30TH INTERNATIONAL TOWING TANK CONFERENCE
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# Report of the Specialist Committee on Ice

## SPECIALIST COMMITTEE ON ICE

## 1. INTRODUCTION

### 1.1 Membership and Meetings

The members of the Specialist Committee on ice of the 30th ITTC are:

- Franz von Bock und Polach (Chair), Hamburg University of Technology, Germany
- Takatoshi Matsuzawa (Secretary), National Maritime Research Institute (NMRI), Japan
- Aleksei Alekseevich Dobrodeev, Krylov State Research Centre (KSRC), Russia (Secretary and member until May 2023)
- Nils Reimer, Hamburgische Schiffbau-Versuchsanstalt GmbH (HSVA), Germany
- John Wang, National Research Council of Canada, Canada
- Yukui Tian, China Ship Scientific Research Centre (CSSRC), China
- Yan Huang, Tianjin University, China
- Jinho Jang, Korea Research Institute of Ships and Ocean Engineering (KRISO), Korea
- Riikka Matala, Aker Arctic, Finland
- Otto Puolakka, Aalto University, Finland

The following committee meetings have been held during the work period:

- October 26, 2021, online meeting; Participants: Franz von Bock und Polach (Chair), Aleksei Dobrodeev (Secretary), John Wang Nils Reimer, Yan Huang, Takatoshi Matsuzawa, Jinho Jang, Otto Puolakka, Riikka Matala, Yukui Tian

- May 6, 2022, online meeting; Participants: Franz von Bock und Polach (Chair), Aleksei Dobrodeev (Secretary), John Wang Nils Reimer, Yan Huang, Takatoshi Matsuzawa, Riikka Matala, Yukui Tian Absent: Jinho Jang, Otto Puolakka,

- October 4, 2022, online meeting; Participants: Franz von Bock und Polach (Chair), Aleksei Dobrodeev (Secretary), Nils Reimer, Takatoshi Matsuzawa, Riikka Matala, Yukui Tian Absent: Jinho Jang, Otto Puolakka, Yan Huang, John Wang

- December 2, 2022, online meeting; Participants: Franz von Bock und Polach (Chair), Aleksei Dobrodeev (Secretary), Nils Reimer, Takatoshi Matsuzawa, Riikka Matala, Yukui Tian, John Wang

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Absent: Jinho Jang, Otto Puolakka, Yan Huang

- February 22, 2023, online meeting; Participants: Franz von Bock und Polach (Chair), Nils Reimer (Acting Secretary), Takatoshi Matsuzawa, Riikka Matala, Yukui Tian Absent: Jinho Jang, Otto Puolakka, Yan Huang, Aleksei Dobrodeev (Secretary), John Wang

- May 12, 2023, online meeting; Participants: Franz von Bock und Polach (Chair), Takatoshi Matsuzawa (Secretary), Takatoshi Matsuzawa, Riikka Matala, Yukui Tian, Otto Puolakka, Yan Huang; Absent: Jinho Jang, John Wang

- July 4, 2023, online meeting; Participants: Franz von Bock und Polach (Chair), Takatoshi Matsuzawa (Secretary), Takatoshi Matsuzawa, Riikka Matala, Yukui Tian, Otto Puolakka, John Wang; Absent: Jinho Jang, Yan Huang

- November 14, 2023, online meeting; Participants: Franz von Bock und Polach (Chair), Takatoshi Matsuzawa (Secretary), Takatoshi Matsuzawa, Riikka Matala, Yukui Tian, John Wang; Absent: Jinho Jang, Yan Huang, Otto Puolakka

- January 30, 2024, online meeting; Participants: Franz von Bock und Polach (Chair), Takatoshi Matsuzawa (Secretary), Takatoshi Matsuzawa, Riikka Matala, Yukui Tian, John Wang Absent: Jinho Jang, Yan Huang, Otto Puolakka

- May 6-7, 2024, Hamburg; Participants: Franz von Bock und Polach (Chair), Takatoshi Matsuzawa (Secretary), Takatoshi Matsuzawa, Riikka Matala, Yukui Tian, John Wang Absent: Jinho Jang, Yan Huang, Otto Puolakka

## 1.2 Tasks

The recommendations for the work of the Specialist Committee on Ice as given by the 29th ITTC were the Terms of Reference (TORs):

1. Continue to maintain, review and update existing accepted procedures and guidelines in accordance with current practice.
2. Continue work on uncertainty analysis including conducting benchmarking study among ice model basins. Focus on the largest error sources is recommended such as the uncertainty related to the ice properties. Based on conducted measurement and analyses, include review how the findings may reflect ice measurements.
3. Develop Guideline 7.5-02-04-02.5 – Ice Property Tests, including findings related to the uncertainty analysis.
4. Revise the procedure 7.5-02-04.1 Ship Trials in Ice. Pay special attention to ice conditions (such as flexural strength, thickness, snow coverage / density and ice types).
5. Continue to develop Guideline for the Testing of Fixed Structures, including monopiles, based on prepared outline (Table of Content). Pay special attention to scaling issues for vertical structures where crushing strength is dominant.
6. Review State of the Art on numerical modelling.
7. Review and study current methods for testing Waves in Ice and based on this prepare outline for Guidelines.
8. Review State of the Art on underwater radiated noise (URN) in ice conditions with respect to the relevance of URN topic in general and in cooperation with the SC on Cavitation and Noise

In the process of the term it was decided to combine the tasks 2 & 3 and join them into one guideline.

# 2. STATE OF THE ART

This section resembles the TORs 6 & 8 which are state of the art reviews on numerical modelling and Underwater Radiated Noise.

## 2.1 Review State of the Art on numerical modelling (TOR6)

This paper contains a review and analysis of some numerical methods, which have found their application in modelling the ice–structure interaction process. It has to be emphasized that the suitability of certain methods may depend on the modelled scenario or purpose.

Recent comprehensive overviews and reviews for structure-ice interaction by Makarov et al. (2022), ships in ice (Xue et al. 2020) and specifically ships in broken ice (Li und Huang 2022) exist. This report provides an overview over the most relevant and frequently used models. Other approaches and methods are briefly stated in a subsection at the end of this section.

A significant aspect of ice-ship interactions is the determination of continuous and arbitrary fragmentation between computational elements. Various forms of rupture can occur when sea ice interacts with the hull of a ship. For example, local buckling damage or global cleavage damage depends on the nature of the ice cover contact, boundary conditions and geometry. Capturing these different failure modes in numerical simulations based on conventional continuum media mechanics can be quite challenging (Liu et al. 2018). In addition to the scenario also the scale of the scenario to be modelled might affect the suitability of the method.

### 2.1.1 Existing methods for numerical modelling of ice-structure and ship-ice interaction.

The following methods exist (Makarov et al. 2022; Xue et al. 2020) :

#### 2.1.1.1 The Finite Element Method (FEM)

The finite element method is a start of the art method in structural engineering and is therefore often very suitable assessing the interaction of ice on a structure. This method solves partial differential equations. The modelled geometry model is discretized into finite elements and partial differential equations are solved.

Several FEM based models exist with different scopes and material models. One model that has been developed in connection with medium scale experiments and is also validated against third party experiments is the MCNS model (Herrnring und Ehlers 2022). This is a finite element based model, which uses a Mohr-Coulomb material model for the ice and a critical strain to split nodes between elements when failure occurs. This is currently one of the most used models due to satisfying experimental validation. This model has also been used for high impact loads (Müller et al. 2023) and was the basis for a model for propeller ice interaction (Böhm et al. 2024). In both of the latter cases experimental data are used for comparison and validation.

Other frequently used FEM models to asses ice loads are Dolney, J. and Daley, C.; Gagnon; Sazidy (2015; 2011; 2015). The model of Gagnon (2011) is a compressible foam model, which does not entirely reflect the phenomenological deformation of the ice, but resulting forces appear to correlate with measurements and observations made to some degree. The exact limitations of the above mentioned models remain to be investigated.

The cohesive element or cohesive zone method (CZM) is another approach for the division or separation of ice elements (Kellner et al. 2021; Konuk et al. 2009a, 2009b). It is often used with finite elements and is part of several solver, hence it is accommodated in this section. Those CZM models use, a traction–separation law (TSL) to capture the softening behaviour. The TSL curve process to cracking and employs one law to estimate both crack nucleation and propagation without any pre-set variables (Mulmule und Dempsey 1997; Xue et al. 2020). Important unknowns of any initial boundary value problem concerning fracture is on how to determine the crack propagation surface (Konuk et al. 2009a, 2009b). Therefore, it is of high importance to determine the traction–separation curve (Xue et al. 2020). The latter may be considered as critical parameters, which can however not be directly measured and may require an indirect calibration with measurements, which might limit the transferability of models to different scenarios.

A finite element model developed specifically for model-ice is found in von Bock und Polach; von Bock und Polach und Ehlers (2015; 2013), where the cracking and failure is modelled through element deletion. This violates the postulation of conservation of mass, however as the element size is aligned with grain sizes it was considered acceptable. The element size makes it also computationally very costly limiting it for practical applications.

#### 2.1.1.2 Smoothed Hydrodynamic Particle method (SPH)

The smoothed particle hydrodynamic (SPH) method is meshless method developed as a meshless particle method (MPM) in a Lagrangian framework to overcome the reliance on meshes of traditional mesh-based methods and has been used in the fields of fluid mechanics, aerodynamics, astrophysics and deformable solid mechanics since its inception. The smoothed particle hydrodynamics approach involves dividing the region into individual particles. These particles have a spatial distance, called the smoothing length, at which their properties are 'smoothed' by a kernel function (Makarov et al. 2022). The effect of each particle on the material properties is assessed according to its density and distance from the associated particle.

The interaction of ships in ice is found in simulations of ship-horizontal ice interactions (Zhang et al. 2019). Similar to the FEM the SPH method allows the integration of specific material models. For example an elastic-plastic intrinsic model with a damage model and a Drucker-Prager yield criterion was introduced within the SPH framework to capture the plastic failure behavior of ice (Zhang et al. 2017). The fluid as an elastic basis is compared with the fluid-solid coupling interaction to investigate its effect on the ice-breaking resistance, i.e., the ice-breaking resistance and the submergence resistance during ice breaking. In the meantime, the SPH method is still in the early stages of development in ice simulation. and the aforementioned models also require an external crack expansion criterion to simulate damage (Zhang et al. 2019).

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#### 2.1.1.3 Discrete Element Method (DEM)

The DEM is primarily used for modeling discrete granular media (Cundall und Strack 1979). Among other meshless methods, DEM models have been used for various problems on ice mechanics summarized in Tuhkuri und Polojärvi (2018) and are recognized as an effective numerical method for analyzing ice ship interactions (Dempsey 2000). The main idea of the method is to represent the simulated medium as a set of computational elements with their own properties (density, elastic modulus, etc.). The method can describe the discrete nature of ice at the microscopic scale and reasonably model the ice-breaking phase in ship-ice interaction at the macroscopic scale representing the process of ice break-up transport and accumulation, and that this process will significantly influence later sea ice break-up events (Tuhkuri und Polojärvi 2018). Discrete elements can have different sizes and shapes, and forces are calculated based on Newton's law and contact force models (Makarov et al. 2022; Tuhkuri und Polojärvi 2018). The DEM-based approach allows for the simulation of broken ice in a non-bonded state, where discrete particles characterize broken sea ice elements individually, and the introduction of a spring bond model for modeling floating and level ice under multi-elements bonding. Especially for operations in ice floes this approach is suitable.

Oceanic Consulting Corporation developed a block-based discrete element approach (DECICE) based on the National Research Council of Canada (NRC) and carried out simulations of ship maneuverability (turning and zigzag maneuvers) (Lau et al. 2011).

The GEM (GPU-Event Mechanics) software from Memorial University of Newfoundland, Canada. This software has pre- and post-processing capabilities, uses a discrete quasi-3D model and block cells, is computationally efficient, and allows for large scale long time simulations in a GPU parallel environment, but the reliability of the computational results is low and the validation results are not very satisfactory (Daley et al. 2014). However, despite missing publications on the GEM insight from the SC members is that the tool has been developed further since 2014, but concluding remarks on capacity cannot be made.

The joining of discrete elements may be facilitated with a finite-element-discrete element coupling method (FEM-DEM). The interaction between the ice blocks is calculated using discrete elements and the internal forces and deformations of the ice blocks are calculated by finite elements. This allows the modelling of larger ice sheets, while accounting for subsequent interactions after initial breaking. Recent developments with in-house codes are made at Aalto University, Finland (Lilja et al. 2019; Ranta et al. 2017). Recent work conducted at the Hamburg University of Technology uses DEM for a ship in ice floes, where the elements themselves are broken as well by different analytical and semi-analytical models (Sapp 2023). The model of Sapp (2023) is as most other codes an in-house development using the earlier development of Erceg et al. (2022) as basis.

The simulation of ice floe fields appears to be the main domain of the DEM method (see also Xue et al. 2020).

### 2.1.2 Other Methods

The above list is not exhaustive as a high variety of numerical methods exist, but of reduced maturity and popularity than those mentioned above. Based on Makarov et al. (2022) the following methods are considered to be mentioned:

- Smoothed Particle Galerkin method (SPG)
- Galerkin Discontinuous Method
- Smoothed Particle Galerkin method (SPG)
- The Lattice Boltzmann Method (Janßen et al. 2015)
- Coupling of methods, such as *FEM–SPH–SPG*
- Ice breaking model (Erceg et al. 2022) based on infinite wedge theory (Nevel 1961)
- Phase field modelling (currently explored at Hamburg University of Technology)

### 2.1.3 Concluding remarks

In addition to the robustness of the theory also the computational costs need to be accounted for in simulating certain scenarios. The following conclusion is drawn by Xue et al. (2020) (Table 1). It is to be underlined that the analysis of Xue et al. (2020) focussed on ship-ice interaction such as icebreaking, but not the calculation of local loads.

| Method | Computational cost | Theory Robustness |
|---|---|---|
| DEM | medium | Low |
| FEM | low | High |
| SPH | high | medium |
| Peri-Dynamics | high | high |

**Table 1: Evaluation of numerical methods for ship ice interaction.**

With respect to ice-structure interaction FEM based models appear to be most frequently used. The modelling of ice structure interaction is usually a local modelling, where the impact of ice on certain hull regions is investigated. The application of FEM may refer to the quality of the models, but is certainly also attributed to the fact that FEM is the superior state of the art for structural analysis and consequently FEM models of ice are preferred to transfer ice induced loads to the structure. Furthermore, FEM has a low barrier for usage, as most material models are already available in different software.

Popular models are: Dolney, J. and Daley, C.; Gagnon; Herrnring und Ehlers; Sazidy (2015; 2011; 2022; 2015).

The potential of certain methods for simulating ice-ship interaction is strongly purpose bound.

## 2.2 Review State of the Art on underwater radiated noise (URN) in ice conditions with respect to the relevance of URN topic in general and in cooperation with the SC on Cavitation and Noise (TOR8)

Within the SC on Ice no experts on noise and cavitation are present. A cooperation with the SC on Cavitation and Noise could not be established. The review was done with best effort under the mentioned conditions.

### 2.2.1 Introduction

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The situation of URN in ice-covered water is quite different from non-ice regions in such as noise sources, propagation, and impact on marine mammals. The Protection of the Arctic Marine Environment Working Group (PAME 2019) published a comprehensive report on URN with Arctic ship traffic analysis, calculation of underwater noise source levels of ships, noise propagation models, and acoustic overlap between Arctic marine mammals and URN (PAME 2019). The report refers to (Roth et al. 2013)describing a result of a full-scale URN measurement on USCG Healy. Although these works of literature partly reveal what URN is in ice-covered conditions, the data still needs to be sufficient to understand URN in ice to develop reasonable prediction models.

### 2.2.2 Propeller-induced URN in Ice

In general, propeller-induced noise is the most considerable in URN from ships. In view of engineering, the design of a propeller in ice differs from that of normal. The interference of ice results in variation of hydrodynamics and propulsion efficiency. The interaction of ice and propeller results in increase of loading characterized of strong randomness and non-linearity. There correspondingly presents the influence on structure response and strength.

The presence of ice changes the cavitation phenomena. Noise of low frequency liner spectrum and high frequency broadband correspondingly varies. Generally, the propeller noise level increases (Acoustics in ice).

How to test, capture and analyse the noise raises needs for new techniques.

Sound radiation in far field with ice would be more complicated. How to deal with it in time domain, spectral domain and spatial distribution would differ from normal.

Throughout the above topics, further studies on theory, mechanism, testing methods, analysis, and prediction seem to be necessary. Some of them can be jointly studied by the SC on Cavitation and Noise and the SC on Ice.

### 2.2.3 Literature Survey

The following sections contain comments and lists of literatures on acoustic studies in ice-covered water excluding for general URN.

#### 2.2.3.1 Shipping Increase in Arctic Region

- PAME (2021) UNDERWATER NOISE POLLUTION FROM SHIPPING IN THE ARCTIC

ASTD (Arctic Ship Traffic Data) for the traffic and Wittekind model for noise level estimation were used and Geospatial noise impact distributions were introduced (PAME 2019). Jalkanen et al. (2022) stated that: "*Shipping noise emissions increase rapidly in Arctic areas and the Norwegian Sea. The largest contributors are the containerships, dry bulk and liquid tanker vessels which emit 75% of the underwater shipping noise source energy*." Furthermore, The STEAM (Ship Traffic Emission Abatement Model) by FMI, with Wittekind model inside, was used to estimate underwater noise, however it appears that this is not including ice (Jalkanen et al. 2022).

#### 2.2.3.2 Soundscape of Arctic / Sound Propagation Models

During the 1960s – 1970s: ambient noise under ice was measured in a few field experiments in the Arctic.

- In the Canadian Arctic Archipelago with measurements of spectrum levels of ambient noise. The noise mechanism: cracking-noise, ice-fracturing noise (Milne und Ganton 1964).

- East Greenland Sea:
The sound spectrum level under ice is lower than in open water areas and some acoustic propagation models with ice cover have been developed (Diachok und Winokur 1974).

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- MIZ in 2013 were simulated and compared. The simulation with the OASES (Ocean Acoustic and Seismic Exploration Synthesis) model suggests that the roughness under ice causes the weakening of the wave (Hope et al. 2017).

- Simon et al. (2018) Modeling acoustic wave propagation and reverberation in an ice covered environment using finite element analysis. Simon et al. (2018) used a 3-D FEM and compared this with OASES (Hope et al. 2017). This appears to be a good background note. Full of model-related references.

- The Acoustical Society of America featured Arctic soundscape in the "Special Issue on Ocean Acoustics in the Changing Arctic" in their journal throughout 2022. According to the supplement of the journal, there existed some presentations relating to Arctic at the society's meetings in 2022 as follows:

    - Heaney et al. (2022): The Arctic underwater soundscape today and as projected for 2030. Projections of ice cover and shipping routes along and between the northern borders of Arctic countries were used to forecast potential future (2030) Arctic soundscapes.

    - Webstey et al. (2022): Ship noise radiation characteristics observed from an Arctic acoustic array. The multi-channel acoustic recordings with a 48-hydrophone array mounted on the ship bottom were conducted in Arctic.

#### 2.2.3.3 Noises in Icebreaking Operation

There is little knowledge of icebreaking noise itself, but the propulsor noise and the cavitation noise during icebreaking are seriously high shown in the following studies.

The Sparton AN/SSQ-57B sonobuoy was employed to record underwater noise in the ice operation of Healy (Roth et al. 2013). The noise sources are: propeller cavitation, propulsion machinery, and medium-speed diesels (operating at slow speeds). The sound scattering or reradiating from the water-ice interface is not thought to contribute meaningfully to the overall noise (Roth et al. 2013). Compared to open-water transit, Healy's noise signature increased approximately 10 dB between 20 Hz and 2 kHz when breaking ice. High noise situations occurred in low speed and high RPM, propeller operating in opposing directions, backing and ramming, resulting in cavitation (Roth et al. 2013).

In Geyer et al. (2016) the noise sources are distinguished by the frequency using the same dataset as in Roth et al. (2013). The ship noise from icebreaking appears at the 25-50 Hz frequency band, while the engine noise appears at around 330 Hz, which is considerably high.

#### 2.2.3.4 Experimental Study of Cavitation in Ice Blockage and Milling Condition

- Atlar, M. et al (2003) Cavitation in Ice-Milling with a Podded Propulsor. 4th ASME/JSME Joint Fluids Engineering Conference, 2003.

The advance coefficient of the propeller with high-speed operation during icebreaking navigation is low (Atlar et al. 2003). For the propeller under heavy load and being blocked by ice can easily cause the surface pressure of the blade to drop sharply and generate cavitation (Atlar et al. 2003).

## 3. PROCEDURES

The following Procedures were revised and updated. In addition to corrections and amendments the symbols in all Procedures were reviewed and corrected follow the ITTC Symbols and Terminology List, Version 2017.

### 3.1 Updates on the Reviewed and Revised Procedures

#### 3.1.1 7.5-02-04-01 General Guidance and Introduction to Ice Model Testing

In this Guidelines there was only some minor spelling error corrections in Equations 1 and 2.

1. The General Guidance and Introduction to Ice Model Testing was reviewed and minor corrections were applied. Small additions were made in section 1 "Purpose of the Guideline" including information whom the guideline shall address.

2. Some language and refinement of terminology were made in section 2.1 "Facilities, Ice Conditions and Ship Model".

3. In section 2.2 "Model Ice Production" The definition of model ice "seeding" was corrected.

#### 3.1.2 7.5-02-04-02 Test Methods for Model Ice Properties

The procedures and guidelines of test methods for model ice properties was reviewed and modified to better describe the current practices. Some editorial changes were done. The most significant changes in the guideline were as follows: When measuring flexural strength using cantilever beam test downwards in situ, it is notified that the force induced by submerging the beam in the water might need to be considered depending on the beam dimensions.

The method for determining level ice shear force is removed from the guideline because the current committee did not recognize the method.

The potential significance of friction coefficient between ice fragments (ice-ice friction) is recognized in the new revision. One method for its determination is provided.

#### 3.1.3 7.5-02-04-02.1 Resistance tests in ice

In addition to minor editorial changes to wording/spelling, two main modifications were made in this procedure regarding:

1. the description of device for force measurement in test methods, and

2. the introduction of a new symbol for rest resistance related to ice and besides resistance due to breaking the ice in analysis of tests in intact level ice.

In Section 2.1 Test Methods, the apparatus for force measurement was modified from dynamometer to force transducer considering that dynamometer is not an optimal term for this part while force transducer is the most accurate one and practically used for ice model basins in resistance tests. "A dynamometer" or "dyno" for short, as known, is a device for simultaneously measuring the thrust, torque and rotational speed (RPM) of an engine, motor or other rotating prime mover so that its instantaneous power may be calculated, and suitable for the occasions of self-propulsion or towed-propulsion testing in ice. In total, three corrections in such a way of replacing dynamometer with force transducer were made where two were for explaining the alternative test setups in 2.1.1 and one was for noting measured towing force in 2.1.2.

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In Section 2.2 Analysis of Results, $R_r$, ice resistance other than ice breaking component $R_{br}$, i.e. rest resistance containing submerging, clearing, etc., was originally given as part of the net ice resistance RI. However, Rr is defined as residual resistance in the current ITTC symbols. To avoid confusion, a new symbol $R_{rR}$ was proposed and put instead in equation (8) and (9) in 2.2.1.3 elaborating correction of minor deviations in flexural strength for resistance. $R_c$, resistance for ice clearing, are also confusable, but no reaction was made because it is not conflicted with any existing ITTC symbols. (RC is used as steady turning radius, but the subscription C is capital in this case.)

#### 3.1.4 7.5-02-04-02.3 Manoeuvring Tests in Ice

During ITTC29 this procedure received a substantial update. Consequently, no significant modifications are proposed.

##### 3.1.4.1 Turning circle test

In this section, the following was added: "*Thruster angles and rudder position can be subjected to changes during the manoeuvre.*"

#### 3.1.5 7.5-02-04-03 Guidelines for Modelling of Complex Ice Environments

This guideline addresses complex ice environments, including ridges, brash ice channels, rubble fields, managed ice, pack ice, compressive ice, and snow-covered ice. Some of these were not explicitly mentioned in the introduction and have been added.

In the previous guidelines, a statement could have been misinterpreted to mean that the crest edges of the ridge are always consolidated. They are not consolidated in some situations, so the description has been corrected as "the crest edges can be consolidated."

When reproducing the brash ice channel, the previous guidelines noted that the size of the ice pieces depends on the scale or scenario. However, what is essential is that the number and size of ice fragments in the reproduced brash ice channel reflect the actual interaction phenomena, so this was clearly stated in the description.

Grammatical errors and missing words were corrected. Sources for some figures and references were added, and the text became more accurate than the previous guidelines overall.

### 3.2 Revise the procedure 7.5-02-04.1 Ship Trials in Ice. Pay special attention to ice conditions (such as flexural strength, thickness, snow coverage / density and ice types) (TOR4)

The entire guideline was re-organised in sections reflecting the procedure and tasks applied on ice trials:

1. Purpose of this Guideline
2. Trial Conditions
3. Performance Tests
4. Manoeuvring Tests
5. Data Acquisition System
6. Data Analysis

In section 1 "Purpose of this Guideline" the text was modified with respect to the main objectives and focus of the guideline.

In section 3.3 "Tests in ridges" a passage was added describing the procedure and limitation for ridge tests astern. New figures have been added to the sections.

The entire section 4 "Manoeuvring Tests" was overworked and descriptions of further relevant manoeuvres such as break out tests and star manoeuvre were added. The figures have been replaced by ones of higher quality. New figures have been included to illustrate the addi-

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tional described manoeuvres. The figures include definitions of the most relevant parameters that are to be determined.

The section 5.3 “Ice properties” has been extended significantly. The descriptions of each property measurement procedure is more detailed and figures are added to provide an impression of field work and illustrate the methods.

The list of data to be recorded was extended in section 5.5. “Initial conditions”.

In Section 6 “Data Analysis” high level descriptions of correction methods and correlation factors are included in the revised guideline.

The language and formatting of the entire procedure is adjusted and revised.

## 4. FINAL REPORT AND RECOMMENDATIONS TO THE 30TH ITTC

### 4.1 Develop Guideline 7.5-02-04-02.5 – Ice Property Tests, including findings related to the uncertainty analysis. (TOR 3&2)

As mentioned previously this TOR3 is combined with TOR2 (“*Continue work on uncertainty analysis including conducting benchmarking study among ice model basins. Focus on the largest error sources is recommended such as the uncertainty related to the ice properties. Based on conducted measurement and analyses, include review how the findings may reflect ice measurements.*”).

The draft of this procedure required significant work and interaction with various experts leading to a delay in finalizing the procedure in consequence of which the draft could not be published as procedure. The draft is submitted to the ITTC and available for future committees to finalize the process. A brief description is provided below:

1. This procedure is considered interim and is not being published at this time due to the lack of review time. The committee hopes that this procedure will be thoroughly reviewed and published in the next term. However, a brief overview is provided. This procedure follows the ITTC 7.5-02-01-01 (ITTC 7.5-02-01-01) Guide to the Expression of Uncertainty in Experimental Hydrodynamics, which is based on the International Organization for Standardization (ISO) Guide to the Expression of Uncertainty in Measurement, also called GUM (JCGM)

2. The primary sources of uncertainty from ice model tests could be the ice properties or repeatability of ice tests. This procedure provides an example of analysing the uncertainty of main ice properties such as ice thickness, ice flexural strength, and hull-ice friction. Repeatability was considered using previous repeat test data.

3. A generic ice resistance correction equation was developed and used for the uncertainty analysis. Type A and Type B uncertainties were considered. The uncertainty for each ice property and repeatability was calculated based on the published dataset, and the total uncertainty results were determined.

### 4.2 Continue to develop Guideline for the Testing of Fixed Structures, including monopiles, based on prepared outline (Table of Content). Pay special atten-

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**tion to scaling issues for vertical structures where crushing strength is dominant (TOR5)**

Especially with respect to the shift towards renewable energies, the topic of fixed structures in ice is considered highly relevant.

The committee prepared a draft submitted to the ITTC. However, within the SC committee it is concluded that the state of the art is not mature enough to propose a procedure. For fixed and vertical structures different scaling principles are needed which are not developed yet as well as the current state of the art model ice is not suitable for vertical and fixed structures. Attempts to for new developments are made, but not fully explored and are rather at trial stage. GESA developed a new model ice with focus on the crushing properties and a high flexural strength. The model ice is produced similar as ice at sea with a water surface excited by a wavemaker. A proof of principle was established, but neither scalability nor scaling laws are explored or defined. The committee agrees that such a guideline is needed especially with respect to offshore wind energy, but more development is needed so that the state of the art is suitable for a guideline.

### 4.3 Review and study current methods for testing Waves in Ice and based on this prepare outline for Guidelines (TOR7)

Currently world-wide three facilities that can produce waves in ice:

- Aalto University (granular model ice),
- HSVA (columnar model ice)
- University of Melbourne (no model ice, frozen water, fresh water ice).

Consequently, the state of the art is slim and it was decided that the state of the art is not mature enough to compile a guideline or significant content. However, it is acknowledged that experimental wave-ice investigation is key to understand the behaviour of such as waves in ice and wave induced break-up.

At this current stage, focus was put on focus on those as those are considered being base cases. In recent works it was identified for wave-level ice interaction especially wave steepness, elastic modulus and the flexural strength are important and on this basis scaling similitudes are developed with a focus on the elastic properties of the ice (Colin Fox 2001; von Bock und Polach et al. 2021a). However, model ice tends to have flexural rigidity or elastic modulus which is not in scale (von Bock und Polach et al. 2019). As already indicated above this might require alternative scaling approaches (case based scaling, von Bock und Polach et al. (2021b).

On this basis in von Bock und Polach et al. (2021a) the Model Ice of Virtual Equivalent Thickness (MIVET) is introduced which is thinner, but with a higher elastic modulus as postulated by introduced scaling laws. It could be shown that the excessive damping in classic model ice is significantly reduced (von Bock und Polach et al. 2021a).

For the testing of waves in ice observing non-linear relationships (Hartmann et al. 2019), damping (Passerotti et al. 2022) or both also the visco-elastic properties must be set in scale as those appear relevant for the progression of waves in ice ( K K Dharma Sree et al. 2019).

It appears that the damping and apparent visco-elastic properties are exaggerated in model ice due to non-linear material behaviour and cross-coupling effects with the low elastic modulus, but to date no validated method exists measuring visco-elastic properties in model ice and scaling those with respect to full-scale values.

Consequently, testing waves in model ice still requires work on fundamentals from ice property testing methods to scaling. Especially practical limitations might require *case based scaling*.

## 5. CONCLUSIONS

### 5.1 State of the Art

The state of the art of underwater radiated noise in ice is beyond the expertise of the SC on Ice. It is acknowledged that it is a topic of relevance, but in future considerations, the SC on Ice should rather act as a consultant to the SC of experts on noise and cavitation.

The state of the art on numerical modelling is rather well described in various review papers and methods appear at least theoretically explored. The next necessary step would be numerical benchmark studies in order to assess the quality of results between the different methods.

The state of the art review indicated furthermore overlap with activities of the ISSC (International Ship Structures Committee) and a joint coordination of ISSC and ITTC activities seems reasonable.

### 5.2 Future Work

Review of the state-of the-art: maintain, revise, and update existing procedures and guidelines in accordance with current practice.

Fundamental uncertainty analysis of model ice properties: benchmark study among ice tanks is preferable.

Members suggest topics to be discussed in the next Committee on Ice as below:

- Guidelines for performance prediction in various ice conditions such as broken, rafted, or deformed ice.
- Knowledge accumulation of snow on ice, which impacts resistance.
- Underwater radiated noise is a hot topic, but testing is inauspicious.
- Scaling of ice-propulsor interaction.
- Uncertainty assessment or more consistent guidelines of brash ice test.
- Fundamental uncertainty analysis of model ice properties: benchmark study among ice tanks is preferable.
- Standardize the simple ice-breaking resistance model to verify the ice tank characteristics.

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