ITTC Quality System Manual
Recommended Procedures and Guidelines

Guideline

Guidelines for Ship Trials in Ice

7.5	Process Control
7.5-04	Full Scale Measurements
7.5-04-03	Ice Testing
7.5-04-03-01	Guidelines for Ship Trials in Ice

Updated / Edited by	Approved
Specialist Committee on Ice of the 30th ITTC	30th ITTC 2024
Date: 05/2024	Date: 09/2024

Table of Contents

Guidelines for Ship Trials in Ice

1. PURPOSE OF THIS GUIDELINE

The purpose of this guideline is to provide the guideline to determine a ship's performance and manoeuvring characteristics in different ice conditions or verify it against specified target requirement. This document aims to provide a basis for planning and executing the full-scale trials. The aim is primarily to list issues that may need to be considered, however, to ensure efficient testing, which necessitates focusing on the relevant measurements.

It is noted that the trials should be done with the permitted operations as well as ship-specific restrictions (such as ramming speed with propellers in advance directions) are to be followed.

2. TRIAL CONDITIONS

It is recommended that the ice trials are carried out within the condition when the flexural strength and ice thickness is expected to be in a range close to the target properties for ship performance. The development of ice conditions in designated areas should be monitored several weeks prior to the trial period. It is noted that the conditions cannot be controlled, and the limits for approvable conditions for testing (regarding at least ice thickness and flexural strength) need to be determined and agreed by all involved parties prior to the testing.

3. TRIAL PREPARATIONS

Ice trials require a significant effort and should therefore be planned carefully and with a sufficient time. A clear definition of the procedures and methods are necessary for a smooth operation on board. The basis of the test program is often determined in the ship's specification. In addition, the following documents should be prepared and approved by all involved parties.

- Safety procedure for vessel operation and people working on ice
- Ice trial procedure describing each test execution
- Ice trial analysis and reporting standards including correction methods for deviation between target and measured trial conditions
- Tentative ice trial schedule

The preparations of ice trial also include the planning and set-up of the instrumentation and data acquisition system as described in section 6 of this procedure.

3. PERFORMANCE TESTS

3.1 Background

A standard performance test includes a constant speed / constant power test. The objective of these tests is to determine the continuous icebreaking capability of the ship in level ice. The collected data provides the speed / power relationship for the ship in specific environmental conditions. Ice performance is mainly influenced by the hull shape and the available net thrust.

3.2 Performance tests in level ice

The recommended procedures for the propulsion test begin by selecting a sufficiently large area of unbroken and undeformed level ice. For each test, the ship is to proceed at a constant power for about two to five ship lengths. The test should be repeated for several different power levels in order to determine the speed / power relationship for the ship. The tests with different power levels may be carried out continuously, without stopping the vessel between the tests. During each test, all ship parameters are to be kept constant, with rudder at amidships, or the azimuthing thruster angles set to provide thrust in the intended direction. The test might need to be performed in several different ice thicknesses and strengths. It is recommended to record these tests on video.

It is recommended to use a digital data acquisition system. This system should be installed and checked by a qualified engineer or technician. In-situ calibrations should be performed to ensure the reliability of the data. Frequent zero checks should also be made. Collected data should be backed up regularly to ensure safe storage of the data.

Open water test results might be needed for the analysis of the ship ice trial results. Bollard pull or push tests, and open water power speed tests provide information on propeller characteristics and open water performance, and they also may provide an instrumentation check of the ship trials. Propeller curves may also be used to estimate a thrust deduction. Dynamics of the propulsion system should be taken into account in the analysis as this may influence the measurements recorded, particularly in situations of propeller-ice interaction.

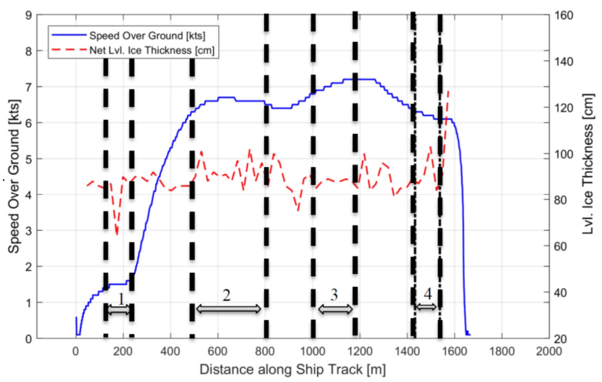

Figure 1: An example plot from a performance test in ice.

Standard statistical processing of the measured data should be performed to determine steady state thrust, torque, and ship speed. Thrust, torque, and power can be plotted as functions of ship speed for the different ice and snow conditions, and ship speed can be plotted as a function of ice thickness (Figure 1). The analysed data may be compared to data from similar ships and to model test data, if available.

3.3 Performance tests in different conditions

The performance test, as described above, can also be carried out in a similar way for other types of ice such as:

- Brash ice channels
- Own channels
- Broken ice fields, such as floe ice field (pack ice) or a rubble field

The purpose of the test in broken channel is to investigate the ability to move ahead or astern in a broken channel. The channel can be an own channel created by level ice breaking of the same vessel or a brash ice channel created by multiple ship passages.

The test in own channel can be performed immediately after the propulsion test in level ice so that minimal additional preparation and effort are required. Additional measurements required for these tests are the ice block dimensions, channel coverage, ice fragment's size, shape in the broken channel, the thickness of ice mass in the channel, and the channel width. The degree (freezing of voids between ice fragments) and thickness of possible consolidated layer should be measured.

Photographs and videos of the brash ice can provide useful information (see Figure 2). The time between the test and the moment when the channel was initially broken should also be recorded.

Figure 2 Brash Ice Channel in Baltic Sea (Aker Arctic)

3.4 Tests in ridges

The standard ship test in an ice ridge is ridge penetration capability. The objective is to determine the advancing capability of the ship in ridges in terms of penetration distance and time required to pass the ridge. The maximum allowed ramming speed needs to be agreed prior to trials.

When the ridge is selected for testing, the intended line for the ship's path should be marked. The surrounding ice thickness and strength, and the above water and underwater ridge profiles must be measured (Figure 3). Ridge consolidation and its structure are also important factors, and they can be determined through the analysis of cores taken from the ridge when possible. The water depth is to be noted to make sure that the ridge is not grounded or likely to be grounded unless it is specifically intended.

Firstly, the ship is backed up from the ridge about two to five ship length depending on the intended ramming speed. When the trial begins, the ship is accelerated to the intended ramming speed towards the ridge. The precise time of impact with the ridge should be noted on the recording instrumentation. If the ship proceeds through the ridge without stopping, the power level is maintained for at least two ship lengths or longer. If the ship stops inside the ridge, the penetration distance is measured, and reverse power is applied incrementally to determine the extraction power level. The ship is then backed out of the ridge to a sufficient distance to achieve the intended ramming speed for the next ramming test and repeat the test. Such repeat ramming tests are continued until the ship penetrates through the entire ridge.

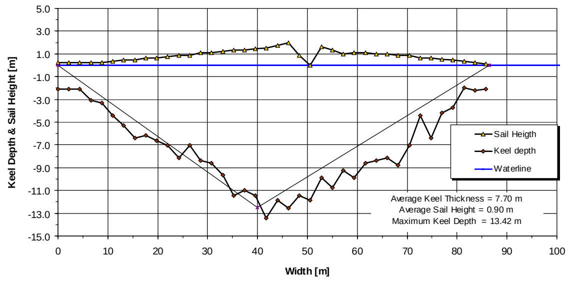

Figure 3: An example of a chart describing a ridge sail and keel. The chart can also include information of consolidated layer and void inside the ridge.

If the ship's performance in an ice ridge is investigated astern or with propellers heading to advance direction, an unconventional propulsion configuration is typically involved. With such unconventional propulsion configurations, the allowed ramming speeds are typically lower compared to ramming speeds with a bow with no propulsors. When the azimuthing propulsors are positioned at the bow or stern for ahead and astern tests, respectively, these thrusters may be utilized to flush the ridge apart by active turning of the units.

The recorded data typically include impact time, ramming speed, ridge penetration distance, ridge profile and properties. In addition, level ice properties, ship acceleration distance, as well as ship propulsion parameters similarly to those from level ice tests. It is also highly recommended that these tests be recorded on a video tape.

The recommended data acquisition system is the same as that for the performance tests in level ice. In-situ calibrations and pre-trial system checks should also be carried out.

The ramming cycle can be presented schematically by plotting the speed of the ship as a function of advanced distance (Figure 4). The ramming cycle may be broken down into several different phases, such as acceleration time in channel, time from of the ridge contact to complete stop, and time to free the ship from the ridge. Figure 5 shows the acceleration phase and penetration phase with the time, penetration distance, and speed.

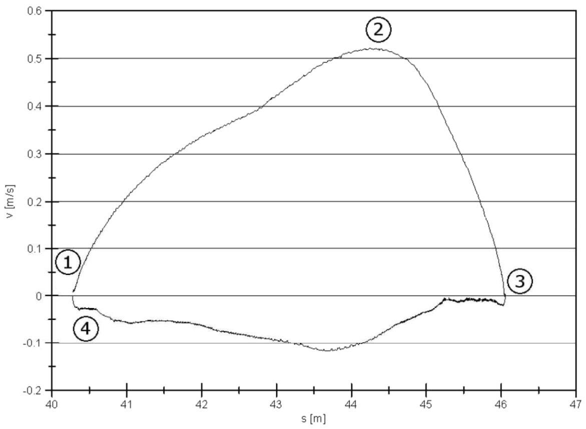

Figure 4: A schematic plot of the ramming cycle (Ehle, 2011): 1 acceleration, 2 impact speed, 3 zero speed, 4 backing to start position

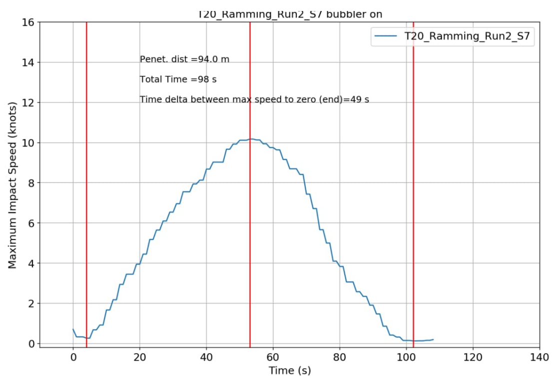

Figure 5: Example of each ramming event (Wang et al., 2023a)

4. MANOEUVRING TESTS

4.1 Background

The objective of the manoeuvring tests is to investigate the effectiveness of the hull and propulsion configuration, and their combined performance in terms of turning capability. Typical tests include turning circle test, star manoeuvre test, and breaking out of channel test.

4.2 Turning circle test

The turning circle test is carried out to verify the vessel's ability to change heading within a restricted space and/or within a certain time. The test is typically started by running straight ahead or astern for at least one ship length before starting the turn by setting rudder or azimuth thruster angles to the pre-defined value. The angles of rudder(s) or azimuth thruster(s) can be controlled by the captain during the manoeuvre or adjusted to maintain a certain speed during turning. This test should be carried out in uniform ice conditions and the final heading angle should be at least 180 degrees from the start of the test. Ship position, heading, turning rate and speed of the vessel need to be monitored and recorded during the entire test. Measurements of the ice thickness and flexural strength can be taken along the broken channel after the completion of the test. The turning performance of the vessel can be evaluated from the turning circle diameter and the required time to achieve a certain change in heading. The exact way of determining the turning circle diameter such as ship's trajectory (track outer edge and turning time need to be clearly defined prior to the test). Further advice on the test methods and analysis can be found in ITTC procedure 7.5 – 02 -04 - 02.3 Manoeuvring Tests in Ice.

4.3 Breaking out of channel test

The objective of this test is to evaluate the vessel's ability to break out of a channel, which is an important measure of safe winter navigation, as this can prevent a potential collision of vessels in convoys. In the test, the channel can be either a newly broken channel by own vessel or a brash ice channel broken by frequently-operated other vessels. In the test, the vessel first advances in the channel, and is then manoeuvred to break out of the channel. The turning command is typically given at a predefined speed. Standard initial speed enables comparison of test results with those from other tests conducted using the same vessel or corresponding vessels. After the test, the vessel's track needs to be documented in a reasonable manner.

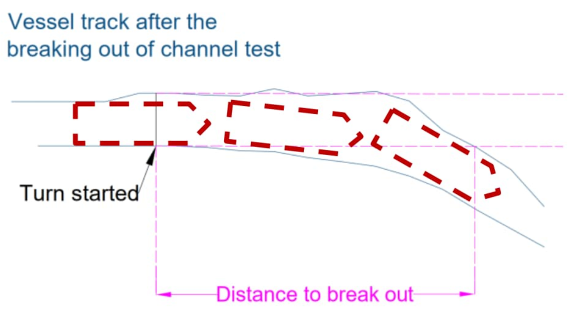

Figure 6: One definition of distance to break out of a channel.

The vessel's performance in breaking out of channel can be evaluated using a measure of distance to break out. One of several possible definitions for breaking out distance is illustrated in Figure 6. In this definition, the distance to break out corresponds to the longitudinal distance between the vessel bow (or stern) at the moment of turning the rudder(s) / thruster unit(s) completely, and the point when the outer shoulder exceeds the channel edge on the turning side. This definition should be applied only when the vessel clearly breaks out of channel and continues advancing in the surrounding ice field. Other definitions for the breakout distance can be determined by ship operators, owners or other involved parties according to their specific needs.

4.4 Star manoeuvre (Captain's turn)

The objective of this test is to evaluate the ship's performance in a star manoeuvre in ice is related to ship's ability to break out of own channel ahead and astern. A schematic picture of a star manoeuvre is presented in Figure 7. It is a practical manoeuvre when manoeuvring space is limited. The vessel turns at least 180 degrees by performing a series of channel breakouts ahead and astern (Figure 8).

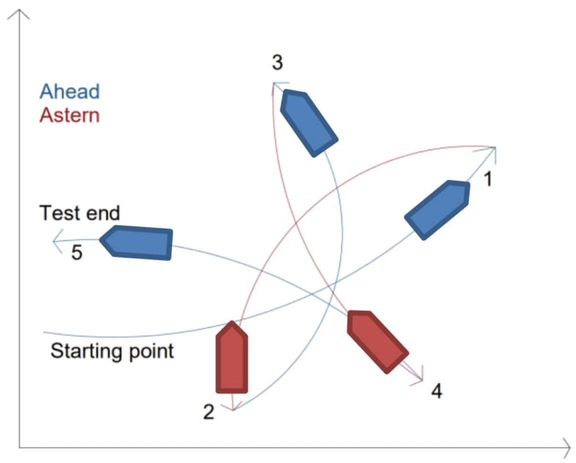

Figure 7: A schematic picture of a star manoeuvre started ahead.

The main outcome of a star manoeuvre is the total space required to turn the vessel, the time spent for the turn, and the number of turns or attempts to breakout of the channel to turn.

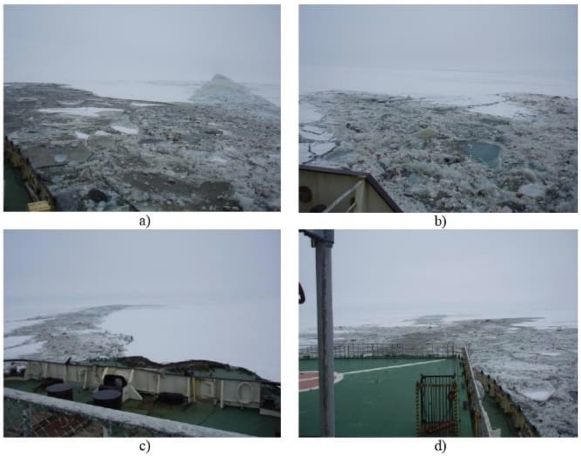

Figure 8: The example of Star Manoeuvre (view from the aft), Dobrodeev (2011).

5. DATA ACQUISITION SYSTEM

5.1 General

During each manoeuvring trial, the data listed in the following sections 5.3 and 5.4 should be recorded from the start of the approach run to the end of the manoeuvre for each test.

5.2 Instrumentation

This section presents specific procedures and necessary equipment for the instrumentation of ice trials.

5.2.1 Hull condition

The hull should be inspected visually (ideally both underwater and above water portions), particularly in the ice belt region. Type and condition of coating should be reported, as well as the time duration from the coating application to the trials.

5.2.2 Shaft thrust

Shaft thrust is normally measured using strain gauge or optical sensing technology. The strain gauge measurements may introduce large errors into the recorded data due to the inherent difficulty in measuring the axial strain of a large shaft. An alternative method is to measure the deformation of the thrust bearing.

5.2.3 Shaft torque

Shaft torque can be measured accurately from strain gauges or optical sensing technology attached to the propeller shaft. Calibrations and zero level checks are important to ensure reliability. It is also recommended to determine shaft friction levels by recording torque at very low shaft rate.

5.2.4 Delivered power

Delivered power can be calculated from the measured torque and shaft rate. For electric propulsion plants the engine input current and voltage can also be used to estimate the delivered power, if the motor efficiency is known accurately.

5.2.5 Rudder or pod angle

Rudder angle should be measured at the rudder stock with a potentiometer or recorded from the ship's instruments.

5.2.6 Shaft rate

Shaft rate should be measured by a pulse transducer installed on the propeller shaft or recorded from the ship's instruments.

5.2.7 Propeller pitch

Propeller pitch can be measured from a pressure sensor in hydraulic lines, or from potentiometers on mechanical arms.

5.2.8 Ship draught

Ship draught should be measured by visual observation of the draught marks at the beginning, during, and at the end of the tests.

5.2.9 Ship speed and position

Ship speed and position should be determined using either an electronic tracking or existing global positioning systems. It is preferable to use global positioning systems due to the flexibility. The difference between speed over ground, speed through water and speed through ice is important and should be considered determining current and ice drift direction and speed.

It is necessary to use at least two electronic tracking devices installed in the bow and aft, respectively, to determine the exact position of the vessel when maneuvering in ice.

5.2.10 Ship motions

Ship motions may be measured by a gyrocompass or accelerometers. The gyro repeaters are to be adjusted until they are synchronized with the master gyro compass reading.

5.2.11 Propeller-ice interaction

Occurrences of propeller and ice interaction can be determined from the records of torque and thrust.

5.2.12 Propeller blade loads

Propeller blade moments, forces, and torque are usually measured only when specially requested. These measurements can be performed by strain gauging one of the blades.

5.3 Ice properties

5.3.1 Ice and Snow Thickness

Ice thickness should be measured along the ship's track, by either measuring the thickness at the channel edge or by drilling holes through the ice.

The accuracy of ice thickness measurements is typically 1-2 cm. The accuracy of snow cover measurements is up to 1 cm.

Measurement frequency should be chosen in relation to ship length, speed, and ice conditions. Measurements may also be taken from other methods such as an electro-magnetic ice thickness measuring system (EM) or calibrated recordings of an over-the-side video which records upturned ice pieces. If this method is used, these measurements should be verified with direct measurements.

The depth and type of snow cover also influence the ship's performance, and should be determined to include its effect on the performance evaluation.

5.3.2 Ice Flexural Strength

Several different methods can be applied to determine the ice flexural strength during ice trials. Methods most commonly used are:

- three-point bending (Figure 9).

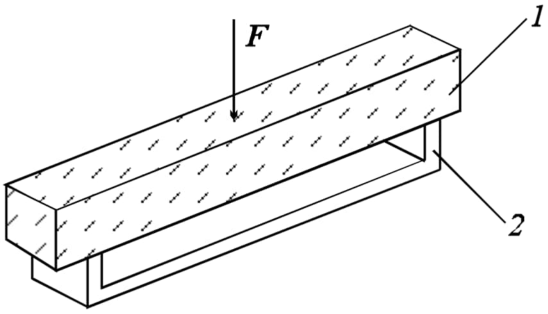

Figure 9: The general scheme of three-point bending test. *F* – load; 1 – ice sample; 2 – supporting structure

- in-situ flexural tests (Figure 10),

Figure 10: The general scheme of in-situ flexural test. 1 – dynamometer; 2 – loading device; 3 – main beam; 4 – load slab; 5 – displacement indicator; 6 – displacement indicator frame.

- Determination of flexural strength by calculation from temperature, salinity (and density) profiles.

In situ cantilever beam tests can be difficult to perform in medium to thick ice. For the determination of flexural strength of saline ice from temperature and salinity profiles several approaches have been proposed in the past (references). For all methods the applicability with respect to ice type, morphology and condition should be checked. From the different methods, the flexural strength can vary and the studies on the relationship between different methods have been carried out (e.g., appendix of Wang et al., 2023b). The flexural strength can vary depending on the method used, and studies exploring the relationship between these different methods have been conducted (e.g., a recent review can be found in the Appendix of Wang et al., 2023b).

5.3.3 Ice Compressive Strength

The compressive strength of ice can be measured by extraction of cores with a special core sampler. Then the ice cylinders are compressed along the longer axes directly on the site where they were selected using hydraulic test press at a constant loading rate (Figure 11). The final failure load is taken as the maximum pressure of pressing machine to fracture the ice cylinder. Further recommendations for compressive strength determination are provided in 7.5-02-04-02 Test Methods for Model Ice Properties. In some cases, utilizing in-site indentation methods may be possible.

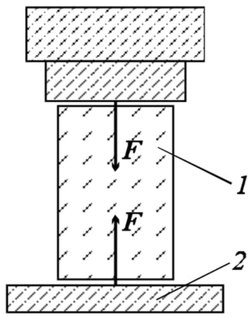

Figure 11: The general scheme of ice compressive strength measurements. *F* – load; 1 – cylindrical ice sample; 2 – supporting structure

5.3.4 Ice State

The type of ice and other parameters describing the ice conditions should be described.

When necessary, the density of full thickness snow samples is measured. A snow sample may be collected with a cylinder of known diameter to determine sample volume. Snow thickness is be measured directly before or after taking the sample. The snow or the water from melt snow sample is placed on a balance to determine the weight of the sample.

5.3.5 Broken Ice Cusp Dimensions

Cusp dimensions may be obtained from calibrated photography.

5.3.6 Water Depth

Water depth should be determined from charts or ship instrumentation, or manually if the water is very shallow. Criteria for evaluation of suitability of water depth can be found in ISO 15016.

5.3.7 Ice/Hull Friction

There are several methods for measuring ice-hull friction. These include moving an ice block along the side of the ship under specified conditions, and installation of a friction panel in the ship’s hull. In addition, sliding tests with coated steel plates under different normal loads can be carried out on the ice surface. For all friction determination methods, a significant uncertainty remains in the contact between ice and plate surface and for load panels in the accurate determination of tangential component of measured load. It is also noted that there might be a huge variation in the coating condition along the hull side.

5.3.8 Wind Speed and Direction

Wind speed and direction should be recorded from the ship's instruments.

5.3.9 Water Current

Water current should be determined (or its effect eliminated) for any accompanying open water tests. The difference between speed over ground and speed through the water may indicate the effect of the current, although not its direction.

5.3.10 Location of Test

Test location should be determined from maps and GPS.

5.3.11 Ridge profile

Ridge profile should be measured both above water and below water. The above water portion may be profiled by survey equipment or by stereo photography. The underwater profile may be measured with sonar or by drilling holes through the ridge. Measuring frequency should be sufficient to accurately describe the ridge profiles (if the underwater profile is measured by drilling, then more than one profile should be completed).

5.3.12 Ridge Structure

Full thickness cores of the ridge should be sampled to investigate ridge consolidation and other structure characteristics. Temperature and salinity profiles of the cores can be determined and plotted as a function of depth. Compressive strength tests of the ice cores removed from the ridge may be performed.

5.3.13 Ice Concentration

Ice piece size and channel coverage may be recorded by use of calibrated video or photography.

5.3.14 Channel Profile

The profile of the channel’s cross section can be measured through drilling holes through the brash ice inside the channel. This necessitates a crane or other method to safely move above the brash ice.

5.3.15 Channel Width

Channel width can be measured directly or by calibrated video or photography approximately twice per ship length.

5.4 Ship parameters

Following ship related parameters should be documented:

- Ship type and design parameters;
- Hull condition and trial (draught, trim);
- Coating condition (frictional properties)
- Shaft thrust;
- Shaft torque;
- Engine type;
- Power;
- Rudder type and number of rudders;
- Rudder angle or pod angle;
- Propeller type;
- Propeller speed;
- Propeller diameter and pitch;
- Number of propellers and turning direction of each propeller;
- Ship speed;
- Ship motions;
- Propeller-ice interaction.

5.5 Initial conditions

The following data is to be clearly recorded for each ice trial:

- Date;
- Time;
- Location of test;
- Water depth;
- Air temperature;
- Wind speed and direction;
- Ice drift speed and direction
- Ice-hull friction.

Following parameters of the level ice should be documented:

- Ice thickness;
- Ice flexural strength;
- Ice compressive strength;
- Ice density;
- Ice type;
- Snow depth
- Snow density;
- Ice temperature;
- Ice salinity;
- Ice morphology;
- Ice pressure;
- Broken ice cusp dimensions;

Following additional parameters for the tests in ridges and channels should be documented:

- Ice thickness (for ice surrounding ridge/channel);
- Ridge/channel profile;
- Ridge structure and consolidation;
- Ice type (for surrounding ice);

Following additional parameters for the tests in ridges and channels can be documented:

- Ice flexural strength (for surrounding ice);
- Ice compressive strength (for surrounding ice);
- Ice temperature (for surrounding ice);
- Ice salinity (for surrounding ice);
- Ice density (for surrounding ice);
- Ice pressure (for surrounding ice).Ice shear strength (for surrounding ice);
- Ice density (for surrounding ice);
- Ice piece size and channel coverage;

6. DATA ANALYSIS

6.1 Correlation between model scale and full scale

To maintain the good reliability of model tests, continuous efforts for collecting full scale and model scale correlation pairs with different ships and in different ice conditions is crucial. The full-scale test results should be compared to existing model scale predictions whenever available. If the ice conditions significantly differ from each other, performing a correlation model scale test after the full-scale trial can be considered.

6.2 Correction due to ship conditions

Any deviation in ship conditions from the specified or reference conditions should be taken into account. Detailed methods for correction are depending on specific ship parameters and should be developed prior to ice trial (e.g. from model tests or calculations). As a minimum, the deviations in ship conditions should be carefully documented for each test.

6.3 Correction due to ice conditions

Deviations between actual and target specified ice conditions need to be taken into account for final ship's ice performance evaluation. Examples for typical correction methods for main ice properties such as thickness and flexural strength can be found in ITTC Recommended Procedure 7.5-02-04-02.1. The detailed correction methods should always be developed considering the specific type of ship and environmental conditions. All available information (such as model test results and technical calculations / simulations) should be made available for development of correction methods.

Uncertainty Analysis can be considered using only select sources, which are assumed to have a significant effect on the measurement. Due to the nature of ice trials, repeating tests in the same ice conditions are impractical.

Deviation of ice conditions, including thickness and flexural strength from the target conditions, can be one of the largest sources of uncertainty. The ice thickness and flexural strength may vary within the same ice floe during the tests. Although careful selection of a large and uniform ice field is important, these deviations cannot be completely eliminated. Therefore, frequent measurements of ice properties are crucial to reduce the level of uncertainty. In this regard, continuous measurement using EM sensor for ice thickness can be both useful and practical. Continuous monitoring of the ice field during the tests is also recommended, as a single fracture leading to the open edge of the floe can cause a significant decrease in load.

Human error, including captain's experience and ability, can be another source of uncertainty, especially in complex operations such as the star manoeuvre. While pre-defined shaft rate and rudder/azimuthing angle may help reduce the operational variability, they may not always provide the best performance.

During the ice trial, obtaining steady condition (i.e., constant ship speed with a constant power in long period of time) is challenging. Many trial segments can be unsteady or transitional conditions if the length of measurements is insufficient.

Some uncertainties in the ship instrumentations and its operational performance can be identified during the bollard tests in open water. The ship can be docked in a large ice floe, where the bollard tests are performed and repeated throughout the trial period. This approach provides an overall assessment of the propulsion system's uncertainty, excluding the uncertainty associated with the ice.

6.4 Additional investigations in ice trials

The propulsion test in level ice may also be used to evaluate the resistance of the ship's hull. This may be achieved by eliminating the influence of the propulsion system. This analysis is most effective if there is very little, or no. ice interaction with the propeller(s). The thrust deduction factor for the vessel's propulsion system must be determined to carry out this analysis. This is typically estimated from model tests or the manufacturer's propeller curves.

If model test results for the vessel are available, then the thrust deduction factor from these results may be used to determine the average resistance from average measured thrust.

The analysis to be performed for the ridge ramming tests includes the calculation of ridge penetration force, or ridge resistance. This is the sum of the propeller thrust and the ship inertial force (which includes the added mass of the water).

7. REFERENCES

Dobrodeev, A, 2011, "The full-scale studies of star manoeuver for icebreaker Vaygach", The Transactions of the Krylov State Research Centre, No 63 (347), pp. 69-72, https://transactions-ksrc.ru/upload/pdf/347/69-72.pdf (in Russian)

ISO15016 Ships and marine technology — Guidelines for the assessment of speed and power performance by analysis of speed trial data, Second edition 2015-04-01

Reimer, N., Schröder, C., Hisette Q., 2018, "Full Scale Trials for the Validation of Ship Performance and Model Tests in Ice" Arctic Technology Conference 2018, Houston, USA

Wang, J., Brown, J., Meadus, C., Hickey, G., Ennis, T., and Winsor, F., 2023a, "Performance Evaluation of CCGS Icebreaker Henry Larsen with Air Bubbler System in Ice", Proc. of the 23rd Int. Ocean and Polar Engineering Conf. (ISOPE2023), Ottawa, Canada.

Wang, J., Brown, J. and Frederking, R., 2023b, "Full-Scale/Model-Scale Comparison of Podded icebreaker's Performance in Ice with Flexural Strength Measurement Study", Journal of Ship Research, Vol. 67, Issue 2, pp. 93-108.