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INFORMATION

From: To:	General Secretariat of the Council Working Party on Shipping
Subject:	Preparation of IMO/SDC 12 (London, 19 - 23 January 2026) – Draft information paper by Finland – Experience-building phase for the reduction of underwater radiated noise from shipping – Applicability of different underwater radiated noise reduction strategies for icegoing vessels

Delegations will find attached a draft information paper by Finland in view of the 12th session of the IMO Sub-Committee on Ship Design and Construction (SDC 12) (agenda item 8).

Finland invites interested Member States to take note of/support the document.

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SUB COMMITTEE ON SHIP DESIGN AND
CONSTRUCTION
12th session
Agenda item 8

SDC 11/INF.X
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EXPERIENCE-BUILDING PHASE FOR THE REDUCTION OF UNDERWATER RADIATED NOISE FROM SHIPPING

Applicability of different underwater radiated noise reduction strategies for icegoing vessels

Submitted by FINLAND

SUMMARY

Executive summary:	This document transmits a research report by VTT Technical Research Centre of Finland on underwater radiated noise (URN) in ice-class ships. The study reviews how ice-class requirements affect URN and the applicability of reduction measures, providing input to the experience-building phase under the Revised Guidelines (MEPC.1/Circ.906/Rev.1).
Strategic direction, if applicable:	1
Output:	1.16
Action to be taken:	Paragraph 5
Related documents:	MEPC.1/Circ.906/Rev.1

Introduction

1 MEPC 82 approved the *Revised Guidelines for the reduction of underwater radiated noise from shipping to address adverse impacts on marine life* (MEPC.1/Circ.906/Rev.1) and invited submissions of information and experience during the experience-building phase. MEPC 82 also endorsed the related Action Plan and extended output 1.16 to 2026, with SDC tasked to progress technical elements.

2 Finland has carried out research to examine how ice-class requirements may influence URN and the applicability of reduction measures. This work was undertaken by VTT Technical Research Centre of Finland.

3 The report "*Addressing underwater radiated noise in construction of ships with ice-class*" in the annex finds that structural reinforcements and operational conditions of ice-class ships can affect URN. While several vibration-control measures remain applicable, some hydrodynamic measures, such as propeller designs optimized for low cavitation in open water, may face limitations due to ice-strengthening requirements.

4 The report concludes that flexible application of the Revised Guidelines is necessary to accommodate ice-class ships, and that additional analysis and experience are required to fully assess the effectiveness of different measures in this context.

Action requested of the Sub-Committee

5 The Sub-Committee is invited to note the information provided above and in the annex.

RESEARCH REPORT

VTT-R-00429-25

Addressing underwater radiated noise in construction of ships with ice-class

Authors:	Antti Hynninen, Antonio Sanchez-Caja, Ilkka Perälä, Juha Virtanen
Confidentiality:	VTT Public
Version:	23.9.2025

Report's title Addressing underwater radiated noise in construction of ships with ice-class	
Customer, contact person, address Business Finland Oy Rauli Hulkkonen, Chief Advisor PL 358, 00181 Helsinki	**Order reference** Dnro 4824/31/2024
Project name Underwater Radiated Noise management for ECO-efficient shipping	**Project number/Short name** 140941 BF_URNECO
Author(s) Antti Hynninen, Antonio Sanchez-Caja, Ilkka Perälä, Juha Virtanen	**Pages** 1+12+1
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Summary

Ice-class ships are vessels specifically reinforced to navigate and operate in icy environments in accordance with "Ice-Class" regulations. While the highest ice-class ships possess the capability to break ice, it is important to distinguish them from icebreakers, which are specialised vessels designed exclusively for icebreaking purposes. In the design of vessels intended for operation in icy environments, it is essential to account for the impact of prevailing weather conditions according to ice-class regulations, which might have impact on underwater radiated noise (URN). Ice-class related design requirements may impact to underwater radiated noise in conflicting ways, and the effects of structural detail modifications are not necessarily predictable for practical cases. Therefore, a simulation-based approach is necessary for actual ship structures. When an ice-class strengthened ship structure is defined, specific simulation software enables calculations of the relevant properties, such as vibrations and hydrodynamics in a straightforward manner.

Some vibration reduction measures, including engine mounting and general machinery isolation, are typically applicable to ice-class ships without major constraints. Noise due to hydrodynamics is somewhat affected by the ice-class related requirements. Several propulsor concepts are effective in open-water conditions but may be less suitable for reducing underwater radiated noise in icy waters due to structural, operational, or acoustic limitations. For instance, CLT, tip-rake, high skew, and highly optimized low-cavitation propellers cannot generally be used in ice-class ships. Some URN reduction measures, such as propeller optimization, have limited use in ice-class ships owing to structural and operational restrictions. This suggests that guidelines on URN reduction should be applied flexibly, depending on ship type and operating environment.

Confidentiality	VTT Public

Espoo 23.9.2025

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Name:	Teemu Manderbacka
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Preface

The URNECO project seeks to develop advanced expertise and technology to mitigate underwater noise generated by ships, particularly considering the diverse conditions of the Baltic Sea. The project primarily focuses on the development of measurement and modelling methodologies. The research work of the project is carried out by the research groups of Turku University of Applied Sciences and VTT. The former focuses on noise measurements and the latter on noise modelling and noise abatement. The other collaborative partners are: ABB Oy Marine and Ports, A-Insinöörit Oy, APL Systems Oy, Kongsberg Maritime Finland Ltd, Meyer Turku Oy, Rauma Marine Construction Oy, Steerprop Ltd. and Finnish Transport and Communications Agency Traficom

Espoo 23.9.2025

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Contents

1. Introduction

Ice-class ships are vessels specifically reinforced to navigate and operate in icy environments in accordance with "Ice-Class" regulations. While the highest ice-class ships possess the capability to break ice, it is important to distinguish them from icebreakers, which are specialised vessels designed exclusively for icebreaking purposes. Various ice-classes for ships exist, and comparisons of their equivalency have been published, such as in [Helcom 2016]. In the Baltic Sea, the Finnish-Swedish ice-classification is used having the ice-classes IA Super, IA, IB and IC [Traficom 2021]. It is important to note that underwater radiated noise (URN), while operating in ice, is much higher than usual noise sources in open water operation. Noise is generated when ice comes to contact with the ship hull, but also when propeller hits the ice blocks. Thus, when operating in ice, there is little possibilities to reduce the URN and therefore this document focuses on the effect of ice-class on the ship open water URN.

In the design of vessels intended for operation in icy environments, it is essential to account for the impact of prevailing weather conditions. This consideration is a common aspect of all ice-class rules. The aspects of ships with ice-class might impact underwater radiated noise, as detailed in Table 1.

Table 1: The aspects of ships with ice-class impacting underwater radiated noise

Aspect	Details	Impact to URN
Structures	The reinforcement of the hull, propulsor, and appendages to withstand the increased loads posed by ice.	Significant impact on underwater radiated noise levels due to changes in cavitation and vibration behaviour.
Machinery	Enhanced engine power and heating systems for fuel and ballast tanks are required to ensure proper operation in icy and cold conditions.	Noticeable impact on underwater radiated noise levels due to stronger structural vibration excitations.
Freezing	Freezing of the deck and superstructure increase the ship's weight, raise the centre of gravity, and affect stability and visibility.	Some impact on underwater radiated noise levels due to added mass.

Underwater radiated noise of a ship is commonly characterized using a term called source level (SL). Source level is a hypothetical far-field sound pressure level at 1 meter from the source. It represents the sound pressure level (SPL) that would have been radiated by an infinitesimal source into a hypothetical infinite uniform lossless medium. Source level simulations are necessary for the development of URN mitigation solutions for both newly built and retrofit ships. Simulating the source level is complex, as it must account for hydrodynamic effects in addition to structure-borne noise resulting from hull vibrations. One of the primary challenges encountered in hydrodynamic simulations is the phenomenon of cavitation. A significant challenge in structure-borne noise simulations arises from the radiation efficiency and vibration velocities of structures, which are impacted by material composition, structural geometry, and the properties of applied excitations. These factors differ between air and water environments due to variations in fluid loading. See Appendix A for details on source level determination challenges.

2. URN reduction approaches

Table 2 extends the three-column table (Table no. 1) presented in the IMO revised guidelines for URN reduction [IMO, 2023] to include general applicability assessments of various URN reduction methods for ice-class ships. URN reduction approaches in the Table 2table have been collected from [VARD, 2023] in which an extensive report illustrating effects of different reduction methods to URN are described. In the table, applicability of URN reduction approaches in ice-class ships (fourth column), is considered. If direct assessment cannot be concluded, specific simulation-based analysis must be conducted. Further, to gain a deeper understanding and effects of individual URN reduction approaches, a detailed study and simulation-based analysis is anyway typically required. In addition, the fifth column has been included to highlight quantitatively effect of each approach to URN. The assessments are based on average effect from dB change specified in [VARD, 2023].

Table 2. URN reduction approaches (wordings from IMO, 2023) applicability to Ice-class ships and quantitative effects to URN. Categorization for URN effects: low (< 5 dB), moderate (5 … 10 dB), high (> 10 dB). Extended from [IMO, 2023 and VARD, 2023]

URN Reduction Approaches	**New ship**	**Existing ship**	**Applicability in Ice-class ships**	**Effect to URN (low/moderate/high)**
Optimize ship hull form (and appendages) design for hydrodynamic performance and homogeneous wake field to reduce cavitation	**X**	**X**	**yes**	**low**
Optimizing propeller design to reduce cavitation, optimizing load, ensuring a uniform water flow and hull-propeller interaction and careful selection of the propeller characteristics such as diameter, blade number, blade area, pitch, skew, rake, and sections and innovation material	**X**	**X**	**propeller design can be optimized also for ice-class ships, but additional analysis is necessary for material strength considerations**	**moderate**
Emerging technologies like wind-assist technologies to reduce propeller loading and cavitation noise	**X**	**X**	**ice-class requirements should be considered**	**moderate**
Air injection to propeller	**X**	**X**	**analysis necessary**	**low**
Wake flow improvement	**X**	**X**	**analysis necessary**	**low**
Careful selection of onboard machinery and installation with appropriate structure-borne noise levels control measures, proper location of equipment in the hull, and optimization of foundation structures	**X**		**yes**	**high**
Machinery installation and isolation for instance resilient mount and flexible coupling in four-stroke engines with a reduction gear, vibration isolation mounts and improved dynamic balancing for reciprocating machinery	**X**	**X**	**yes**	**high**

Optimizing the ship's trim to reduce the required power and therefore propeller cavitation noise	X	X	**analysis necessary**	**low**
Improving voyage planning (e.g. optimum route, coordinated across fleets, national and international designated protected areas/sea-ice covered region, including well-known habitats or migratory pathways)	X	X	**analysis necessary**	**low**
Decreasing propellor RPM by reducing the shaft RPM (and/or engine output) for ships equipped with fixed pitch propellers	X	X	**no, applicable only for open-water operation**	**moderate**
Ships routeing measures to avoid national and international designated protected areas including well-known habitats or migratory pathways	X	X	**yes, but ice conditions can limit routing possibilities**	**---**
Propeller maintenance (and cleaning/coating)	X	X	**yes, not for coating**	**low**
Hull maintenance (coating and in-water hull maintenance and cleaning, except acoustic anti-fouling systems where possible in national and international designated protected areas)	X	X	**yes, not for coating**	**low**

3. URN due to vibrations of reinforced structures

An ice-class hull is reinforced with thicker plates and additional stiffener frames. Stiffened structures generally help to reduce vibrations. However, in some instances, stiffener frames can improve radiation efficiency, which indicates that stiffened structures are not always quieter. Additionally, ice-class classification requires more engine power, affecting also to powertrain components such as shafts, bearings, and couplings. The heavier powertrain can alter excitation transfer paths and influence underwater radiated noise accordingly, usually by an increasing manner.

As noted above, ice-class related design requirements may impact to underwater radiated noise in conflicting ways, and the effects of structural detail modifications are not necessarily predictable for practical cases. Therefore, a simulation-based approach is necessary for actual ship structures. When an ice-class strengthened ship structure is defined, vibro-acoustic specific simulation software enables calculations of the relevant properties, such as radiation efficiency, in a straightforward manner. Additionally, when the behaviour and excitations of on-board machinery, which generate vibrations to supporting structures, are known, URN levels due to structure-borne noise can be estimated by the simulation-based approach for a specific case in question. It is important to note that not all structural details, including final dimensions, need to be included in the simulation model. However, the simulation model can be used to estimate relative changes to underwater radiated noise following appropriate ice-class design modifications.

URN reduction approaches mentioned in the Table 2, "*Careful selection of onboard machinery and installation …*" and "*Machinery installation and isolation …*" are referring to structural vibration sources from on-board machinery. When addressing mechanical or structural noise in ships, it is primarily caused by the operation of various machinery and resulting vibration excitations. The machinery onboard includes engines, generators, turbines, compressors, HVAC (heating, ventilation, air-conditioning) systems, and fluid flow in piping, which are the main sources of vibration and noise. Additionally, operational equipment on deck can also contribute to mechanical noise. Generally, reducing the vibrations at these components results in lower levels of structure-borne and air-borne noise within ship compartments, thereby also minimizing underwater radiated noise. Mechanical vibrations originating from machinery are transmitted to support structures and other ship components through transfer paths such as shafts, bearings, and couplings. Air-borne noise from machinery can induce additional vibrations in the hull structure, consequently affecting the underwater radiated noise.

In ship structures, vibration levels can be mitigated by either controlling the initial machinery excitations or relevant excitation force transfer paths. As previously mentioned, ice-class strengthened ships require more engine power, which usually leads to an increase rather than a decrease in engine source excitations. Also, the power requirement due to ice-class can lead to excess power in open water operation which in turn might cause the engines to be run in sub-optimal power range leading to increased vibrations. To manage the impact of machinery excitations on structural vibrations and structure-borne noise, various isolation and damping techniques can be employed.

The maritime industry utilizes several technologies to manage and mitigate noise and vibration:

- Anti-Vibration Mounts: These are used to separate machinery from the structure of the ship, reducing the transmission of vibrations.
- Floating Floors: A type of deck construction that incorporates a damping layer and an air gap to isolate vibrations from the rest of the ship structure.
- Soundproofing Panels: Installed in various parts of the ship to reduce the transmission of airborne noise.
- Active as well as passive Noise and Vibration Control Systems. Active systems use sensors and actuators to detect and counteract unwanted noise and vibrations in real-time.

These methods are applicable not only to ice-class strengthened ships but also to conventional ships for controlling noise and vibration. To estimate the complete transfer path from excitations to underwater radiated noise, semi-empirical calculation methods can be found in literature for limited situations. However, using of vibro-acoustic simulation models is recommended, as specific material combinations and complex ship designs influence URN in ways that cannot be accurately predicted by intuitive reasoning or simple (semi-empirical) calculation methods.

4. URN due to hydrodynamics in ice-class ships

Hydrodynamic noise, especially in cavitation conditions, in ice-class ships is generally different—and often more pronounced—than in conventional ships. Below is listed some key differences:

1. Propeller Design and Operation. Ice-class ships use robust propellers designed to withstand ice loads. These propeller designs are usually not optimal for quiet operation. For example, these propellers can produce more cavitation noise, especially when operating in ice-infested waters or under heavy load.
2. Operational Profiles. Ice-class ships often operate at lower speeds in ice-covered waters but require higher thrust due to increased ice resistance. Their main engines are typically optimized for high power during icebreaking operations, which can result in a suboptimal RPM range and reduced efficiency when operating in open-water conditions. This mismatch may lead to increased noise from both the propulsion system and hull flow. In contrast, conventional ships generally operate at more stable and optimized speeds, resulting in lower variability in hydrodynamic noise.
3. Hull Design and Ice Reinforcement. Ice-class ships have reinforced structures to withstand ice impacts. Also, the bow and stern shape of the vessel might be optimized for operations in ice and not open-water operation. These changes can lead to increased flow turbulence around the hull, especially near the bow and stern, which contributes to higher hydrodynamic noise.
4. Ice Interaction Effects. When navigating through ice, the ice-hull and ice-propeller interactions generate impulsive and broadband noise that is not present in ships operating in non-icy waters. This includes: i) Crushing and breaking ice, ii) Ice rubbing along the hull and iii) Ice ingestion by propellers.

Several *propulsor concepts*, while effective in open-water conditions, may be less suitable or even problematic for reducing underwater radiated noise in icy waters due to structural, operational, or acoustic limitations. For example, *CLT, tip-rake, high skew and highly optimized low-cavitation propellers* are not typically used in ice-class ships due to structural fragility under ice loads. The extended blade tips are vulnerable to damage, which can lead to increased vibration and noise. Also, propeller *concepts with holes near the tip* to reduce cavitation noise might be ineffective in ice conditions due to hole blockage.

"*Air-injection systems*" or "*Air Lubrication Systems*" have been used in icebreakers for decreasing friction between ice and hull. However special care in design should be taken to prevent problems in icy conditions. Ice particles and slush can enter the air injection nozzles or ducts, leading to blockages or damage, reducing both noise mitigation and drag reduction effectiveness; ii) Freezing of Air Lines and Nozzles: this is especially problematic during start-up or low-speed operations in ice; iii) Reduced Effectiveness of noise reduction during ice contact; iv) Structural Vulnerability: the air outlets along the hull are vulnerable to mechanical damage from ice impacts, especially in the bow and midship regions where ice loads are highest; v) Energy and System Complexity: maintaining an air-injection system in ice waters requires additional energy for heating, de-icing, and pressurization. This adds complexity and maintenance demands, which may not be justified if the system is frequently inoperable due to ice.

Energy saving devices (ESD) for improved propeller flow, such as pre-swirl stators (PSS) or Becker Mewis and Schneekluth type ducts, are exposed to potential ice contact. This can lead to structural damage or ice piece getting stuck in the ESD. In ice-covered waters, damage to stators may increase noise levels if the structures are not adequately reinforced. While ESDs can reduce broadband noise under normal conditions, they may also introduce tonal components at specific frequencies—such as blade passing frequency—due to ice blockage or flow disturbances. These tonal noises can be ecologically significant.

Other concepts have moderate suitability in heavy ice. *Ducted propellers* are known for improved thrust at low speeds, protection for the propeller and enhanced bollard pull. However, they have challenges and limitations. Ice can accumulate inside the nozzle, potentially clogging the propeller and reducing thrust.

Azimuthing propulsors offer excellent manoeuvrability and good ice breaking and hull cleaning capabilities. However, similarly as propellers, they must be reinforced for ice conditions. This can lead to less optimal open water performance and increased noise levels.

5. Operational measures to reduce URN

Reducing vessel speed usually leads to lower URN as less power is required. When operating in ice, vessel speed is usually reduced due to added ice resistance. In these conditions more power is required, and the propeller can operate in an unfavourable condition as needed thrust is high, but speed might be low. Thus, when operating in ice the vessel has less options for running with reduced power and usually high power is required.

Route planning to avoid national and international designated protected areas can be harder in ice covered regions. Vessels usually choose the route where there is less ice or clear ice channels are present. Thus, the route chosen by vessels is highly affected by the ice conditions and there are limited options for routing to avoid protected areas.

6. Conclusions

Ice-class related design requirements may impact to underwater radiated noise in conflicting ways, and the effects of structural detail modifications are not necessarily predictable for practical cases. Therefore, a simulation-based approach is necessary for actual ship structures. When an ice-class strengthened ship structure is defined, specific simulation software enables calculations of the relevant properties, such as vibrations and hydrodynamics in a straightforward manner.

Some vibration reduction measures, including engine mounting and general machinery isolation, are typically applicable to ice-class ships without major constraints. Noise due to hydrodynamics is somewhat affected by the ice-class related requirements. Several propulsor concepts are effective in open-water conditions but may be less suitable for reducing underwater radiated noise in icy waters due to structural, operational, or acoustic limitations. For instance, CLT, tip-rake, high skew, and highly optimized low-cavitation propellers cannot generally be used in ice-class ships. Some URN reduction measures, such as propeller optimization, have limited use in ice-class ships owing to structural and operational restrictions. This suggests that guidelines on URN reduction should be applied flexibly, depending on ship type and operating environment. Table 3 summarizes noise categorization between Ice-class and conventional ships.

Table 3. Summary table for noise categorization between Ice-class and conventional ships.

Feature	Ice-Class Ships	Conventional Ships
Propeller Noise	Higher due to robustness and cavitation due to high loads at low speeds.	Lower with optimized open water designs.
Machinery Noise	Higher required engine power required	Lower power possible
Operational Noise	Variable, more thrust required.	More stable and predictable.
Flow Noise	Reinforced and optimized hull for icy waters, more noise due to turbulent flow.	Lower noise due to streamlined, optimized hull for open water.
Ice Interaction Noise	Significant, if contact with ice.	Significant, if contact with ice.

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Appendix A, Source level determination challenges

At a fundamental level, the overall noise source level of a ship can be determined by summing the individual contributions from the propulsor, ship hull, and onboard machinery.

$$L_s = 10\log_{10}\left(10^{\frac{L_{s,propulsor}}{10}} + 10^{\frac{L_{s,hull}}{10}} + 10^{\frac{L_{s,machinery}}{10}}\right) \tag{1}$$

The most significant contribution to the propulsor noise comes from cavitation phenomenon. Another major source of noise is structure-borne noise, which arises from hull vibrations caused by machinery excitations and cavitation. Therefore, the contributions can also be differentiated into cavitation noise and structure-borne noise, simplifying Equation (1) into:

$$L_s = 10\log_{10}\left(10^{\frac{L_{s,cav}}{10}} + 10^{\frac{L_{s,str}}{10}}\right) \tag{2}$$

Cavitation's complexity makes it hard to create simple equations for corresponding noise level:

$$L_{s,cav} = 20\log_{10}\frac{\tilde{p}_s}{p_r} \tag{3}$$

where $\tilde{p}_s$ is the root mean square source pressure and $p_r = 1\ \mu\mathrm{Pa}$ is the reference pressure. Note that the source pressure depends, among other factors, on the cavitation form. The four primary forms of propulsor cavitation are tip vortex cavitation, characterized by load-dependent vortices that create string- or rope-like core cavities; leading edge cavitation, which forms sheet-like cavities typically on the low-pressure side; back-bubble cavitation, observed at high speeds where the outer blade sections develop vapor bubbles at their thicker parts; and hub vortex cavitation, resulting also in rope-like cavities. [1]

Source level due to structure borne noise is:

$$L_{s,str} = 10\log_{10}\frac{W_{str}}{W_r} \tag{4}$$

where $W_r = \frac{4\pi p_r^2}{\rho c}$ is the reference power, ρ is density and c is speed of sound. Structure borne sound power due to vibrations is written[2] [3]:

$$W_{str} = \rho c \sigma S \langle \overline{v}_\perp{}^2 \rangle \tag{5}$$

where σ is the radiation efficiency, S is the area of the vibrating structure and $\langle \overline{v}_\perp{}^2 \rangle$ is the average of squared vibration velocity normal. A significant challenge in structure-borne acoustic power is that radiation efficiency and vibration velocities are influenced by both the material and geometry of the structure, as well as by the applied excitations. Additionally, they differ significantly in air and water due to fluid loading.

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