The Specialist Committee on Ice

Technical Committees and Group of the 28 th ITTC

1 INTRODUCTION

1.1 Membership and Meetings

The members of the Specialist Committee on Ice of the 28th International Towing Tank Conference are as follows:

Akihisa Konno (Chair), Kogakuin University, Japan

R. U. Franz von Bock und Polach (Secretary), Hamburg University of Technology, Germany (Previous affiliation: Aalto University, Finland)

Kirill Sazonov, Krylov State Research Center, Russia

Topi Leiviskä, Aker Arctic Technology Inc., Finland

Jungyong (John) Wang, National Research Council of Canada, Canada

Yinghui Wang, China Ship Scientific Research Centre (CSSRC), China

Nils Reimer, Hamburgische Schiffbau-Versuchsanstalt GmbH (HSVA), Germany

Victor Westerberg, SSPA Sweden AB, Sweden (until August, 2015)

Yan Huang, Tianjin University, China (from November 2015)

David Molyneux, Memorial University of Newfoundland, Canada (from November 2015)

Mikko Suominen, Aalto University, Finland (from October 2016)

Four Committee meetings were held as follows:

- February 3-4, 2015, Tokyo. All members at that moment attended. (Konno (Chair), von Bock und Polach (Secretary), Leiviskä, Sazonov (w/ Interpreter Fatieva), Westerberg, Reimer, J. Wang, Y. Wang)
- June 31-July 1, 2015, St. Petersburg. Konno (Chair), von Bock und Polach (Secretary), Leiviskä, Sazonov (w/ Interpreter Fatieva), Reimer, Y. Wang, Westerberg
- June 28-29, 2016, Hamburg. All members at that moment (Konno (Chair), von Bock und Polach (Secretary), Molyneux (new member), Huang (new member), Reimer, J. Wang, Leiviskä, Sazonov (w/ Interpreter Fatieva), Y. Wang)
- Feb 8-9, 2017, Helsinki. Konno (Chair), von Bock und Polach (Secretary), Huang, Reimer, J. Wang, Leiviskä, Sazonov (w/ Interpreter Fatieva), Y. Wang

We also held a Skype conference and two teleconferences as follows:

- Skype conference on Apr. 26, 2016. Konno, von Bock und Polach, Leviskä, Reimer, J. Wang, Molyneux, Y. Wang.
- Teleconference on June13, 2017. Konno, J. Wang, Reimer, Suominen.

- Teleconference on June 16, 2017. Konno, J. Wang, Molyneux, Suominen.

1.2 Tasks

The tasks of the Specialist Committee on Ice given by the 27th ITTC consist of two stages. In the first stage, we were recommended to prepare reports for the following three tasks along with recommendations for future work to the AC by the first meeting of the 28th ITTC.

(1) Review the state of the art of ice tank testing in level ice.

(2) Review the current state of practice for modelling of complex ice environments.

(3) Review of station-keeping of floating structures and ships in managed ice, and develop a proposal to conduct benchmarking.

Therefore, we reviewed these testing situations, prioritized the tasks and submitted the report to the AC. The AC generally approved our recommendations. Therefore, in the second stage, we conducted the following:

(1) Revision of guidelines related to level ice in the following order of priority: General guideline (7.5-02-04-01), Resistance tests (7.5-02-04-02.1), Propulsion tests (7.5-02-04-02.2), Manoeuvring tests (7.5-02-04-02.3) and others.

(2) Propose a new guideline on definitions and measurement standards for complex ice environments.

(3) Design a benchmark study on station keeping in ice.

The AC also recommended us to carefully consider the level of effort that will be required to put this information into a guideline and proceed only if it is practical to do so in the remaining time. We discussed that, and concluded that we would concentrate on updating important three guidelines (General guideline, Resistance tests and Propulsion tests) and implementing a new guideline for complex ice environments.

2 THE MECHANICAL BEHAVIOR OF MODEL ICE

A study on the mechanical behaviour of fine grained (FG) model ice is conducted in connection with the development of a numerical model in von Bock und Polach (2016). On this basis another experimental study was conducted with columnar saline doped model ice by Gralher (2017). In both studies the tensile, compressive and flexural strength was tested and their relation to each other assessed.

It was found that both model ice types appear to have a large plastic deformation domain and that the elastic range is very small. So far it was presumed that the deflection of a cantilever beam takes place in the elastic regime. Consequently, the determination of the elastic modulus with the deflection of an infinite plate is not considered to provide a significant model ice property. Instead it is recommended to determine the strain modulus that is determined by cantilever beam tests. This strain modulus is mixed composition of plastic and elastic responses, but reflects the stiffness a ship encounters when breaking the ice well.

The ratio of the elastic modulus and the beam bending strain modulus can be used to assess the plasticity of the model ice (von Bock und Polach and Molyneux, 2017).

3 SCALING METHODS

3.1 State-of-the-art

The state of the art scaling approach in model scale testing is Froude and Cauchy scaling. In both cases the Froude, respectively Cauchy number, are to be identical in full-scale and model-scale. The Froude number builds the ration between gravitational and inertia forces, whereas the Cauchy number builds the ration between inertia forces and the elastic forces in the ice. This is the standard for the scaling of almost all structure ice interaction, however, the not for all scenarios elastic, inertia or gravity forces are significant, which challenges the applied scaling approach.

3.2 Case Based Scaling

The scaling according to Froude and Cauchy similarity is appropriate for the scaling of ships breaking level ice, but may not be applied to other ice structure interaction scenarios.

Vertical structures in ice drift compress ice slowly which is strain rate sensitive in full-scale but inertia forces are of small significance. In the same way are in other full scale scenarios such as ships is brash ice or propeller ice interaction other forces of significance an need to be considered in scaling (von Bock und Polach and Molyneux, 2017). It appears infeasible to define a scaling law that is suitable for all scenarios. Instead it should be considered to define individual scaling laws for the specific full scale scenarios, i.e. case based scaling. This is a topic of high relevance in future.

4 EXPERIMENTS AND SUPPLEMENTS FOR NEW/REVISED GUIDELINES

4.1 Ice Resistance Guideline (for level ice and pre-sawn ice)

For the resistance tests in intact and pre-sawn level ice, towing forces from both ice conditions are the primary measurements. Pre-sawn ice is ice that has been pre-cut to approximate the bow breaking pattern (see Figure 1).

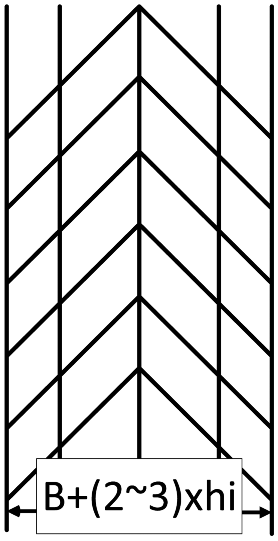

Figure 1 Typical pre-sawn cutting pattern

Once those forces are measured, the breakdown ice resistance components addressed in Equation (1) can be identified.

$$R_{IT} = R_{br} + R_c + R_b + R_{IW}$$

$$R_I = R_{br} + R_c + R_b \qquad (1)$$

where,

R_{IT} =total resistance in ice

R_{br} =resistance due to breaking the ice

R_c =resistance due to clearing the ice

R_b =resistance due to buoyancy/static clearing the ice

R_{IW} =resistance due to open water

R_I =net ice resistance

The following is an explanation to identify each ice resistance components. Since the ice sheet is already cut (broken) in the pre-sawn test, everything except the breaking term is measured, i.e. $R_c + R_b + R_{IW}$. Since R_{IW} is known from the separate open water tests, the pre-sawn test determines $R_c + R_b$ for the tested speed.

By conducting a pre-sawn test at very low speed, (e.g. $V_M = 0.02$ m/s), the dynamic forces associated with ice block rotation, ventilation, and acceleration are assumed to be negligible, leaving the buoyancy or static clearing resistance, R_b, as only component. Having measured R_b, which is independent of velocity, it is subtracted from $R_c + R_b$ to give R_c, which is the velocity dependent term. Thus, R_{br} can be calculated from Equation (1), and all components will be determined.

In order to scale the model results to full-scale, it is convenient to deal with non-dimensional coefficients for the resistance terms. These are defined as:

$$C_{br} = \frac{R_{br}}{\rho_I B_{WL} h_I V_M{}^2} \tag{2}$$

Where,

C_{br} is the coefficient of the breaking resistance, R_{br}

ρ_I is the density of the ice (kg · m^{-3})

B_{WL} is the maximum waterline beam of the model(m)

$h_I h_I$ is the ice thickness (m)

$$C_c = \frac{R_c}{\rho_I B_{WL} h_I V_M^2} \tag{3}$$

Where,

C_c is the coefficient of the clearing resistance, R_c

$$C_b = \frac{R_b}{\Delta\rho g B_{WL} h_I T} \tag{4}$$

Where,

C_b is the coefficient of the buoyancy resistance, R_b

$\Delta\rho$ is the difference in density between ice and the ice tank water (kg · m^{-3})

g is the acceleration of gravity

T is the maximum draft of the model (m)

A non-dimensional ice strength number is defined as:

$$S_n = \frac{V_M}{\left[\dfrac{\sigma_{FI} h_I}{\rho_I B_{WL}}\right]^{1/2}} \tag{5}$$

Where σ_{FI} is the flexural strength of the ice (Pa)

The ice thickness Froude number, Fr_I, is defined as:

$$Fr_I = \frac{V_M}{\sqrt{g h_I}} \tag{6}$$

Once all non-dimensional coefficients are defined, the breaking resistance coefficient C_{br} is plotted against the ice strength number on an ln-ln scale graph. From the resulting linear regression line, the slope and intercept can be used to determine C_1 and C_2 in Equation (7). The clearing resistance coefficient C_c is plotted against Fr_I on an ln-ln graph and C_3 and C_4 in Equation (7) can be determined by its regression equation. R_b is plotted against the calculated ice buoyancy, $\Delta\rho g B_{WL} h_I T$, to give a buoyancy coefficient which is C_5. As shown in equation (7), each breakdown resistance component can be defined with S_n and Fr_I so that total resistance in any target ice condition can be corrected.

The form of ice resistance with non-dimensional coefficients is shown below.

$$\begin{aligned} R_{IT} &= C_1 \times S_n{}^{C_2} \rho B_{WL} h_I V_M{}^2 \\ &+ C_3 \times Fr_I{}^{C_4} \rho B_{WL} h_I V_M{}^2 \\ &+ C_5 \times \Delta\rho g B_{WL} h_I T + \text{Open Water} \end{aligned} \tag{7}$$

5 METHODS TO DETERMINE ICE RESISTANCE USING SELF-PROPELLED MODEL TESTS

An increasing share of self-propulsion model tests is one of the modern trends in test practices of ice basins. Most leading ice basins took to using self-propelled models rather than non-propelled models in ice resistance towing tests. This change of approach to towing tests is driven by a number of factors, the most important of which are modern requirements that ships should also have good astern propulsion performance in ice. Another reason is the need to study propeller interaction with ice in ahead and astern modes.

In Russia, Germany and Finland the ice basins have employed different experimental techniques to determine ship ice resistance using self-propelled models. Descriptions of these techniques including analysis of their possible error sources are given below.

5.1 Method of Krylov State Research Centre

5.1.1 First Method

Traditionally, in the KSRC ice basin practices the self-propelled models have been used to find ice resistance of model in astern mode. In this case the captive test method is employed when a model is rigidly fixed to the towing carriage via dynamometer and outfitted with running propellers. Propeller thrust is measured with special-purpose dynamometers. The experimental setup in astern test mode is shown in Figure 2.

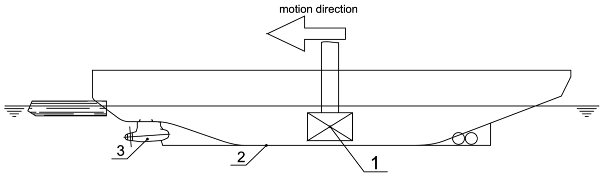

Figure 2 Astern test setup: 1-dynamometer; 2-ship model hull; 3-propulsion pod model

For a propelled ship model running astern the ice resistance R_I is found from the following force equation:

$$R_I = -(F_{meas} + (1-t)\cdot \sum_i P_i), \qquad (8)$$

where: F_{meas} -force measured by dynamometer; t -thrust deduction factor; $\sum_i P_i$ -total thrust of propellers.

It is seen from Equation (8) that under this model test procedure it is required to know the thrust deduction to determine the ice resistance. Usually this factor was chosen based on test results from a hydrodynamic basin.

When no data were available from hydrodynamic tests, the thrust deduction factor was determined in ice basin as per the following procedure. The model was towed at a constant towing carriage speed with the propeller driven during the same test run at two numbers of revolutions n_1 and n_2 different from each other by 1 rps. Measurements gave $F^{(1)}_{meas}$, $\sum_i P^{(1)}_i$ and $F^{(2)}_{meas}$, $\sum_i P^{(2)}_i$. Based on the assumption that the mean ice resistance was constant in the test run, eq. Equation (8) was used to calculate some mean thrust deduction factor $\bar{t}$ from Equation 9:

$$\bar{t} = 1 - \frac{F^{(1)}_{meas} - F^{(2)}_{meas}}{\sum_i P^{(2)}_i - \sum_i P^{(1)}_i}. \qquad (9)$$

According to theory, the thrust deduction factor depends on the propeller thrust-loading factor K_{DE} proportional to n^2. Therefore, K_{DE} variations fell within $8\%-10\%$, which was assumed acceptable for the purposes of ice model tests. It should be noted that this approach somewhat allowed for the difference between the thrust deduction factor in ice and in open (ice-free) water.

Disadvantages: requirement for special-purpose tests to determine the thrust deduction factor in open water.

5.1.2 Second Method

A model with running propellers is towed at a specified speed by towing carriage. The force of model/carriage interaction F_I is measured. The speed of propeller rotation is chosen to match the propulsive thrust with the model speed. In this case a close to full-scale flow pattern around the hull is obtained.

Experiments in a continuous ice sheet, when completed, leave a channel packed up with brash ice. This channel after being cleared of brash ice is used to repeat the self-propelled model tests, now in open water. These experiments are conducted at the same speed of propeller rotation and model speed to measure the force of model/carriage interaction F_W.

The pure ice resistance force R_I is calculated based on the test data obtained in ice and open water conditions using Equation 10:

$$R_I = F_I + F_W. \qquad (10)$$

It should be noted that the forces F_I and F_W retain their actual signs when being summed up.

Rigid connection between the self-propelled model and towing carriage makes it possible to accurately set the model speed in ice. The force between towing carriage and model measured by dynamometer indicates whether the propeller thrust is higher than the ice-plus-water resistance or not sufficient to overcome this total resistance. This force is defined by Equation 11:

$$F_I = R_I + R_W - T_E, \qquad (11)$$

where R_W —model resistance due to water, T_E T_E —effective thrust of model' s propulsion system.

Model tests in a channel cleaned of brash ice make it possible to determine the hydrodynamic resistance force F_W more accurately than it is done using the Finnish method because in these tests the hydrodynamic resistance has practically no wave-making component. In ice basin the hydrodynamic resistance should be determined following all requirements which are applied to the same kind of experiments when conducted in towing tanks. In these tests the force between model and towing carriage is determined, which is defined according to Equation 12:

$$F_W = T_E - R_W. \qquad (12)$$

From Equation (11) follows the ice resistance in Equation 13

$$R_I = F_I + T_E - R_W. \qquad (13)$$

Then the final formula for the ice resistance is Equation (10).

5.2 Method of Aker Arctic

The ice basin of Aker Arctic is using a different technique involving a series of preliminary open water tests usually carried out in the ice basin itself. Under this method ice resistance is determined using self-propulsion tests at the ship propulsion point.

Model ice resistance is determined in a number of steps.

Self-propelled model is tested under bollard pull condition in open water. In this case the propeller thrust is measured at different propeller speeds. These data are then used to find the speed which provides the specified thrust of propulsion system in bollard pull condition.

Towing tests of model with running propellers are performed in open (ice-free) water with the model fixed to the towing carriage via dynamometer. Propellers are run at speeds corresponding to 80, 100 and 120 % power consumption. In these tests the brake force (which is applied from the towing carriage side to model) is measured versus model speed (at constant number of revolutions that could be different for side propellers and middle propeller). The open-water tests give brake force versus model speed. Typical results of such tests are shown in Figure 3. For convenient use in further studies these test data are used to plot regression curves.

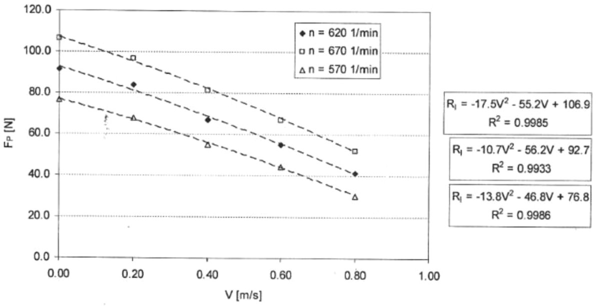

Figure 3 Brake force versus model speed at constant revolution number of propellers. Astern mode

Thus, brake force F_p is defined according to Equation 14:

$$F_p = \sum P_i(v)\,(1 - t) - R_w(v), \quad n = \text{const} \tag{14}$$

where $\sum P_i(v)$ —total thrust of propellers at ship model speed v; t —thrust deduction factor; $R_w(v)$ —hydrodynamic resistance of water at ship model speed v.

From the analysis of this formula it follows that F_p is a difference between the thrust of model propellers and water resistance. Hence, if a model in ice tests is running at some speed at constant number of propeller revolutions, its net ice resistance is exactly equal to F_p obtained at the same model speed.

With this approach, there is no need to determine the thrust deduction factor and water resistance of model separately because these are taken into account automatically. Moreover, there is no need to change propeller thrust neither in ice tests nor in hydrodynamic tests. Obvious prerequisites for such method are that propeller revolutions should be accurately set and maintained. In addition, it is necessary to have a system for measuring the speed of self-propelled models.

Self-propulsion model tests in ice are performed at the same number of revolutions as in open water. The model ice resistance is determined from model speed measurements and plots of added resistance versus speed, which were obtained earlier.

The main error sources in this method are uncertainties related to determination of the ship model speed in self-propulsion tests at the ship propulsion point, possible errors in evaluation of brake force in open-water tests as well as assumption of identical thrust deduction factor in ice and open water.

It is well known that free motion of model in ice is a non-stationary process due to non-uniform ice failure. For this reason the ice resistance is changing in time with the amplitude of such variations increasing as the ice thickness is increased and the model speed is reduced. Moreover, it is a quite difficult technical task to measure speed of a freely floating body.

Towing tests of self-propelled models in open water to determine the brake force should be conducted strictly in line with all metrological requirements for such tests. First of all it applies to the time interval between model test runs (which is specific to each test basin and should be determined using special-purpose experiments). If this rule is not met, it may lead to significant errors in brake force evaluations, in particular it concerns shallow-water tests. Also, in open water tests, especially at higher speeds, the water resistance may include a considerable wave-making component. There is no wave-making phenomenon when models are moving in ice.

At present, it is impossible to judge whether the interaction coefficients obtained in open water are valid for ice conditions because there are no experimental procedures in place for finding interaction coefficients when models are moving in ice. As an argument for the validity of this assumption we may refer to an over 50-year practice of its application resulting so far in no significant errors.

5.3 Method of HSVA

HSVA ice basin is using both self-propelled and non-propelled models in ice resistance tests. Ice resistance tests with self-propelled models are performed in a captive setup. The model is towed at a given speed, while propeller revolution numbers are varied. Propeller revolutions range from practically zero to a certain value specified to assure that the force recorded by dynamometer changes its direction (model now pulling the towing carriage). A mandatory test condition is practically zero number of propeller revolutions. Based on the results of this test, the ice resistance of model is found (Figure 4).

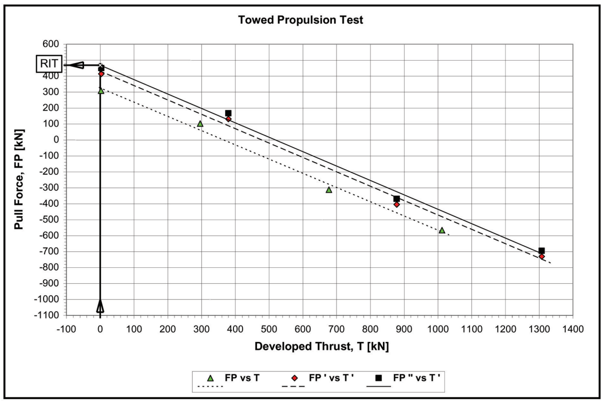

Figure 4 Determination of ice resistance by HSVA method

The test data obtained at different propeller revolutions are used to find precisely the thrust of propulsion system under given ice conditions at ship propulsion point. For this purpose, they use the relationship of force measured by dynamometer versus propeller thrust. For estimation of thrust in this relationship the force on dynamometer is assumed to be 0 (Figure 5).

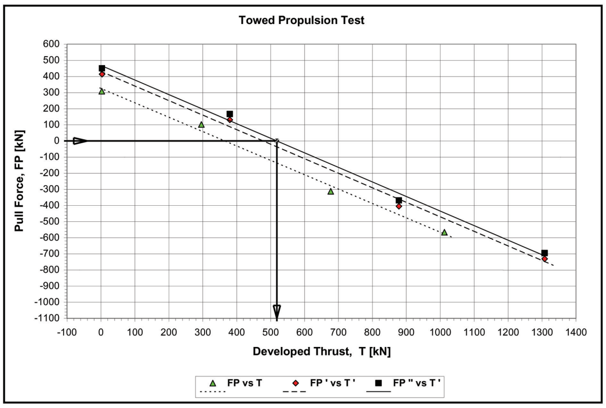

Figure 5 Determination of propeller thrust by HSVA method

This procedure makes it possible to readily estimate the thrust deduction factor at ship propulsion point.

6 REVIEW OF STATION KEEPING TESTS IN DIFFERENT ICE MODEL BASINS

6. 1 Introduction, Definition of Station Keeping in Ice

Station keeping in ice describes the use of all methods that assist a ship or floating structure against deviation from a certain position when exposed to drifting ice. This may include a mooring system, an active dynamic positioning system or a thruster assisted mooring system in which the position deviation is controlled by the mooring lines and the thrusters are used to control the vessels orientation (heading). For floating structures, usually managed ice is assumed while for icebreakers or offshore supply vessels heavier ice conditions might occur during the station keeping operation.

As thruster involved station keeping is usually related to a dynamic positioning (DP) control system which can be based on different algorithms developed by the DP manufacturer. The influence of the actual DP system is not related to model testing and should therefore not be included in a benchmark study. It is therefore recommended to limit the benchmark study to a moored station keeping tests.

6.2 Description of Station Keeping Testing Methods in Different Ice Model Basins

Generally, a mooring system in a basin can either be arranged below or above water. While especially for mooring systems above water (dry mooring systems) the correct load application points of mooring lines are difficult to be adjusted. Usually the system stiffness is simulated by a combination of springs and stopper lines. Thereby several springs will be arranged serial to approximate a non-linear characteristic between deflection and restoring force (Figure 6).

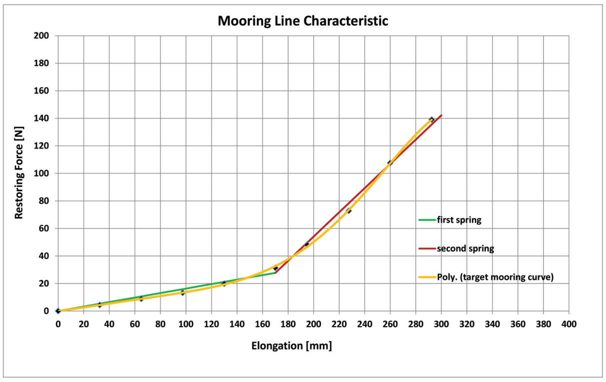

Figure 6 Target mooring response characteristic (yellow) approximation by serial spring system (green, red)

The length of each stopper line can be adjusted to set the deflection at which the stiffness of the discrete system is changing. A pretension can be applied to the system according to the specification from the real mooring system. Depending on the type of floater the mooring lines will be connected via a turret or directly to the structure. In case of a "wet" mooring system arranged below water the restricted water depth in the basin is usually not sufficient to reflect the full scale water depth at suitable scale ratios. Therefore, a typically truncated system is modeled in the basin.

For the conduction of station keeping tests two different principal methods are possible in most ice basins: The floating structure is stationary moored in a section of the ice tank and the ice is pushed by a carriage. The floating structure is towed by main carriage at ice drift speed through resting ice (reversed motion).

7 PROPOSAL FOR A BENCHMARK TEST

7.1 Principle Steps for Development of Benchmark Test Station Keeping in Ice

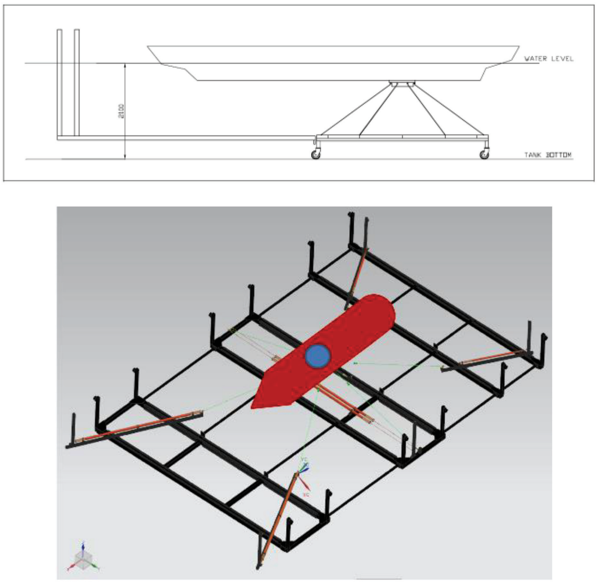

Figure 7 Principle set up of mooring systems on underwater carriages/movable frames in ice basins

Figure 8 depicts the required steps for preparation of benchmark campaign.

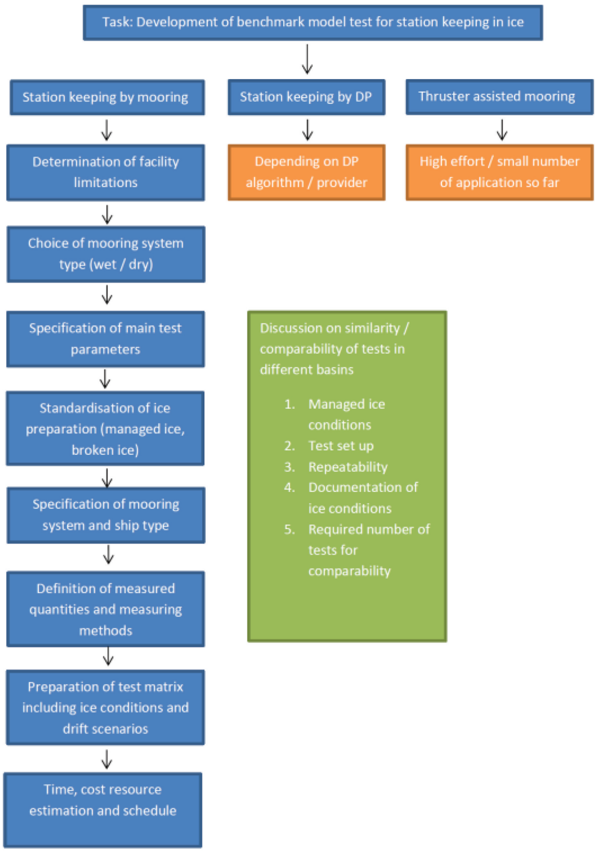

Figure 8 Required steps for preparation of benchmark campaign

7.2 Limitations of Ice Basins

Station keeping tests with wet mooring system requires certain minimum basin dimensions (length, width, depth). If the depth of the basin does not allow modelling of entire mooring system, a truncated system can be installed instead. The dimensions of participating basins are to be compared (Table 1), minimum possible values for a benchmark test can be selected from this comparison.

Table 1 Dimensions of candidate-basins for a benchmark test

Basin	Length × Width × Depth	Max. model length	Pull capacity
Aalto U	40×40×2.8	7	5
AARC	70×8×2.3	10	50
HSVA	72×10×2.5/5.0	10	50
KSRC	80×10×2.0/4.5	10	?
NRC	90×12×3	12	60

Ice properties are to be defined which reflect a realistic scenario of conditions for a floating structure. At the same time different types of model ice are to be taken into account. Most commonly moored floating structures are assumed to operate in managed ice to reduce ice loads on these structures. For purpose of benchmark test, it is recommended to choose level ice of thin to medium thickness instead of managed ice as the variations in preparation process of managed ice would reduce the comparability significantly.

7.3 Choice of Testing Method

As most of the ice basins are frequently using the reversed motion method it is proposed for the benchmark test.

7.4 Choice of Model Type

For the model used in a benchmark test, a rotation-symmetric geometry is proposed to avoid occasional load events that might occur a with ship shaped model. As most of the model ice types commonly used were originally developed to model bending failure, a conical shaped model is prioritized. Possible dimensions of this model are given in Figure 5.

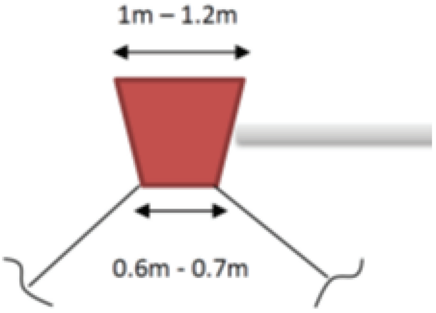

Figure 9 Exemplary model with simplified geometry to be used for benchmark campaign

7.5 Mooring System Type

- wet mooring system with four lines each representing one bunch
- linear load response characteristic (one spring)
- number of mooring lines is reduced to four (each line representing one bunch of real system)

7.6 Test Matrix

Table 2 Test matrix for benchmark tests

test series	ice thickness	flex. strength	speed
1	20 mm	30 kPa	0.05-0.1 m/s
2	25 mm	30 kPa	0.05-0.1 m/s
3	30 mm	30 kPa	0.05-0.1 m/s

7.7 Quantities to Be Determined

- mooring line load

- motion of model (6 DOF)
- model ice thickness
- model ice flexural strength
- model ice density
- model ice friction coefficient
- video observation of each test from different view angles

7.8 Conclusions

Even if the test set up and test matrix will be simplified there will still remain significant effort to perform the benchmark campaign. Additionally, there are still some open questions regarding the related analysis and comparison of results from each ice basin. The equivalency of loads and response of the model structure in different model ice types is to be further studied on forehand.

8 ICE MODEL BASIN

8.1 New/Refurbished Ice Model Basins

8.1.1 Large Ice Model Basin at HSVA

Basin Particulars

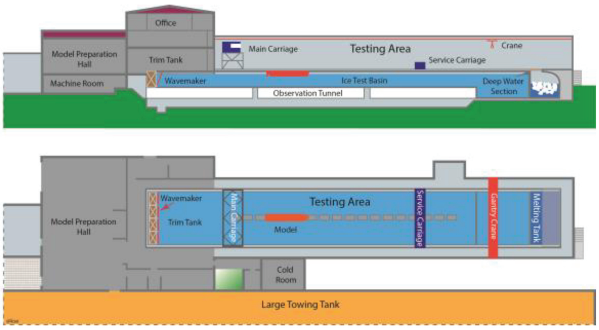

Figure 10 Schematic view of HSVA's large ice model basin

- Length: 70 m
- Width: 10 m
- Depth (main section) 2.5 m
- Depth (deep section) 5.0 m
- Freezing rate: up to 2.5 mm/h
- Main carriage speed 0.001 to 3 m/s
- Main carriage towing capacity: 5 t

Ice Types

Figure 11 Level ice, brash ice, broken ice, pressure ridges

Mobile Wave Generator

- Type: elevated hinged flap
- Width 10 m (4×2.5 m module)
- Wave types: regular, irregular
- Max. wave height: 0.25m
- Max wave period: 3s
- Frequency range: 0.5-5 Hz

8.1.2 Aalto Ice Tank

8.1.2.1 Description

Aalto Ice Tank is a 40 m × 40 m water basin equipped with a cooling system and e-

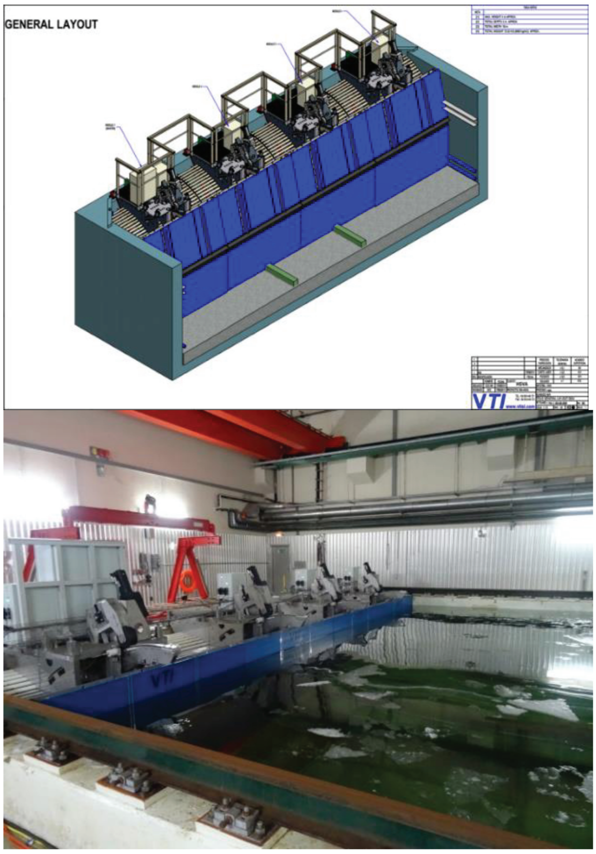

Figure 12 Mobile wave generator in HSVA's ice tank

quipment to produce model-scale sea ice. The model scale ice is fine grained chemically doped model ice and generated through a spraying process. Besides typical experiments in the ice model basins (resistance, propulsion, and modeling of natural ice formations, such as ice ridges) the large width of the basin enables all types of manoeuvring test.

While the infrastructure is called an ice tank, the facility is multifunctional and can also be used for open water tests. The basin has wave makers that allow research on problems related to ice and waves. Aalto Ice Tank is an open access facility and available for use for academic professionals and industrial experts according to Aalto University's access guidelines and pricing principles.

Aalto Ice Tank, established early 1980's, has been thoroughly renovated and upgraded since 2015. The renovation and upgrade have included general infrastructure, cooling system, and measurement infrastructure (measurement carriage and the wave maker). In addition, plans to install a permanent rising fake bottom, to enable shallow water experiments are ongoing. Aalto Ice Tank will be opened for researchers and industrial partners in 2018.

Figure 13 Turning circle test in model scale ice in Aalto Ice Tank.

8.1.2.2 New / Revised Measurement Techniques

Machinery vision has been increasingly applied to the model scale testing in ice. These systems are used to measure the floe and ice piece size, but also to determine the movements of the ship model and model scale ice.

8.1.3 New Ice Basin of Krylov State Research Centre

In 2014 the Krylov State Research Centre completed erection of a new ice model basin. The main purpose of this newly built ice basin is to enhance experimental capabilities based on available expertise gained from previous model investigations in ice. Table 3 summarizes the main design particulars of the basin.

Table 3 New Ice Basin of the Krylov State Research Centre

Characteristics	New
Basin length including bay, m	102

Ice sheet length, m	80
Basin width, m	10
Basin depth, m (in brackets-depth of 20% length section at the basin end)	2 (4.6)
Ice thickness range, mm	10-130
Speed of towing carriage, m/s	0.0005-1.5
Average time to make one ice sheet, days	1-2

A wide range of model tests can be staged in the new ice basin to investigate various ships and marine structures. For this purpose, new ice-making and test techniques have been developed in an effort to raise the productivity of experiments. Special design efforts have been taken to provide the best possible visualization of ice/structure interaction processes in this new ice test facility. For this purpose the basin bottom is provided with large view ports to allow observation, video and photography from the bottom. In addition, two observation tunnels are provided on both sides of the basin.

The development of new ice basin has involved elaboration of procedures and methods to raise the efficiency of various types of tests. It is for example a method to produce an ice sheet featuring two different ice thicknesses which, combined with a large width of the basin, would allow researchers to handle a bigger scope of ice tests within one day.

Apart from the towing carriage the basin is equipped with a planar motion mechanism, which can also be outfitted with measuring instrumentation. This feature enables a wide range of non-standard tests like interaction of tankers with icebreakers and offloading terminals or ship operation tactics in ice. The towing carriage is equipped with a planar motion mechanism to measure ice forces and moments on a model during curvilinear motion.

One of the major advantages of the new ice model basin supported by elaboration of suitable experimental procedures and methods is a unique setup for physical modeling of ice management operations being second to none in the world practice. This sophisticated complex consists of a remotely controlled propulsion system (including podded option) mounted on ship model and instrumented to measure instant forces and moments.

The ice basin is capable of modeling and reproducing the following ice conditions:

- continuous level fast and drifting ice;
- brash ice, broken ice, ice floes;
- ice ridges, ice hillocks, rubble ice;
- simulation of ice compression processes;
- fresh and old channels in ice.

8.1.4 Tianjin University

In August 2016, a new ice basin (Fig.1) was built at the new campus of Tianjin University. It is 40m (long) × 6m (wide) × 2.0m (deep) with a cooling system sending cold air from top of the insulated room that can be cooled down to an air temperature of -22℃.

Figure 13 New ice basin in Tianjin University

8.1.4.1 Generating Snow Cover on Model Ice

Snow cover is usually the concomitant circumstance for natural ice in Arctic. Due to its different physical and mechanical properties comparing with fine-grained level ice, snow cover is supposed to lead the ice-vessel interaction processes to different patterns.

Huang (2013) developed a method for generating snow covered ice sheet in lab. One essential technique of this method is performing two-order water pulverization in cold air to provide a sufficient nucleation of the water particles in air. And the other technique included in this method is forcing water vapour flowing over a cold snow surface to accelerate the formation of coarse-grained snow ice. By applying these two techniques in certain sequence layered snow cover can be made. Detailed procedures were introduced by Huang et.al (2016). The resulting snow cover is displayed in Figure 14.

8.1.4.2 Using of Tactile Sensor

Tactile sensor composed by piezoelectric sensing elements has been used in some tests in depicting local ice pressure on hull structure during recent years (e.g. Määttänen et al., 2011; Kujala and Arughadhoss, 2012). Recently in works performed in the ice basin of Tianjin University, tactile sensor was also introduced in measuring the spatial and temporal ice pressure distributions on the model vessel's bow in resistance tests, as shown in Figure 15. Through analyzing the tactile senor data, breaking component of ice resistance can be identified.

8.1.4.3 Trends in Model Ice Experiments

So far, the simulations of deformed and managed ice conditions have been an important trend in ice model tests. When vessel passing through or offshore structure surviving in such conditions, accumulation of ice rubbles, dynamic response of structure and refreezing effect of ice pieces are the key problems in investigations as well as estimation of ice load.

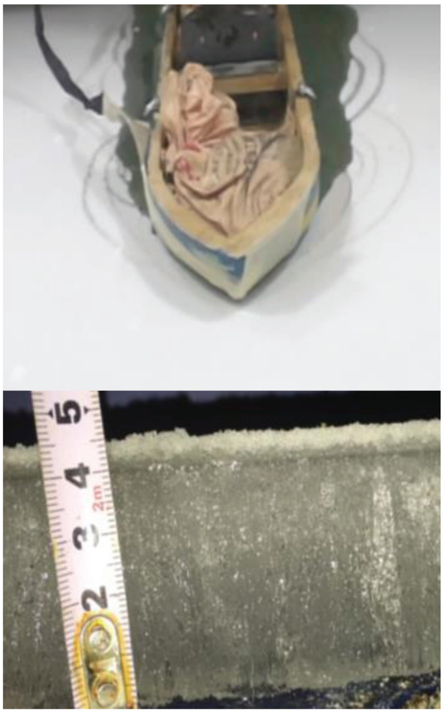

Figure 14 Artificially produced snow cover in the ice basin of Tianjin University

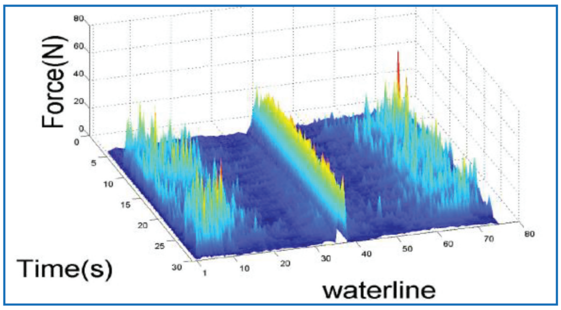

Figure 15 Distribution of ice load on vessel's bow

Another important trend is probably simulating the ice-ship or ice-structure impaction. Such simulation is important for strength design of vessel or offshore structure, but high reliability simulation and evaluation are still in great challenge for ice model tests.

High performance propulsion system has

been fast developed in recent years, especially the pod system. Then investigating and evaluating the performance of propulsion system in complicated ice condition will be an important trend in ice model tests.

8.2 Operating Ice Model Basins

An overview over the operating ice model basins is found in Table 4.

Table 4 Operating Ice Model Basins

Facility	Country
Aalto University	Finland
Aker Arctic	Finland
Japan Marine United (former Universal Shipbuilding Corporation) (former NKK), Japan	Japan
Krylov State Research Centre	Russia
Maritime Ocean Engineering Research Institute (KRISO), Korea	Korea
NRC / OCRE (National Research Council-Ocean, Coastal and River Engineering)	Canada
National Maritime Research Insitute (NMRI)	Japan
The Hamburg Ship Model Basing (HSVA)	Germany
Tianjin University	China

9 REVIEW OF NUMERICAL METHODS FOR ICE-INFESTED WATERS

In recent years, numerical methods are investigated and extended for simulating ship navigation or operation of ocean structures in ice conditions. Although theoretical or empirical methods are still deployed (Ko, Ahn & Park, 2015), many researchers employ modern numerical methods such as Discrete (Distinct) Element Method and Smoothed Particle Hydrodynamics.

9.1 Discrete (Distinct) Element Method (DEM)

Discrete Element Method (Distinct Element Method, DEM) already has a long history of deployment in the field of ice mechanics. Nowadays, several software packages implement DEM as one of their functionalities. For example, STAR-CCM+ version 9 or later implements DEM.

Open source implementations are also available. For example, LIGGGHTS implements DEM (Kloss et al., 2012). Morgan et al. (2015), Morgan (2016), and Yulmetov, Bailey and Ralph (2017) employed this software to simulate ice structure interaction.

Many researchers implement their own DEM codes for their studies. To name a few: Sawamura, Kioka and Konno (2015), Kim and Sawamura (2016), Sawamura and Kioka (2016), Sawamura (2017), Kim, Im and Sawamura (2017), Liu et al. (2015), Lishman and Polojärvi (2015), Ji and Kong (2016), Gong, Polojärvi and Tuhkuri (2017), and Long and Ji (2017).

9.2 Physically Based Modelling and Non-smooth DEM

Physically Based Modelling is an implementation of DEM method with different way of calculating contact forces. It is considered as non-smooth DEM, which is distinguished with classical (smooth) DEM.

Applications of these methods increase in recent years. Uto et al. (2015) employed Physically Based Modelling to simulate a station-keeping drillship in pack ice condition. van den Berg & Lubbad (2015) deployed non-smooth DEM for modelling ice rubble. van den Berg, Lubbad & Løset (2017) extended the method.

9. 3 Smoothed Particle Hydrodynamics (SPH) and Moving Particle Semi-implicit Method (MPS)

Smoothed Particle Hydrodynamics (SPH) is one of Lagrangian methods to handle continuum mechanics. It was originally developed for fluid simulations, but is now extended to handle solid mechanics. Some commercial software such as LS-DYNA implements SPH to handle fluid and/or solid simulations.

Applications of this software to ice mechanics were reported by Das et al. (2014), Das and Ehlers (2015), Patil, Sand and Fransson (2015) and Ervik et al. (2017).

Moving Particle Semi-implicit (MPS) method was separately developed and investigated with SPH as an implementation of incompressible fluid simulation, but can be considered as an implementation of SPH with different spatial discretization schemes. Recently, it is also extended to handle solid mechanics. Ren et al. (2017) deployed this method to simulate interaction of an ice beam and a large water droplet.

9.4 Fluid Structure Coupling

Fluid structure interaction (FSI) is one of the most important but difficult fields of investigation with numerical simulations. However, a few commercial packages implement FSI recently so that it becomes easier.

Song, Kim & Amdahl (2015) employed LS-DYNA to investigate collision of steel structure with an ice floe. Shigihara, Ishibashi & Konno (2015) employed STAR-CCM+ to investigate collision of ship with a single ice floe. Vroegrijk (2015) also employed STAR-CCM+ to investigate ship navigation in brash ice channel.

9.5 Other Numerical Methods

There are a few other schemes to implement ice mechanics. Liu & Ji (2017) employed Rigid Body Spring Model (RBSM) to implement continuum mechanics with crack propagation. van Vliet & Metrikine (2017) developed a new lattice model to simulate the interaction of conical structure with level ice.

10 RECOMMENDATIONS

(1) Adopt the updated procedure No. 7.5-02-04-01.

(2) Adopt the updated procedure No. 7.5-02-04-02.1.

(3) Adopt the updated procedure No. 7.5-02-04-02.2.

(4) Adopt the new procedure "Modelling and Testing in Complex Ice Environments."

(5) Confirm that the procedure 7.5-02-04-02.4 "Tests in Deformed Ice" has been removed from the register. It was approved to be removed at the 27th Full Conference 2011, but is still listed in the register in ITTC website.

11 RECOMMENDATION FOR FUTURE COMMITTEE

(1) Update procedure "Modelling and Testing in Complex Ice Environments" to cover multi-year ice, re-frozen ice / consolidated ice, glacial ice (bergs, bergy bits, growlers), compressive (pressured) ice and snow-covered ice.

(2) Conduct review of the manoeuvring experiments in ice, and consider updating procedure 7.5-02-04-02.3 "Manoeuvring Tests in Ice" in cooperation with the Manoeuvring Committee.

(3) Conduct survey of uncertainly in ice model basins and consider updating procedure 7.5-02-04-02.5 "Experimental Uncertainty Analysis for Ship Resistance in Ice Tank Testing."

12 REFERENCES

Das, J., Polić, D., Ehlers, S. and Amdahl, J., 2014, "NUMERICAL SIMULATION OF AN ICE BEAM IN FOUR-POINT BENDING USING SPH", Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE2014), OMAE2014-23228.

Das, J. and Ehlers, S., 2015, "NUMERICAL SIMULATION OF CRUSHING AND BENDING FAILURE OF ICE USING SPH", Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering (OMAE2015), OMAE2015-41266.

Ervik, Å,Høyland, K., Grimstad, G. and Nord, T. S., 2017, "A Continuum Model of Large Deformation Continuous Ductile Ice Crushing", Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 17).

Gong, H., Polojärvi, A. and Tuhkuri, J., 2017, "Preliminary 3D DEM Simulations on Ridge Keel Resistance on Ships", Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 17).

Gralher, S., 2017. "Experiments and Numerical Analysis of the Mechanical Properties of Columnar Model Ice", Master's Thesis at Hamburg University of Technology.

Huang, Y., 2013. "A method for generating snow covered ice sheet in lab", Chinese Patent No. 201310756056.5.

Huang, Y., Sun, J.Q., Li, W., 2016, "Experimental observations of the flexural failure process of snow covered ice", Cold Regions Science and Technology, 129, 14-30.

Ji, S. and Kong, S., 2016, "Interaction between Level Ice and Ship Hull based on DEM simulations", Proceedings of the 23rd IAHR International Symposium on Ice.

Kim, H. and Sawamura, J., 2016, "A Simulation Study on the Turning Ability of Ice-going Ship Navigating in Pack Ice", Proceedings of the 23rd IAHR International Symposium on Ice.

Kim, H., Im, N. and Sawamura, J., 2017, "Experimental and Numerical Investigation of Ship-Ice Interactions in Pack Ice", Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 17).

Kloss, C., Goniva, C., Hager, A., Amberger, S., Pirker, S., 2012, "Models, algorithms and validation for opensource DEM and CFD-DEM", Prog. Comput. Fluid Dyn. Int. J. 12, 140. doi:10.1504/PCFD.2012.047457

Ko, D., Ahn, K. and Park, K., 2015, "NUMERICAL APPROACH OF TIME DOMAIN SIMULATION FOR ICE BREAKING SHIP IN LEVEL ICE", Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 15).

Kujala, P., Arughadhoss, S., 2012. Statistical analysis of ice crushing pressures on a ship's hull during hull-ice interaction. Cold Regions Science and Technology, 70, 1-11.

Lishman, B. and Polojärvi, A., 2015, "2D DEM OF ICE RUBBLE: THE EFFECT OF RATEDEPENDENT FRICTION", Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 15).

Liu, L., Bailey, L., Sarracino, R., Taylor, R., Power, C. and Stanbridge, C., 2015, "NUMERICAL SIMULATION OF ICE RIDGE GOUGING", Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering (OMAE2015), OMAE2015-41886.

Liu, L. and Ji, S., 2017, "Bond Model of Dilated Polyhedral DEM and its Applications in Sea Ice Simulation", Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC ' 17).

Long, X. and Ji, S., 2017, "The Attributes of Local Ice Pressure Analyzed by Discrete Element Method", Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC ' 17).

Määttänen, M., Marjavaara, P., Saarinen, S., Laakso, M., 2011. Ice crushing test with variable structural flexibility. Cold Regions Science and Technology, 67, 120-128.

Morgan, D., Sarracino, R., McKenna, R. and Thijssen, J. W., 2015, "SIMULATIONS OF ICE RUBBLING AGAINST CONICAL STRUCTURES USING 3D DEM", Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 15).

Morgan, D., 2016, "An Improved Three-Dimensional Discrete Element Model for Ice-Structure Interaction", Proceedings of the 23rd IAHR International Symposium on Ice.

Patil, A., Sand, B and Fransson, L., 2015, "SMOOTHED PARTICLE HYDRODYNAMICS AND CONTINUOUS SURFACE CAP MODEL TO SIMULATE ICE RUBBLE IN PUNCH THROUGH TEST", Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 15).

Ren, D., Park, J.-C., Hwang, S.-C., Jeong, S.-Y., and Kim, S.-Y., 2017, "Brittle Failure Simulation of Ice Beam Using a Fully Lagrangian Particle Method", Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 17).

Sawamura, J., 2017, "2D Numerical Modeling of Icebreaker Advancing in Ice-covered Water", Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 17).

Sawamura, J., Kioka, S. and Konno, A., 2015, "Experimental and numerical investigation on ice submerging for icebreaker with 2D model test using synthetic ice", Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 15).

Sawamura, J. and Kioka, S., 2016, "Numerical Modeling of Icebreaking and Ice-clearing for an Icebreaker Advancing in Sea ice", Proceedings of the 23rd IAHR International Symposium on Ice.

Shigihara, T., Ishibashi, D. and Konno, A., 2015, "Experimental and Numerical Investigation of a Model-Scale Ship and Ice Floe (Second report)", Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC ' 15).

Song, M., Kim, E. and Amdahl, J., 2015, "FLUID-STRUCTURE-INTERACTION ANALYSIS OF AN ICE BLOCK-STRUCTURE COLLISION", Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 15).

Uto, S., Matsuzawa, T., Shimoda, H., Wako, D., Konno, A., Asanuma, T. and Otsubo, K., 2015, "STATION KEEPING IN ICE-ICE TANK EXPERIMENT AND ESTIMATION OF ICE LOAD ON SHIP-SHAPED FLOATING STRUCTURE UNDER MANAGED ICE CONDITION-", Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC ' 15).

van den Berg, M. and Lubbad, R., 2015, "THE APPLICATION OF A NON-SMOOTH DISCRETE ELEMENT METHOD IN ICE RUBBLE MODELLING", Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 15).

van den Berg, M., Lubbad, R. and Løset, S., 2017, "Accuracy of a Non-Smooth Time Stepping Scheme with Non-Rigid Contacts for Ice-Structure Interaction", Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 17).

van Vliet, R. and Metrikine, A. V., 2017, "Simulating Interaction Between Level Ice and Conical Structures with a 2D Lattice Model", Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 17).

von Bock und Polach, R.U.F., 2016, The Mechanical Properties of Model Ice: Experiments, Numerical Model and Scaling, Doctoral thesis, Aalto University & Norwegian University of Science and Technology.

von Bock und Polach, R.U.F. & Molyneux, D., 2017. MODEL ICE: A REVIEW OF ITS CAPACITY AND IDENTIFICATION OF KNOWLEDGE GAPS. Proceedings of the ASME 2012 36th International Conference on Ocean, Offshore and Arctic Engineering (OMAE2017), Trondheim, p. 9.

Vroegrijk, E., 2015, "VALIDATION OF CFD+DEM AGAINST MEASURED DATA", Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering (OMAE2015), OMAE2015-41770.

Yulmetov, R., Bailey, E. and Ralph, F., 2017, "A Discrete Element Model of Ice Ridge Interaction with a Conical Structure", Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC' 17).

13 LITERATURE PUBLISHED IN RECENT YEARS

13.1 Model Tests of Ships and Ice Resistance

Kuulialaa L., Kujalaa P., Suominena M., Montewka J. Estimating operability of ships in ridged ice fields. Cold Regions Science and Technology, 2017, v.135, pp.51-61.

von Bock und Polach, R. Numerical analysis of the bending strength of model-scale ice. Cold Regions Science and Technology, 2015, v.118, pp.91-104.

Kjerstad Ø.K., Metrikin I., Løset S., Skjetne R. Experimental and phenomenological investigation of dynamic positioning in managed ice. Cold Regions Science and Technology, 2015, v.111, pp.67-79.

Makkonen L., Tikanmäki M. Modeling the friction of ice. Cold Regions Science and Technology, 2014, v.102, pp.84-93.

Myland D., Mierke D. Methodology for Investigation of Ice Breaking Performance. Proceedings of the Twenty-sixth (2016) International Ocean and Polar Engineering Conference, Rhodes, Greece, June 26-July 1, 2016, pp.1257-1261.

Andryushin A., Zuev P., Kuteinikov M., Grigorjeva O., Bolshev A., Frolov S. Determination of Ice loads Acting on Bow and Stern of the Modern Ice Ships and Icebreakers. Proceedings of the Twenty-sixth (2016) International Ocean and Polar Engineering Conference, Rhodes, Greece, June 26-July 1, 2016, pp.1298-1305.

Tikanmäki M., Makkonen L. Ice-ice friction in warm temperatures with and without excess water. Proc. 23rd IAHR International Symposium on Ice, Ann Arbor, Michigan, USA, May 31 to June 3, 2016.

Sawamura J., Senga H., Imaki K., Suga K., Kim H. Ice Resistance Test using Synthetic Ice for a Ship Advancing in Ice-covered Water. Proc. 23rd IAHR International Symposium on Ice, Ann Arbor, Michigan, USA, May 31 to June 3, 2016.

Park K.D., Kim H.S. Study on the ship ice resistance estimation using empirical formulas. Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2014, June 8-13, 2014, San Francisco, California, USA.

Myland D., Ehlers S. Theoretical investigation on ice resistance prediction methods for ships in level ice. Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2014, June 8-13, 2014, San Francisco, California, USA.

von Bock und Polach R., Ehlers S. On the scalability of model-scale ice experiments. Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2014, June 8-13, 2014, San Francisco, California, USA.

von Bock und Polach R., Tõns T., Erceg S. Ice resistance calculation methods and their economic impact on ship. Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2015, May 31-June 5, 2015, St. John ’ s, Newfoundland, Canada, OMAE2015-41342.

van der Werff S., Brouwer J., Hagesteijn G. Ship resistance validation using artificial ice. Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2015, May 31-June 5, 2015, St. John’s, Newfoundland, Canada, OMAE2015-41804

Lau M. Model-scale/full-scale correlation of NRC-OCRE’s model resistance, propulsion and maneuvering test results. Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2015, May 31-June 5, 2015, St. John’s, Newfoundland, Canada, OMAE2015-42114

Kim H., Lee C.-J., Kang K.-J., Jeong S.-Y., Yum J.G., Jeong U.C. Study on the equivalent model test and analysis method of brash ice at KRISO ice tank. Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions June 14-18, 2015, Trondheim, Norway.

Sawamura J., Kioka S., Konno A. Experimental and numerical investigation on ice submerging for icebreaker with 2D model test using synthetic ice. Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions June 14-18, 2015, Trondheim, Norway.

Ha J.-S., Cho S.-R., Jeong S.-Y., Yeom J.-G., Kang K.-J. An experimental study on a new method used to prepare granular EG/AD model ice. Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions June 14-18, 2015, Trondheim, Norway.

Timofeev O.Ya., Sazonov K.E., Dobrodeev A. A. New ice basin of the Krylov State Research Centre. Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions June 14-18, 2015, Trondheim, Norway.

Mård A. Experimental study of the icebreaking process of an icebreaking trimaran. Proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions June 14-18, 2015, Trondheim, Norway.

Izumiyama K. Local Ice Load on Ship Hulls-An Approach from Model Testing. Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions, June 11-16, 2017, Busan, Korea.

Evers K.-U. Model Tests with Ships and Offshore Structures in HSVA's Ice Tanks. Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions, June 11-16, 2017, Busan, Korea.

Lau M. Friction Correction for Model Ship Resistance and Propulsion Tests in Ice. Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions, June 11-16, 2017, Busan, Korea.

Matsuzawa T., Shimoda H., Wako D., Uto S., He Q., Watanabe S. Load-Varying Methods for Ship Power Estimation in Brash Ice Channel by Ice Tank Model Test. Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions, June 11-16, 2017, Busan, Korea.

Perälä I., Kinnunen A., Koskinen P., Heinonen J. Full-scale Ice Impact to an Azimuthing Thruster in Laboratory Conditions. Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions, June 11-16, 2017, Busan, Korea.

Dobrodeev A., Sazonov K., Andryushin A., Fedoseev S., Gavrilov S. Experimental Studies of Ice Loads on Pod Propulsors of Ice-Going Support Ships. Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions, June 11-16, 2017, Busan, Korea.

13.2 Model Tests of Engineering Structures

Hendrikse H., Metrikine A. Edge indentation of ice with a displacement-controlled oscillating cylindrical structure. Cold Regions Science and Technology, 2016, v.121, pp.100-107.

Xu N., Yue Q., Bi X., Tuomo K., Zhang D. Experimental study of dynamic conical ice force. Cold Regions Science and Technology, 2015, v.120, pp.21-29.

Dalane O. Influence of pitch motion on level ice actions. Cold Regions Science and Technology, 2014, v.108, pp.18-27.

Lu W., Lubbad R., Høyland K., Løset S. Physical model and theoretical model study of level ice and wide sloping structure interactions. Cold Regions Science and Technology, 2014, v.101, pp.40-72.

Du X., Huang Y. A Model Test Study of Ice-Induced Vibration in Four-Legged Jacket Platforms with Conical Structure in Bohai Bay. Proceedings of the Twenty-sixth (2016) International Ocean and Polar Engineering Conference, Rhodes, Greece, June 26-July 1, 2016, pp.1317-1323

Höderath A., Ziemer G. Local Design Pressures for Fixed Offshore Structures-Utilization of Scale Model Tests. Proc. 23rd IAHR International Symposium on Ice, Ann Arbor, Michigan, USA, May 31 to June 3, 2016.

Bridges R., Riska K., Schroeder C. Model tests for ice encroachment and formation of rubble ice. Proc. 23rd IAHR International Symposium on Ice, Ann Arbor, Michigan, USA, May 31 to June 3, 2016.

Ziemer G., Evers K.-U. Ice model tests with a compliant cylindrical structure to investigate ice-induced vibrations. Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2014, June 8-13, 2014, San Francisco, California, USA.

Ziemer G., Evers K.-U. Influence of structural compliance and slope angle on ice loads and dynamic response of conical structures. Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2015, May 31-June 5, 2015, St. John's, Newfoundland, Canada, OMAE2015-41769.

Zvyagin P., Sazonov K. Analysis and probabilistic modeling of the unstationary ice loads stochastic process, based on experiments with models of offshore structures. Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2015, May 31-June 5, 2015, St. John's, Newfoundland, Canada, OMAE2015-41619.

Dobrodeev A., Zvyagin P., Sazonov K. Study on distribution law and stationarity of global ice loads registered in experiments in ice tank. Proceedings of the ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2016, June 19-24, 2016, Busan, South Korea, OMAE2016-54100.

Ziemer G., Hinse P. Relation of Maximum Structural Velocity and Ice Drift Speed during Frequency Lock-In. Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions, June 11-16, 2017, Busan, Korea.

Tsarau A., Sukhorukov S., Herman A., Evers K.-U., Løset S. Loads on Structure and Waves in Ice (LS-WICE) project, Part 3: Ice-structure interaction under wave conditions. Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions, June 11-16, 2017, Busan, Korea.

Cheng S., Tsarau A., Li H., Herman A., Evers K.-U., Shen H. Loads on Structure and Waves in Ice (LS-WICE) Project, Part 1: Wave Attenuation and Dispersion in Broken Ice Fields. Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions, June 11-16, 2017, Busan, Korea.

13.3 Full-scale Measurements

Bekker A., Suominen M., Peltokorpi O., Kulovesi J., Kujala P., Karhunen J. Full-scale measurements on a polar supply and research vessel during maneuver tests in an ice field in the Baltic sea. Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering, OMAE2014, June 8-13, 2014, San Francisco, California, USA.