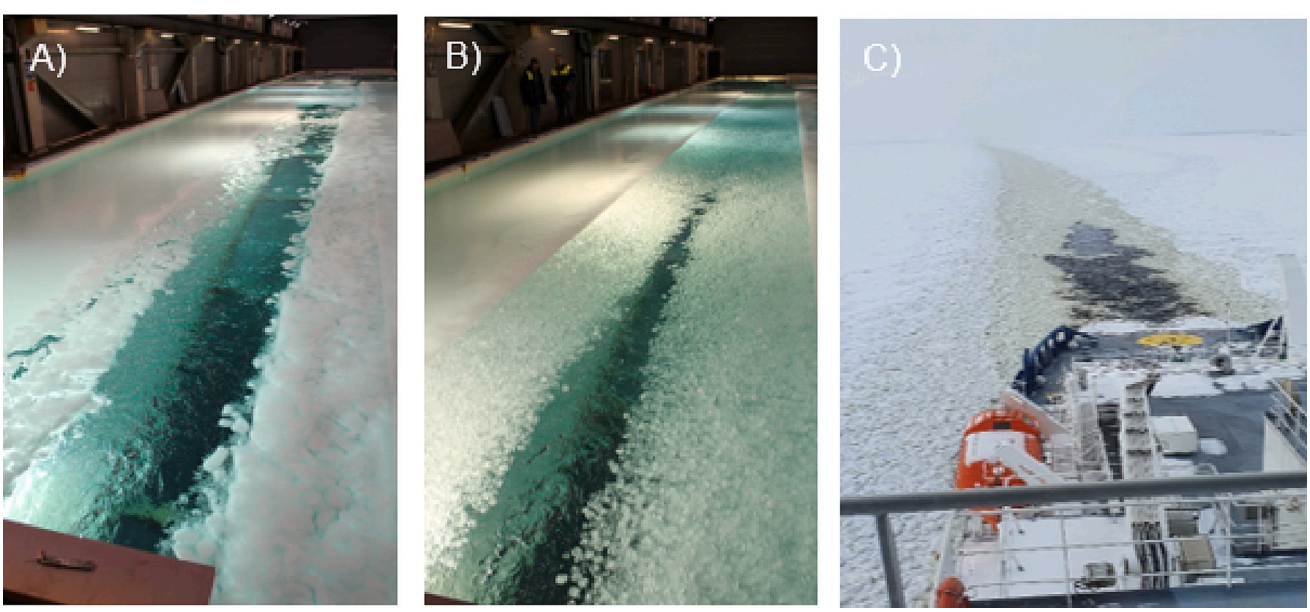

Fig. 2. Brash ice channel in full scale (C) and in model scale (A and B). Model brash ice in A) is made of 42 kPa FGX model ice and model ice in B) is made of unscaled fresh-water ice cubes. The channel closing behind the vessel is similar in B) and C), as opposed to A), in which the channel does not close after the vessel passage. (Matala and Suominen, 2022).

2. Level ice vs brash ice channel

2.1. Vessel resistance in level ice and in an old brash ice channel

The vessel resistance in level ice has been considered as a part of fine ship design for more than a century. One of the reportedly first contributors in this field was Runeberg (1989), who proposed a formula for vessel's ice resistance. Already Runeberg considered the bow angles influence on the breaking process in his formula. The ice resistance predictions developed within the following decades assumed the breaking component induced by bow to dominate the vessel resistance, and the frictional resistance component at vessel sides was included in the calculations only in late 1950's by Tarhis (Myland, 2019). Further, Kashtelyan et al. (1968) established the vessel resistance in level ice division to four components, which are (1) the resistance from ice breaking at the bow, (2) the ice resistance from submerging the ice pieces, (3) the resistance component related to vessel speed, and (4) open water resistance. This division is still well-known, and it has been applied by numerous naval architects and researchers later (e.g. Enkvist, 1972; Vance, 1974). At the latest, the semi-empirical method created by Lindqvist (1989) established a common approach to vessel resistance in level ice, and later research has been focusing on refinements of details (e.g. Kämäräinen, 2007).

To describe the vessel's resistance in an old brash ice channel, it is convenient to follow the same resistance component division. Mellor (1980) divides the brash ice resistance into three components: (1) bow resistance induced by the brash ice internal friction, (2) frictional resistance at the bow and (3) frictional resistance at the vessel side. The idea of applying soil mechanics was applied already in Mellor's work. Malmberg's (1983) research on ridge resistance developed further the Mellor's formula and merged two resistance components acting in the bow area into one, resulting in two components: (1) resistance at the bow and (2) the frictional resistance at the vessel side. There is a good agreement of the component division, and many other researchers follow Mellor's and Malmberg's footsteps (Kitazawa and Ettema, 1985; Wilhelmson, 1996). Recently, a mathematical model developed by Dobrodeev and Sazonov (2019) divide the brash ice channel resistance further into four components, namely (1) resistance due to brash ice displacement, (2) resistance due to accelerating ice fragments into instant velocity, (3) resistance due to the friction at the vessel bow, stern and bottom, and (4) resistance due to the friction at the vessel side, including ice piling. However, components 1 and 2 can be understood to relate to the displacement component and components 3 and 4 to the frictional component. There seems to be a good agreement of the dominating brash ice resistance components, as similar division to (1) the frictional force and (2) the deformation force has been chosen by Gong et al. (2019) to simulate vessel's ridge resistance using DEM. An unconsolidated ice ridge is in principle very similar ice condition with brash ice in an old brash ice channel, except for the ice fragment shape and the feature dimensions.

The most substantial difference between the resistance components in level ice and in an old brash ice channel is that the breaking component is lacking from the ship's ice resistance in an old unconsolidated brash ice channel, which increase the weight of the prevailing resistance components. However, there is also other differences, as the frictional component size is influenced by at least two separate factors. First, the brash ice fragments have a completely different form and frictional properties when compared to freshly-broken ice fragments (Kannari, 1982). Second, the ice fragment coverage area might be substantially different for the same vessel in level ice and in broken ice. E.g. Lindqvist (1989) calculation method determining vessel level ice resistance assumes 70% of vessel bottom to be covered with ice floes, whereas calculation methods determining vessel channel resistance assume vessel bottom free of ice.

2.2. Forces and kinematics in vessel operations in a brash ice channel

Brash ice in an old channel is understood as cohesionless, granular and floating material, as it was defined by Mellor (1980). The brash ice cohesion and internal friction angle were studied further by e.g. Ettema and Urroz (1989) and more recently by Patil et al. (2022), who presented experimental measurements to support the assumption. Fig. 3 visualizes a merchant vessel in a brash ice channel. When moving ahead at speed v_{vessel}, the vessel bow submerges and displaces aside the brash ice mass. Vessels with low stem angles submerge more ice pieces than vessels with higher stem angles. A submerging component can be separated from the combined displacement-and-submerge component for vessels, which measurable submerge ice. The vessel's bow is directly in contact with the adjacent ice fragments, which interact with the ice fragments next to them forming a force chain. This corresponds to the full-scale observations of brash ice mass dynamic behaviour. Fragments in a full-scale brash ice channel can be seen in Fig. 4 to explicate the fragments' appearance in nature.

Submerging forces are related to buoyancy that is related to dimensions of the submerged ice, gravity, and density difference between the water and ice fragments. Fig. 4 illustrates the forces for a bow shape, which has a high stem angle and does therefore submerge only marginally ice fragments. The hull of a moving vessel accelerates ice fragments having a mass $m_{fragment}$ with an acceleration $a_{fragment}$, which cause a force $F = m_{fragment} \bullet a_{fragment}$. Thus, the bow resistance due to displace would be simply $R_{displace} = \sum (m_{fragment,\ n} \bullet a_{fragment,\ n})$. The acceleration of the ice fragments is influenced by the surrounding brash ice field, which defines how the movements are restricted and how freely the ice fragments are moving. However, for realistically modelling the process in reduced scale, it is sufficient that the physical condition and fragment interaction in the model correspond well to full scale.

The frictional component originates from the brash ice mass at the vessel side and bow both below (wet contact) and above water (dry contact) and relates to friction coefficient between ice fragments and hull and the normal force at the surface. It is notified that the friction coefficient between the ice fragments (also referred as ice-ice-friction) is considered to mainly relate to the displacement component, which on its behalf influences the contact pressure at the ship side, which contributes to ship frictional resistance component.

Fig. 5 presents our current understanding on factors affecting the vessel brash ice resistance. The factors in Fig. 5 are discussed in detail in Matala and Suominen, 2022 together with their relations and their importance. The displacement component, which is proven to be problematic with the currently-applied model scale test procedures, seems to be pronounced in resistance of a modern merchant vessel in an old brash ice channel, while the other resistance components – friction and submerging – can be sufficiently scaled with the current model ice. Therefore, we aim to improve the testing practices primarily by improving the correct modelling of the processes related to brash ice displacement. To model the displacement correctly, the factors related to displacement resistance component, highlighted in Fig. 5, need to be studied. From brash ice property perspective, the important components are porosity, compressibility and internal friction angle (Fig. 5). Porosity is highly interrelated to other brash ice properties and difficult to considered separately. According to our earlier research on brash ice properties, both compressibility and internal friction angle are influenced by shape-depended particle mobility, which is linked to particle surface properties and deformability (Matala and Gong, 2021), i.e. to ice fragment interaction.

In this study no special focus is given to the properties with minor influence on the displacement component, which are piece size and piece size distribution, piece shape, and angle of repose. The piece size and piece size distribution have minor influence on the granular ice properties according to soil mechanics (Cabalar, 2018; Matala, 2021), given that the piece size relation to the ship beam is sufficient. Piece shape has a potentially notable, however indirect influence on the

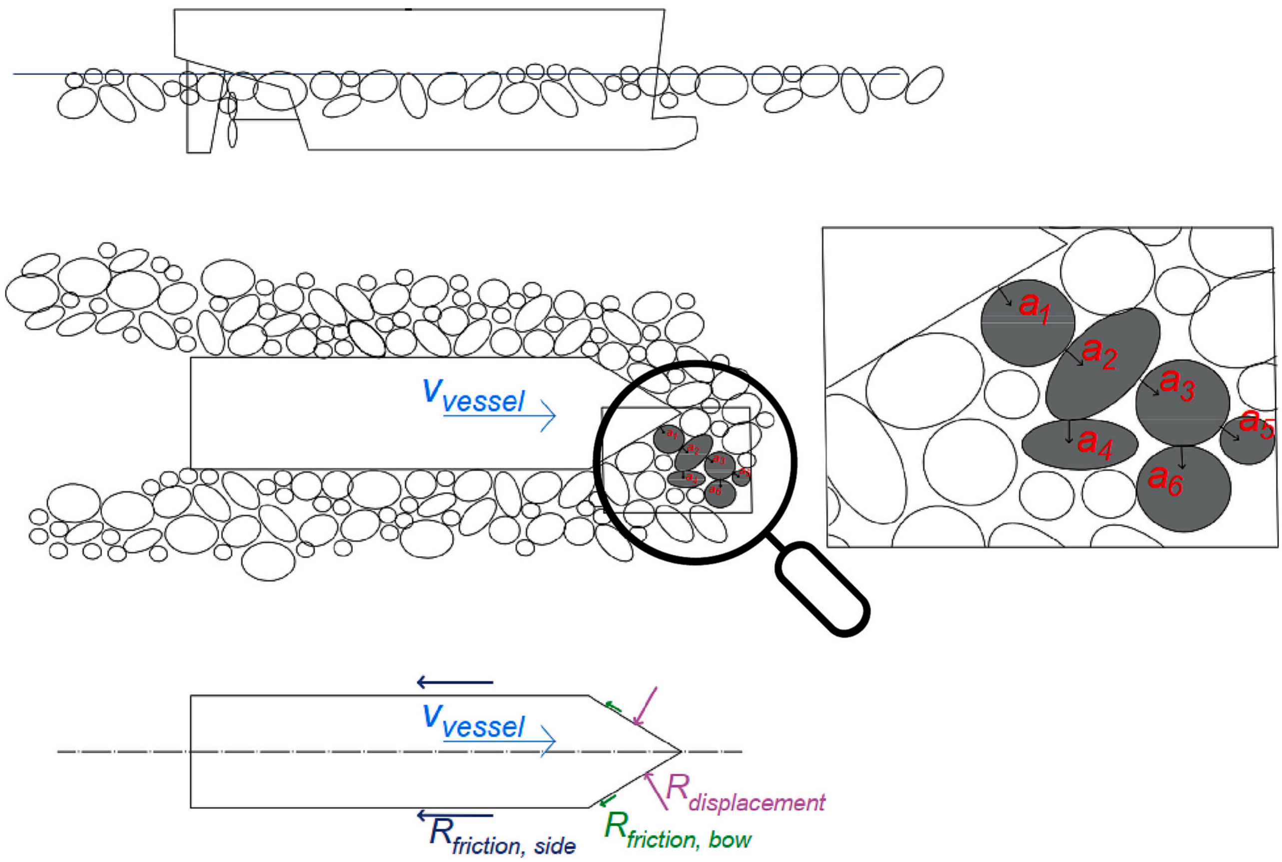

Fig. 3. Vessel in a brash ice channel.

Fig. 4. Brash ice in an old brash ice channel.

granular ice properties as a form of interparticle mobility (Matala and Gong, 2021). The influence of brash ice angle of repose into the displacement component is considered to be minor. Angle of repose's influence on ship resistance mainly relates to the height of the frictional area at the ship side (Matala and Suominen, 2022).

For the ice performance perspective, it is primary important to predict the performance in a standardized condition, which would sufficiently well correspond to the determining condition for FSICR performance prediction to ensure the good harmonization between ice classes and ships' ice performance, which is vital for the safe and efficient winter navigation system. As an example, air temperature is not specially considered in this paper, because it would mainly influence the properties of the consolidated layer, and regardless the air temperature, the temperature of the brash ice fragments remains quite close to 0 °C within the winter season. The consolidated layer is outside of our scope as we are considering an unconsolidated channel. For the same reason, the influence of snow is excluded from the scope, while a snow cover can alter the frictional properties of ice fragments above the water.

2.3. Brash ice fragment interaction

In this paper, the term "brash ice fragment interaction" describes the resistance on interparticle movements, covering both stresses induced by interparticle friction and cohesion.

Soil engineers define cohesion as molecular interaction (Helenelund, 1967). The same stresses build granular material shear stress. Within soil mechanics, a traditional method to describe a material shear strength (τ_f) is Mohr-Coulomb law [Eq. 1]:

$$\tau_f = c + \sigma_n \bullet tan(\varphi) \quad (1)$$

in which c is cohesion, σ_n is normal load and φ is internal friction angle (Helenelund, 1967). According to Helenelund (1967), in nature intermediate soil types possess both the frictional term and the cohesive term, but cohesive term is dominant ($\varphi \approx 0$) for fine-grained (non-granular) materials and the frictional term is dominating ($c \approx 0$) for coarse-grained granular materials. Similarly, also e.g. Green and Marcuson (2014) assumes $\varphi \approx 0$ for fine-grained (non-granular) materials and Mirnyy and Merkin (2016) assumes $c \approx 0$ for coarse-grained (granular) materials. Both studies also discuss the influence of other material parameters, such as material saturation or strength of particles, to existence or absence of the components c and φ.

Cohesion as a component on granular material "shear resistance" is a

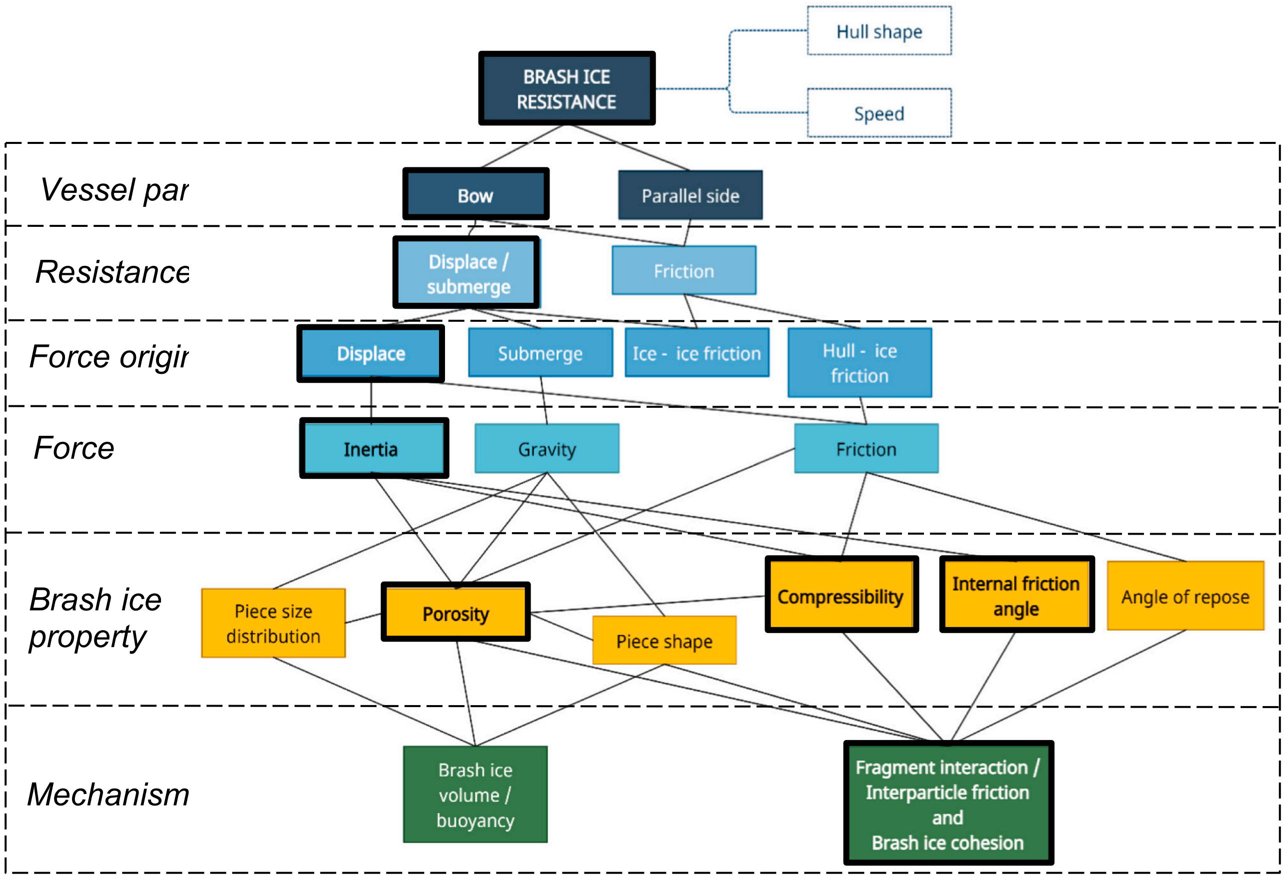

Fig. 5. Vessel resistance in a brash ice channel. The factors highlighted with black rectangles are found central for correctly modelling an open water optimized vessel in brash ice (Matala and Suominen, 2022).

term difficult to determine for brash ice, as it can cover both the Mohr-Coulomb-type granular material shear resistance and resistance induced by interparticle freeze-bonding. According to most resent understanding (e.g. Heinonen, 2004) shear properties are complex and thus simple assumptions such as $\varphi \approx 0$ or $c \approx 0$ might not be justified. However, it is possible to hypothesise that there is a principal difference in shear behaviour between nature brash ice and soft model ice with scaled-down strength. Hereby, in nature the brash ice best corresponds to intermediate soil type with small cohesion component and dominating frictional component. Further, based on our earlier observations (Matala, 2021) the model ice made of solid ice cubes would possess only frictional component and soft model ice with scaled-down strength would possess dominating cohesion component.

Soil engineers determine material cohesion c using a shear box. However, the tools developed by soil engineers are practically not applicable for ice engineers (Ettema and Urroz, 1989). A technically successful measurement using a shear box represents the force chains of the particular test (Polojärvi et al., 2015), which would consequently influence on any estimate of cohesion made based on such test. With solid ice cubes with unscaled strength the measurement could be satisfactory providing that the measurement device dimensions relation to ice fragment size would be sufficient, however the issues related to possible freeze-bonding remain. The model ice with scaled-down strength would deform in shear box measurement and fail at low loading, because the peak loads induced by the particle force chains would be at maximum equal to the ice fragment compressive strength. For these reasons, even a carefully executed shear box measurement would be unusable in attempts to correlate nature sea ice with soft model ice, as the shear behaviour of granular and non-granular materials is completely different. It is also notified that any correlation measurement in full scale would be challenging to arrange so that it could reliably measure such small forces.

In this paper, the term "cohesion" is used to describe any non-frictional resistance occurring on interparticle movement. In addition to molecular interaction, our definition of "cohesion" covers the possible freeze-bonding and any non-frictional resistance on interparticle movement. In particular, the resistance induced by ice fragment deformation is included on our definition of cohesion. This definition is justified by considering the soft model ice fragments as non-granular material with dominating cohesion component. This definition enables discussion on the influence of ice fragment interaction, although it can hardly allow quantitative consideration of cohesion. Quantitative consideration is also limited by the challenges on measuring exact cohesion.

3. Scaling principles

3.1. Scaling principles in level ice model testing

The derivation of similitude laws is mostly based on use of dimension analysis, differential equations, energetic methods, or combined application of these methodologies. Model scale testing in ice apply dimension analysis. To confidently predict the prototype behaviour based on model test experiments it is vital to ensure that the scaling assumptions are correct (Coutinho et al., 2015). The state-of-the-art scaling approach is presented in detail e.g. in Vance, 1974 and von Bock und Polach and Ehlers, 2015.

In the below formulas, subscript "p" refers to prototype and "m" to model. Other abbreviations are as follows: ρ = water density, V = vessel displacement, L = advance length, t = time, m = mass, g = acceleration due to gravity, E = elastic modulus, ε = strain; A = area; ϑ= viscosity; v = velocity.

The geometrical similarity [Eq. 2] is satisfied when all linear dimensions are scaled using a constant scaling factor, λ.

$$L_p = \lambda \bullet L_m \tag{2}$$

The dynamic similarity is satisfied when the prototype forces relate to model forces by a constant factor (λ^3), which is established below for gravitational forces [Eq. 3], inertia forces [Eq.4] and elastic forces [Eq. 5].

$$F_{gravitational} = mg = \rho V g \tag{3}$$

$$F_{inertia} = ma = \frac{\rho \mathrm{V} L}{t^2} \tag{4}$$

$$F_{elastic} = E\varepsilon A \tag{5}$$

3.1.1. Froude Fn – inertia and gravity forces [Eq. 6]

Satisfying Froude similitude ($Fn_p = Fn_m$) is needed when the problem involves wave making and dynamics at the ice cover. In this sense, the application of Froude similitude is reasoned as vessels typically advance in a brash ice channel at relatively high speed.

$$Fn = \frac{v}{\sqrt{gL}} \tag{6}$$

From the dimension analysis it follows that to establish the kinematic similarity between the prototype and model, the relation between prototype and model time is square root of the scaling factor [Eq. 7]:

$$\frac{t_p}{t_m} = \sqrt{\frac{L_p}{L_m}} = \sqrt{\lambda} \text{ and } \frac{v_p}{v_m} = \sqrt{\lambda}. \tag{7}$$

3.1.2. Cauchy Ca – ice elastic and inertia forces [Eq. 8]

Cauchy similitude ($Ca_p = Ca_m$) ensures the realistic ice breaking process in model scale.

Cauchy similitude necessitates equal ratio between inertia and elastic forces.

$$Ca = \frac{v^2 \rho}{E} \tag{8}$$

From the dimension analysis it follows that to establish the similarity of the icebreaking process, the ratio between elastic modulus of the prototype and model must be scaled according to Eq. 9:

$$\frac{E_p}{E_m} = \lambda \tag{9}$$

3.1.3. Reynolds Re – frictional and viscous forces

Reynolds similitude ($Re_p = Re_m$) would enable correct modelling of frictional and viscous forces. The viscous forces occur when the water flows close to the vessel and ice surfaces.

The Reynolds number can be presented as follows [Eq. 10]

$$Re = \frac{Lv}{\vartheta} \tag{10}$$

from which it follows that to satisfy the similitude, it should be that [Eq. 11]

$$\frac{\vartheta_p}{\vartheta_m} = \lambda^{3/2} \tag{11}$$

Since such liquid has not been found for testing purpose, but the tests are traditionally conducted in water, the Reynolds similitude is not modelled correctly. In practice this causes an error in modelling the water flow around the vessel hull and ice fragments. The viscous forces depend on the speed. Thus, the error is small at slow speeds, but should be considered when model testing is conducted at high speeds (Vance, 1974). To maintain the efficiency of the winter navigation, the FSICR set a minimum advancing speed of five knots as a performance requirement for ice-classed ships in the determining ice condition (Trafi, 2017). Five knots as a minimum, it follows that the vessels advance in a brash ice channel typically at relatively high speed. Thus, the current procedure of abandoning Reynolds similitude needs to be reassessed in this regard.

3.2. Forces and kinematics in vessel model and a model brash ice interaction

The dynamic scaling necessitates correctly scaling the forces (Vance, 1974). The forces acting on the interaction between a merchant vessel and brash ice in a channel were introduced earlier in Chapter 2.1. It was concluded that for modern hull shapes, the displacing and friction resistance components are dominating. However, traditional ice-going merchant vessels might involve notable resistance induced by submerging ice pieces.

As the friction coefficient is nondimensional, the forces induced by friction are scaled correctly if the normal load on the surface is modelled correctly, which necessitates correct modelling of gravitational forces if submerging is involved in the bow area (related to ice-ship friction) and the correct modelling of brash ice internal forces inducing the contact pressure at the ship side (brash ice contact pressure relates to ice-ice-friction, frictional resistance to ship-ice-friction). Modelling the gravitational forces induced by submerging of ice fragments is straight-forward, because gravity is the same in model scale and full scale and the density difference between ice and water is approximately the same in model scale and in full scale.

Contrarily to submerging forces, modelling the displacement forces and the frictional force induced by the brash ice contact pressure at the ship side is not as straight-forward with the current model test principles. The current procedure of scaling down the flexural strength according to Froude scaling significantly alters the interparticle interaction because the soft ice easily deforms, the interparticle friction increases and the separate brash ice fragments can merge into non-granular mass with properties different to targeted brash ice material (Matala and Suominen, 2022). Correctly modelling the displacement forces necessitates realistic modelling of the interparticle interaction and, further, building realistic force chains between the brash ice fragments. Modelling ice inter-particle contact forces is central on that account. Moreover, whereas flexural strength is a key parameter in modelling of an icebreaking vessel advancing in level ice, it is irrelevant in broken ice, as practically no bending failure occurs. To satisfactorily model a vessel in brash ice, the realistic ice fragment interaction should be prioritized over correctly scaling the non-existent bending failure.

3.2.1. Modelling frictional forces

Modelling frictional forces involve both the friction between the vessel hull and ice fragments and modelling the friction between ice fragments. The non-dimensional friction coefficients should be correctly modelled without applying any scale factor (ITTC, 2014). The frictional properties of brash ice fragments above water can differ significantly due to snow (Schulson, 2018), however in our research we focus on defining a standardized testing condition, and therefore the influence of snow is excluded from this analysis.

Modelling frictional forces between the vessel hull and ice fragments is implemented in ice model testing utilizing established procedure of ITTC (ITTC, 2017), in which a certain friction coefficient between the model's surface and ice is targeted to correspond to a newly-painted ship hull contact to ice. This correlation regarding the targeted model surface and model ice friction coefficient have been established by empirical correlation tests for a vessel breaking level ice, however the coefficient between a ship and solid and spherical brash ice fragment is presumably lower. Measurement results of the friction coefficient between the unbroken sea ice and steel or ship coating has been published earlier by e.g. Wang et al., 2018 and Makinen et al., 1994. FSICR (Trafi, 2017) states that the friction coefficient between ship hull and ice floes varies between 0.05 and 0.15 in full scale, and this information is applied in ship-brash ice interaction research by e.g.Konno et al. (2011) and Koivurova (2020).

Modelling the frictional forces between the ice fragments would require ensuring the similarity of brash ice fragments surface properties in model scale and in full scale. The realistic modelling of the friction between the ice fragments is especially interesting to us, because we intend to improve the modelling of the resistance component induced by displacing the brash ice. It is notified that model ice scaled-down flexural strength principally alters the frictional properties of the brash ice fragments as the fragments are soft, deformable, and slushy. Therefore, we propose following criteria for model ice attempting to correctly model the friction component between brash ice fragments in a channel:

Criteria 1: The friction between the ice fragments should be similar in model scale and in full scale.

3.2.2. Modelling ice fragment contact forces

Modelling the interaction of ice fragments in brash ice seems to relate to brash ice internal friction angle and cohesion properties based on earlier analysis of Fig. 5. The following criteria attempts to correctly model the displacement component in a model brash ice channel:

Criteria 2: Brash ice internal friction angle should be similar in model scale and in full scale.

Criteria 3: Brash ice cohesion should be corresponding in model scale and in full scale after considering an appropriate scaling factor for model scale cohesion.

These Criteria 2 and 3 directly relate to the displacement component of the vessel resistance formed by brash ice in a channel. The resistance is induced by accelerating the brash ice fragments, and as such these represent inertia forces.

3.3. Introduction of the channel similitude number

To satisfactory model the vessel in a brash ice channel, forces related to ice-ice and ice-hull interaction need to be correctly scaled. To do this, we propose a new "Channel similitude number", *Ch*, to be applied to complement the Froude similitude. As a part of the approach the scaling down the ice strength according to Froude similitude needs to be abandoned. It is notified that Cauchy similitude is nevertheless satisfied because both the ice strength and elasticity would directly correspond to nature sea ice.

Based on the three criteria derived in Chapter 3.2, we conclude that the most significant forces forming the vessel total resistance in an old brash ice channel are frictional forces, cohesion forces and inertia forces. Dimensionless frictional forces are assumed to scale down by ensuring model ice fragment surface characteristics being similar to full scale. Thus, the Channel similitude number aims to correctly model the relation of the remaining forces – cohesion and inertia [Eq. 12]:

$$Ch = \frac{F_{cohesion}}{F_{inertia}} \tag{12}$$

Earlier we concluded that cohesion should be small in an unconsolidated brash ice channel (e.g. Mellor, 1980). Brash ice shear-deformation have earlier been treated applying Mohr-Coulomb failure criterion (Ettema and Urroz, 1989; Patil et al., 2022). The Mohr-Coulomb law, links material shear strength τ_f to normal load σ_n, internal friction angle (ϕ) and cohesion c (Ettema and Urroz, 1989) as presented in [Eg. 1]:

As discussed earlier in Chapter 2.3, using this equation assumes the brash ice is completely free of any consolidation and freeze-bonds would cause no additional resistance in shearing. Cohesion force would then be [Eq. 13]

$$F_{cohesion} = A \bullet c = A \bullet \left[\tau_f - \sigma_n \bullet tan(\varphi)\right] \tag{13}$$

and scaling factor for cohesion forces [Eq. 14]

$$\frac{F_{cohesion,p}}{F_{cohesion,m}} = \frac{A_p \bullet \left[\tau_{f,p} - \sigma_p \bullet tan(\varphi_p)\right]}{A_m \bullet \left[\tau_{f,m} - \sigma_m \bullet tan(\varphi_m)\right]} = \frac{(\lambda \bullet L_m)^2 \bullet \left[\lambda \bullet \tau_{f,m} - \lambda \bullet \sigma_m \bullet tan(\varphi_m)\right]}{{L_m}^2 \bullet \left[\tau_{f,m} - \sigma_m \bullet tan(\varphi_m)\right]} = \lambda^3 \tag{14}$$

From Eq. 4 and Eq. 13 it follows that

$$Ch = \frac{F_{cohesion}}{F_{inertia}} = \frac{A \bullet c}{\frac{\rho V L}{t^2}} = \frac{c}{\rho v^2} \tag{15}$$

To satisfy the proposed case-based scaling principle, the Channel similitude, it requires

$$Ch_p = Ch_m \rightarrow \frac{F_{cohesion,p}}{F_{inertia,p}} = \frac{F_{cohesion,m}}{F_{inertia,m}} \tag{16}$$

4. Evaluation of the new scaling principle

In our earlier research, we systemically conducted brash ice property measurements on different model brash ice types (Matala, 2021) and later ice model tests in brash ice channels in the similar model brash ice types and compared the test results to corresponding full scale measurements (Matala and Suominen, 2022). The model ice types consisted of solid fresh-water ice cubes and fine-grained FGX-model ice with scaled-down flexural strength (corresponding to 500 kPa and 1000 kPa or 1300 kPa in scale ~1:20). The brash ice made of FGX-model ice with scaled-down flexural strength changed over time and as a result of test repeat and ice handling, see Matala (2021). We concluded that the interparticle interaction is increased in model brash ice with scaled-down strength due to increased friction and ice fragment metamorphosis, which we understand as part of cohesion. Hence, it is evident that the cohesion forces for such model ice is notable, not negligible. Below we reflect our observation from the earlier research to the three Criteria proposed in Chapter 3.2 and into the correlation tests performed as part of our earlies channel research (Matala and Suominen, 2022).

4.1. Evaluation beased on the criteria

Criteria 1: "*The friction between the ice fragments should be similar in model scale and in full scale.*"

Table 1 presents ice-ice friction measurements for FGX-model ice and for fresh-water ice. The fresh-water ice value is based on Makkonen and Tikanmäki (2014) measurements and model, and FGX-model ice values are measurements collected within Aker Arctic confidential client projects. Based on Makkonen and Tikanmäki (2014), the ice-ice friction coefficient is highly depended on the speed and contact being dry or wet. Therefore, we compare FGX-model ice experiments and fresh-water values at the same speed, 20 mm/s (1.7 knots at scale 1:20). From the data in Table 1 it is apparent that ice-ice friction between fresh-water

Table 1
Ice-ice friction measured between fresh-water ice and FGX-model ice.

Ice type	Velocity [mm/s]	Friction coefficient μ []	source
Fresh-water ice friction, −2.8 °C, wet contact	20	0.045	Makkonen and Tikanmäki, 2014
FGX-model ice, σ_f = 55.1 kPa	20	0.369	Aker Arctic measurement (confidential report A-544)
FGX-model ice, σ_f = 63.1 kPa	20	0.160	Aker Arctic measurement (confidential report A-510)
FGX-model ice, σ_f = 55.7 kPa	20	0.176	Aker Arctic measurement (confidential report A-510)

fragments is less compared to FGX model ice. Consequently FGX-model ice would not fulfil the Criteria 1. While acknowledging that the sea water ice-ice friction might marginally differ from fresh-water ice-ice friction, the frictional properties would be accurately modelled by using the same material in model scale as is targeted in full scale as the frictional coefficients are non-dimensional.

Criteria 2: *"Brash ice internal friction angle should be similar in model scale and in full scale."*

Our investigation on brash ice properties (Matala, 2021) indicated that brash ice made of FGX-model ice with scaled-down strength altered significantly as a result of brash ice handling or test repeat, and no internal friction angle could be measured from repeated tests. This observation is consistent with our discussion about shear behaviour of non-granular materials in Chapter 2.3. Despite the weaknesses in the measurement, this indicates that the internal friction angle is very sensitive for any loading for soft model ice, which makes the brash ice behaviour unpredictable. As internal friction angle is considered a substantial property in the correct modelling of vessel resistance in a brash ice channel, relying on a material which evidently possesses unpredictable and easily-altering internal friction angle is intolerable.

In turn, the internal friction angle of brash ice made of fresh-water ice cubes remained similar in test repeat, although the measured value was lower than the targeted comparison value in nature, see Matala (2021). The observed lower value could relate to the applied fresh-water ice cube form and surface properties, which increases with the decreasing roundness (Matala and Gong, 2021). The fresh-water cubes were possibly unnaturally homogenous and smooth compared to full scale brash ice fragments. However, in practice this issue could be relatively easily solved as the shape and surface properties of used ice cubes could be chosen differently to ensure a better correlation of internal friction angle.

Criteria 3: *"Brash ice cohesion should be corresponding in model scale and in full scale after considering an appropriate scaling factor for model scale cohesion."*

As earlier discussed, accurate measurement of cohesion is challenging and therefore the evaluation is done primarily using indirect methods. Within the model tests in brash ice channels, it was observed that a channel filled with brash ice made of fresh-water ice cubes closed easily after a vessel passage indicating a small overall resistance on the ice fragments interparticle movement (Matala and Suominen, 2022). In addition, our research on brash ice properties (Matala, 2021) concluded that there was less resistance on interparticle movement in brash ice made of fresh-water ice cubes when compared to brash ice made of model ice with scaled-down strength. This was based on lower value in the angle of repose and compressibility index measurements.

Moreover, as we understand the forces induced by ice fragment metamorphosis being a part of cohesion, it is apparent that cohesion is different for soft, easily deforming model ice compared to solid fresh-water ice cubes.

To assess the magnitude of Channel similitude number in nature and in model scale for soft model ice and for fresh-water ice cubes, we calculate the Channel similitude number [Eq. 15] in these conditions utilizing the cohesion measurements presented by Ettema and Urroz (1989) and FGX model ice and fresh-water ice densities according to Table 2. For reference, Table 3 lists available cohesion measurements in details. Table 3 also considers the scaling factor ($c_p = \lambda \bullet c_m$) in accordance with the applied scale (λ). The scaled-up cohesion values are distinctly high compared to full-scale representative value. This is potentially remarkable, albeit the scaling relates to the applied scaling procedures and the application should therefore be considered carefully. In Table 2 we included the maximum and minimum reported cohesion values for both model ice with scaled-down strength and fresh-water ice with unscaled strength. However, the minimum value of Keinonen and Nyman (1978) seems relatively optimistic and should be interpreted with caution, as the original measurement points only cover two different normal loads, and the curve defining both the cohesion and internal friction angle could have been chosen differently. The number is calculated at speed of five knots and a scaling factor of $\lambda = 20$. Channel similitude number calculated for each scenario is presented in Table 4.

It is important to bear in mind that the cohesion measurements involve several potential sources of errors, the cohesion measurements are typically highly scattered, and any quantitative cohesion measurement result even at best only represents the cohesion in a particular test. Therefore, these exemplary Channel similitude numbers should be understood as indicators of reasonable magnitudes in different scales using different model ice types. Notwithstanding these limitations, the comparison of maximum Channel similitude numbers offers some support for the hypothesis that the interparticle cohesion has pronounced influence in soft model ice with scaled-down strength, and it is apparent that Channel similitude number in a model test conducted in FGX model ice might not be identical with Channel similitude number in full scale.

The early assumption of practically cohesionless brash ice in an old brash ice channel seems to be justified according to recent field measurements (Patil & al., 2022), and as a consequence the proposed Channel similitude number *Ch* should be small both in full scale and in model scale.

Table 2
Numerical values applied for calculating Channel similitude number for prototype and model.

	Model ice, *m*	Nature ice, *p*
Ice density [kg/m^3]	931 (Matala and Suominen, 2022)	920 (Matala and Suominen, 2022)
Maximum cohesion, c [kPa]	4.1 (Weiss et al., 1981)	0.9 (Hellman, 1984)
Minimum cohesion, c [kPa]	0.1 (Keinonen and Nyman, 1978)	0.0 (Urroz and Ettema, 1987)

4.2. Evaluation based on the set correlation tests

The quantitative comparison of Channel similitude numbers further supports using fresh-water ice cubes in channel testing instead of soft model ice. The ship resistance correlation tests in model scale and in full scale are presented in detail in Matala and Suominen (2022) and we recommend familiarizing the test context and potential uncertainties from there. These tests in old channels in model scale and in full scale indicate that the tests conducted in the brash ice made of model ice with scaled-down strength overestimated the vessel resistance by 171% (parental ice target strength corresponded to 500 kPa; first test in the ice field) or 163% (parental ice target strength corresponded to 1300 kPa; first test in the ice field) for an example ship with a high stem angle (referred in Matala and Suominen, 2022 as "Vessel 1"), while the tests conducted in the brash ice consisting of solid ice cubes predicted resistances closest to the full-scale measurement by overestimating the resistance by 105%. It is however notified that the repeated tests in the brash ice consisting of solid ice cubes overestimated the resistance less (by 69% and 44%). In the other correlation test sets (referred in Matala and Suominen, 2022 as "Vessel 2" and "Vessel 3"), the repeated tests predicted a resistance close to the first tests in model ice made of solid ice cubes, and the higher difference between the repeated tests, which was observed in this particular data set with "Vessel 1" was considered to be a result of non-intended consolidation in the first test. Therefore, the lower resistance level observed in the repeated tests is assumed to represent the resistance level in a non-consolidated brash ice field consisting of solid ice cubes. For comparison, the corresponding values for an example ship with a low stem angle (referred in Matala and Suominen, 2022 as "Vessel 3") the first conducted channel test underestimated the ship resistance by 3% (parental ice target strength corresponded to 500 kPa), overestimated the ship resistance by 36% (parental ice target strength corresponded to 1000 kPa), or underestimated the ship resistance by 9% (brash ice consisting of solid ice cubes).

Table 3
Cohesion values reported by different researchers. The references representing ice types with scaled-down strength are highlighted in yellow and the references representing ice types with unscaled strength with green.

Reference	Measurement method	Measured cohesion	Ice type / Scale	Cohesion scaled into full scale
Prodanovic (1979)	Direct shear box measurement	0.25 - 0.56 kPa	model ice, scale: 1:50	12.5 - 28.0 kPa
Weiss (1981)	Direct shear box measurement	1.7 - 4.1 kPa	model ice, scale: 1:10	17.0 - 41.0 kPa
Keinonen & Nyman (1978)	Direct shear box measurement	0.01 kPa	model ice, scale: 1:10 - 1:50	0.1 - 0.5 kPa
Hellman (1984)	Direct shear box measurement	0.0 - 0.9 kPa	artificial ice fragments; strength corresponds to natural ice, fragment size scaled down; 1:1	0.0 - 0.9 kPa
Urroz & Ettema (1987)	Direct shear box measurement	0.0 kPa	naturally frozen ice / plasticblocks; 1:1	0.0 kPa
Leppäranta & Hakala 1992 (Heinonen, J. 2004)	Full-scale loading test	1.5 - 4.9 kPa	full-scale, ice ridge, scale: 1:1	1.5 - 4.9 kPa

Table 4
Maximum and minimum Channel similitude numbers calculated for prototype and model. Model scale values are calculated both for model ice with scaled-down strength and with strength corresponding to nature ice.

	Ch max	*Ch min*
Nature ice, full scale	Ch_p, *max* $= 0.14$	Ch_p, *min* $= 0.00$
Model scale, ice with unscaled strength	Ch_m, *ice cubes, max* $= 2.95$	Ch_m, *ice cubes, min* $= 0.00$
Model scale, model ice with scaled down strength	Ch_m, *max* $= 13.31$	Ch_m*min* $= 0.32$

While these results are possibly reflected by the unpredictable nature of brash ice resistance tests in full scale, these indicate that the brash ice type influence is higher for the ship with a high stem angle than to the ship with a low stem angle, and that the potential overestimation can be significant.

We acknowledge that choosing model brash ice made of fresh-water ice cubes might not be the only solution to realistically model the fragment interaction. Fresh-water ice cubes appear to be a simple and therefore attractive option, but any material fulfilling the set three criteria would function as acceptable media for brash ice in a model scale test in an old brash ice channel.

5. Discussion

In this paper, we propose a new scaling principle for model scale tests in an unconsolidated old brash ice channel and evaluate the principle based on our experiments on model brash ice and on our experiments on ship resistance tests in old brash ice channels in model scale and in full scale. The proposed principle is based on realistically scaling the phenomenon and processes dominating in a vessel resistance in brash ice inside a channel, which according to our experience relate to brash ice fragment interaction. Our experimental results support the scaling principle we propose, as the same model ice type was evaluated as the best option both based on the set three criteria and based on the comparison of the correlation test results from vessel resistance tests conducted in model scale and in full scale.

Our earlier channel model test measurements indicated that the model resistance estimate measured in channel filled with soft model ice fragments is typically conservative especially for ships with high stem angle. The reason for the conservative result relation to the bow shape is understood to relate to the resistance's displacement component, which is pronounced for these vessels with high stem angles, because the submerging component is minor. This is why we chose to focus on developing further the modelling of the resistance component induced by displacing the ice fragments. We believe the reason for the observed discrepancies in modelling the displacement component is the unrealistic brash ice fragment interaction. More specifically, the soft model ice fragments tend to change shape and form instead of building force chains similar to nature brash ice. Because the reason for conservative resistance test result is in incorrect fragment interaction process, the problem cannot be solved simply by applying a correction factor into resistance measured applying soft model ice, but the model ice should be developed further to better model nature brash ice.

The Channel similitude number, which we propose in this paper appears to be satisfactory based on our experimental results. However, it can be argued that the Channel similitude number is not the only possible solution. The main limitation of this approach is related to challenges on accurately and reliably measuring brash ice properties, especially cohesion. Research of brash ice cohesion has a long history, but still the measurements involve potential sources of error. Regardless these challenges in parameter definition, we think the main concern should be given to the mechanism, in which the brash ice column fails in shearing. However, research is also needed on brash ice cohesion assessment to add understanding on the topic.

The Channel similitude number contributes to verification of the realistically-modelled behaviour of brash ice by stating that the brash ice interparticle cohesion in relation to inertia forces in nature is small. This is not satisfied with model ice, if the targeted strength is scaled down according to current practices. Therefore, an applicable approach could be similar to current practice of satisfying Cauchy similitude by requiring limits for $E/\sigma_f > 2000$; a limit could be set for Channel similitude number, for example $Ch < 3.0$ at speed of five knots. Further research should focus on determining the appropriate limit.

The proposed Channel similitude number aims to provide a standardized testing condition, which would provide uniform and fair ice performance predictions for the purpose of FSICR ice class granting process. It is acknowledged that the targeted condition – the old brash ice channel – is hardly uniform in the nature nor it can be controlled. Therefore, we target to provide a standardized testing condition, which sufficiently well corresponds to the representative form of the targeted condition in the nature, which would consequently act as a foundation for better-harmonized relation of the ship's ice performance and ice class. Thus, the new approach would benefit from a large amount of experimental correlation tests with different bow shapes in different old brash ice channel conditions, which could finally validate the method. The same principles which are derived in this research for the unconsolidated brash ice channel are applicable for any unconsolidated brash ice tests. Additional research on modelling the consolidated layer is required to extend the methodology to cover also consolidated old brash ice channels and thereby also FSICR ice class 1 A Super.

6. Conclusion

This study has explored the currently applied model scale testing principles and scaling laws suitability in model scale tests conducted in an unconsolidated old brash ice channel. Our earlier research on vessel's resistance in an old brash ice channel shows the current model-test-based channel resistance determination practice might overestimate the resistance especially for the modern merchant vessel bow types with high stem angles. We concluded that the scaled-down flexural strength completely alters the ice fragments interaction, which based on our earlier research is a substantial factor in ship's resistance in an old brash ice channel. The fragment interaction alters specifically the displacement component of the ship's ice resistance, which is pronounced for the modern bow shapes with high stem angles. The estimate of the ship's resistance in an old brash ice channel is a substantial step in the FSICR ice-class granting process, because it is used to determine the ship's required minimum engine output, and consequently, there is a risk of overpowering the ships in occasions, in which the channel resistance estimate is conservative. Therefore, we propose a new scaling law for model scale testing in ice to model the brash ice behaviour more realistically. This Channel similarity number *Ch* would consider the relationship of cohesion forces and inertia forces. As unconsolidated old brash ice is understood as practically cohesionless granular mass, the Channel similitude number *Ch* should be small for both prototype and the model to satisfy the similitude criteria. More research is required to determine higher limit for Channel similitude number value, which would be able to model vessel in an old brash ice channel realistically. Also, a practical, repeatable, and reliable method should be developed to evaluate cohesion. The continuous efforts with collecting full scale – model scale correlation test results are necessary to validate the method for all hull shapes and to different brash ice channel conditions. Separate research on the consolidated layer is necessary to extend the methodology to cover also FSICR 1A Super and thus all FSICR ice classes.

CRediT authorship contribution statement

Riikka Matala: Methodology, Formal analysis, Investigation. **Mikko Suominen:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The resistance data is presented together with the earlier research, but some parts of the data (such as ship exact characteristics) are confidential.

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