ITTC Quality System Manual

Recommended Procedures and Guidelines

Guideline

Guidelines for Modelling of Complex Ice Environments

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Guidelines for Modelling of Complex Ice Environments

1. PURPOSE OF THIS GUIDELINE

The purpose of this guideline is to provide an overview for the modelling methods of complex ice environments in model scale. Such complex environments are ridges, brash ice channels, rubble fields, managed ice and pack ice.

This guideline does not restrict the method used to prepare a feature of complex ice environments. The purpose of the methods presented is to share one of the methods to prepare the model ice condition and to help understanding the nature of complex environments in ice.

2. ICE RIDGES

2.1 Background

Ridges, caused by ice floes compressed together, present a significant obstruction to ship navigation in ice covered waters. Ridges are constructed in model scale to assess a ship's ability to operate in realistic extreme ice conditions. Ridges are divided into two categories, first-year and multi-year ridges.

There are some general differences between first-year and multi-year ice ridges. Multi-year ice ridges, as shown by investigations, typically feature a considerably smoothened keel and a solidity ratio close to 1. Such ridges often have broader keels than first-year ridges, and keels that are slightly less deep relative to the sail height. It should be noted that multi-year pressure ridges have a high degree of consolidation. As a rule, on the crest edges the ridge is fully consolidated. The keels of first-year ice ridges are mostly loose or unconsolidated. Resistance and propulsion tests can be performed in ridges. Ridge penetration by ramming is the standard ship model test in ice basins as it reflects closely the full-scale process of ridge penetration. The objectives are, for example, to determine the ramming capability of the ship in ridges, in terms of penetration distance as a function of impact speed, ridge characteristics, and penetration force (propeller thrust plus inertial force). Correlation of ridge profile and ship penetration is important for the subsequent analysis.

2.2 Procedures for Preparing First-year Ridges in Model Basins

Ridges are generally prepared from a level ice sheet which is grown to the required thickness. There are several methods for constructing a first-year ice ridge, which are described below.

Figure 1: Ice sheet cut free at the sides

One accepted method approximates the formation of a ridge in nature by the compressing two ice floes. To construct a ridge in this manner, a section of the ice sheet is cut free from the side walls of the tank (see Figure 1), cut into strips of a certain width and pushed against the remaining ice sheet by means of the carriage's pushing board.

The ridging process is facilitated by a beam (see Figure 2) with an inclined face placed across the tank. The free ice strips are pushed against the beam and crushed into rubble ice fragments which accumulate under the beam. Depending on the requirements of the ridge keel profile, the beam should be moved repeatedly forward during the ridging process.

Figure 2: Beam with inclined face breaking the ice downwards

Secondly, the remaining unbroken ice sheet is pushed over the ridge, by means of the carriage's pushing board (see Figure 3), forming the consolidated layer. The ridge has a typical natural underwater profile and is embedded in level ice.

The ice thickness, flexural strength and temperature of the level ice sheet are measured prior to preparing the ridge, to determine the correct time at which to build the ridge. The temperature and strength of the consolidated layer is highly dependent on the constituent properties of the ice sheet used to make the ridge.

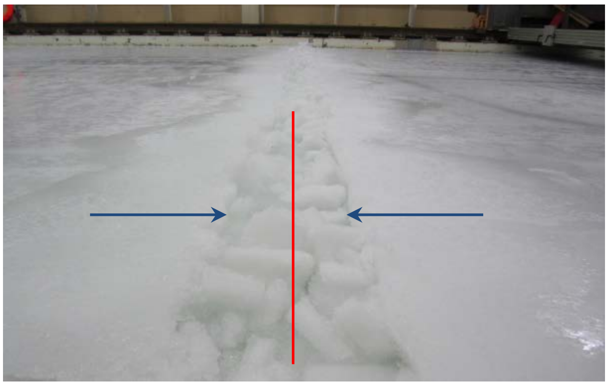

Figure 3: Piled up ridge sail surrounded by unbroken ice sheets

Additionally, there are alternative approaches to create ridge like ice features.

Such a ridge can be created by compressing ice floes within the tank into a multi-layered rubble field. The ice floes used to make the ridge can be created at the end of a test program in level ice.

Another method is described by Molyneux and Spencer (2013). The steps in this method are as follows:

Grow level ice sheet to required thickness.
Cut ice sheet across the tank in the required width and location of the ridges.
Break ice between the cuts into floes, and leave them in place.
Add ice, from the free end of the ice sheet, onto the area of the ridge until the required volume of ice is used. Stirring the ice pieces during the ridge construction is recommended, to make sure that the ice block diameter is about 5-6 times the ice thickness, and that the blocks are randomly oriented.
Freeze consolidated layer if required.

The method of ridge construction chosen should have no impact on the requirements for measurement of its properties or the type of experiment to be carried out. A not exhaustive list of ridge production methods is in Tuhkuri, J. and Lensu, M., 2002.

2.3 Ridge Properties

Ice ridges consist of two distinct types, first year ridges and multi-year ridges. Multi-year ridges are not commonly tested in ship model basins. The most favourable way for obtaining ridge dimensions and properties is to conduct measurements directly in the ship's operating region, if possible.

The measurement of the ridges can be done continuously or discrete way. If field data for the specific region is not available, then qualitative data for first year ridges in three different geographic regions is given in (Timco, G. W. and Burden, R. P., 1997).

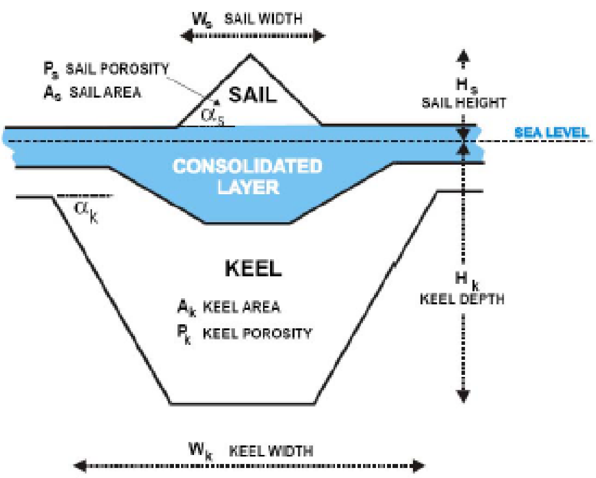

Figure 4: Idealized first year ridge geometry

The geometric definition of an idealized first year ice ridge is given in Figure 4 (Timco, G. W., Croasdale, K. and Wright, B., 2000). The sail and keel angles of natural ridges are about 25 (Timco, G. W. and Burden, R. P., 1997). The ratio of sail width and keel height is around 1:4.31 (Strub-Klein, L. and Sudom, D., 2012). First- year ice ridges consist of ice blocks and voids, filled with water if below the waterline. In the absence of any other data it can be assumed that approximately 70-75 % of the overall volume of the ice ridge is ice, and 25-30% is void space / porosity.

The important properties of ice ridges are transverse profile, shear strength, thickness of consolidated layer and void space / porosity. The methods for major properties measurement are described elsewhere. See 7.5-02-04-02 "Test Methods for Model Ice Properties."

In addition to measurements, the porosity can be calculated as follows.

$$p = 1 - \frac{V_{ICE}}{V_{TOT}} \quad (1)$$

where p is the porosity; V_{ICE} is the ice volume of the parent ice sheet which is used to form ridges, but also rubbles or brash ice; V_{TOT} is the volume occupied by the outer faces of the investigated ice feature.

2.4 Procedures for Tests in Ridges

The thickness of a ridge is not constant. Thus, the ridge resistance cannot be reflected by an average value, as it varies when a ship penetrates a ridge (see Figure 5). The definition for ridge resistance is the same as level ice resistance from the integral of towing force. The scaling of ridge resistance is again straightforward if all the parameters are scaled properly.

The parameters commonly measured are the speed over time, the penetration depth into the ridge and the ship motions

In case the ship penetrates the ridge in a continuous mode, the change of speed is of significance

Normally, the ship model does not penetrate ridges in a continuous fashion. The ships have to ram a ridge several times. The ridge penetration by ramming is accomplished by consuming the inertia of the vessel in entering the ridge. The penetration depth made in each ram and also the time consumed by each ramming cycle should be noted.

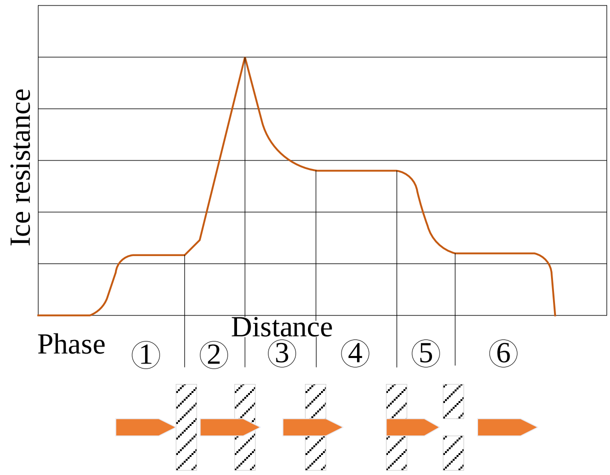

Figure 5: Qualitative illustration of the resistance of ship model penetrating a ridge. With the ship resistance plotted over the ship position.

Observations or measurements on the backing-out or being stuck can be made additionally.

3. BRASH ICE CHANNEL

3.1 Background

Brash ice channels are usually shipping channels created by icebreakers, to provide navigation routes for ships with lower ice breaking capacity than the icebreakers. With an increasing number of ship passages the shape of the channel changes. Ice pieces are pushed towards the edges and the thickness in the middle is reduced. As a consequence of frequent ship passages the ice pieces are spherically shaped. The thickness of the brash ice within the channel is thicker than the surrounding level ice field. The Finnish-Swedish ice class rules (TraFi & Swedish Transport Agency, 2011) contain a procedure for model tests in old brash ice channels for the ice class certification of ships.

3.2 Manufacturing Methods

The brash ice channel is generally manufactured from a level ice sheet into which the channel edges are cut. In the next step the ice within the channel edges is broken into smaller pieces. Those are the brash ice channel fragments and their size depends on the scale and modelled scenario, but if the scale factor is so big the size of fragments should be as smaller as possible to make in ice tank. Thereafter, the ice pieces in the channel are compacted to increase the brash ice porosity and the thickness of the ice within channel. If required, the brash pieces are manually rearranged.

The channel width depends on the scenario to be modelled, e.g. two times the beam width of the ship for ice class certification test (TraFi & Swedish Transport Agency, 2011).

If required, additional solidification or a refrozen top layer can be established by additional freezing.

3.3 Channel Properties

The average brash ice thickness is to be measured in relatively small spatial distances to assess changes over a small grid. The spatial distribution in the longitudinal direction should be between 1.5m – 2m and in lateral direction in sufficiently small intervals. The guidelines of the FSICR suggest 10 cm - 20 cm. The recommended thickness measurement method is to use slide gauges that have sufficient planes on top and at the bottom. In any measurement method, the disturbance of ice in the channel should be minimized.

Another parameter of significance is the coverage of ice within the channel. This can be assessed from photographs.

3.4 Ice Properties

The strength of the ice is traditionally expressed by the flexural strength of the parent ice sheet. As the ice does not fail in bending the strength of the ice might be reflected by other more appropriate parameters such as crushing or compressive strength.

The refrigeration of the tank can lead to new freeze bonds between the brash pieces which affect the resistance. However, no established measurement methods are yet available. The porosity may be calculated using the general formulation in eq. (1).

3.5 Tests

In brash ice channels the interaction of the propeller and the brash ice can be significant. Test are to be conducted in accordance to the guidelines 7.5-02-04-02.2 “Propulsion Tests in Ice” or, if applicable for resistance tests 7.5-02-04-02.1 “Resistance Tests in Ice”.

4. RUBBLE FIELD

4.1 Background

Ice rubble fields represent significant areal accumulations of contiguous, first-year ice rubble (Prodanovic, 1979). By comparison with first year ice ridges, a rubble field is a jumble of ice fragments or small pieces of ice that covers a larger expanse of area without any particular order to it. The height of surface features in rubble ice may be lower than in ridges. Resistance and propulsion tests can be performed in rubble fields, as well as ice load estimation for ocean structures.

4.2 Methods for Preparing Rubble Fields in Model Basins

An ice feature approximating a natural rubble field can be created by compressing ice floes within the tank, into a single- or multi-layered rubble field. The steps in this method are as follows:

Breaking or cutting a parental sheet into small floes (diameter about 2 to 4 times ice thickness of the parental sheet). Thereafter, the small ice pieces (the single rubble layer) are commonly compressed / accumulated to generate a multi-layer rubble field.

4.3 Properties of Rubble Fields in Model Basins

4.3.1 Thickness of rubble field

Thickness of the rubble field shall be measured. Here, the same method to measure the profile of ice ridge can be applied. See 7.5-02-04-02 “Test Methods for Model Ice Properties.”

4.3.2 Porosity of rubble fields

The porosity of rubble fields shall be measured or calculated. Measurement method of porosity is described in 7.5-02-04-02 “Test Methods for Model Ice Properties.” The calculation can be done according to eq. (1).

4.3.3 Shear strength of ice rubble

Shear strength of ice-rubble can be measured in accordance to 7.5-02-04-02 “Test Methods for Model Ice Properties”, if it is required.

4.4 Experiments and Testing

Resistance and propulsion tests can be performed in rubble fields see 7.5-02-04-02.1 "Resistance Test in Ice" and 7.5-02-04-02.2 "Propulsion Test in Ice."

5. PACK ICE

5.1 General

Pack ice refers often to ice floes, but can be used for any accumulation of ice in various shapes and sizes other than fast ice. A classification of ice floe size classes from "very small" to "great" is found in Table 2 of 7.5-02-04-01 "General Guidance and Introduction to Ice Model Testing". However, in ice tank operations the size of ice floes is limited. Ice floes – and sometimes other ice features - occur as pack ice which concentration is commonly classified in tenth (10/10, 9/10, 8/10 …1/10) ratios of surface covered by ice / overall surface area.

Pack ice can be formed through break-ups (stress releases) in a continuous ice sheet through causes such as winds, currents, waves or other.

5.2 Preparation

The pack ice is prepared first defining the desired coverage on which basis parts of the parent ice sheet are removed to obtain the desired covering ratio.

The remaining level ice field is broken up into smaller pieces by mechanical breaking, cutting or small waves.

Special attention must be paid to an adequate size of the floes relative to the available basin space. If floes are too large, ice floes could be easily pushed against the basin walls. This creates unnaturally high forces, when a ship or structure pushes through the pack ice.

The strength of ice-rubble can be measured in accordance to 7.5-02-04-02 "Test Methods for Model Ice Properties", if it is required.

5.3 Experiments and Testing

Resistance and propulsion tests can be performed in pack ice according to 7.5-02-04-02.1 "Resistance Test in Ice" and 7.5-02-04-02.2 "Propulsion Test in Ice."

During the experiments it is recommended to monitor and document the behaviour of the floes.

6. MANAGED ICE

6.1 Background

In full scale the managed ice is created by single or multiple icebreakers during their ice management duties. This is the main difference to pack ice, which is formed by nature. Ice management duties consist of breaking up ice floes upstream of the main installation in order to reduce the reaction load between the ice and the structure.

Generally, ships or structures, whether dynamically positioned or moored require ice management in order to hold station. The parameters to be considered are: ice floe size, ice thickness, ice concentration, ice drift speed, ice drift angle, ice strength, brash ice/small ice pieces inclusion, hull ice friction and optionally ridge fragments.

6.2 Managed Ice

6.2.1 Managed Ice Condition in Full Scale

In order to create a realistic managed ice field in the model basin, several key components should be modeled. As shown in Figure 8 (Hamilton, J., et al., 2011), the managed ice in full scale would include target large ice floes (100m – poorly managed, 50m – medium; 25 m – well managed), brash ice (less than 2 m) from icebreaker's propeller milling or multiple transits and small sizes of ice pieces (10 - 15m) from icebreaking action. These features should be modeled properly in model scale.

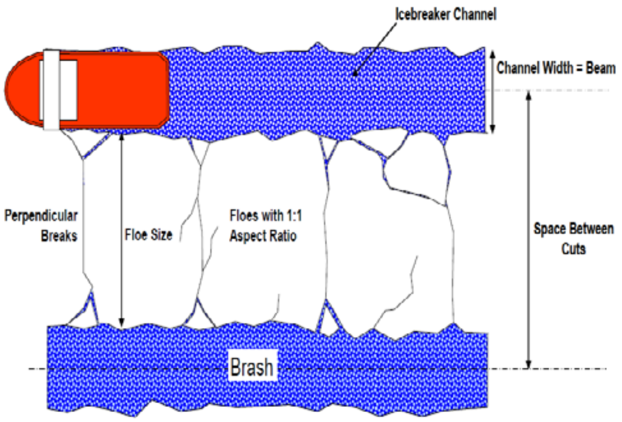

Figure 6: The scheme of managed ice arrangement in full scale

Figure 7: Managed ice in full scale (Hamilton et al., 2011)

6.2.2 Managed Ice Condition in Model Scale

Based on these observations, it is suggested that the managed ice field in the model basin would have 1:1 aspect ratio ice floes with 30 - 40% of a mixture of brash and small ice pieces.

In order to minimize the side wall effect, the minimum number of ice floes across the basin should be more than four (>4) with the suggested portion of brash/small ice pieces. Model test should be ceased at least 1 ship length from the end of the basin to avoid the end wall effect.

Generally, it is preferred that ice floes do not have sharp angles at four corners since they could be easily interlocked. Each corner of the ice pieces should be cut to reduce interlocking but it doesn't require any specific shape.

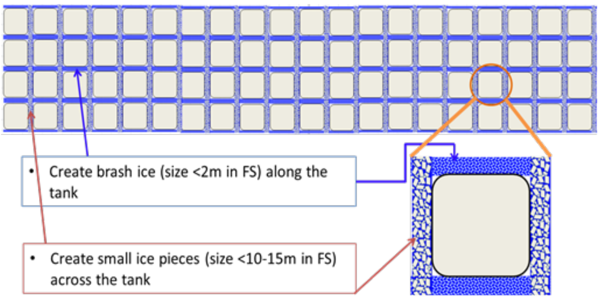

Figure 8: First stage of ice preparation (100 m floes) in the model basin

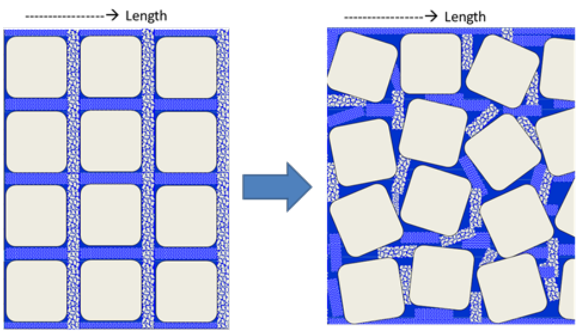

Figure 9: Second stage of ice preparation in the model basin

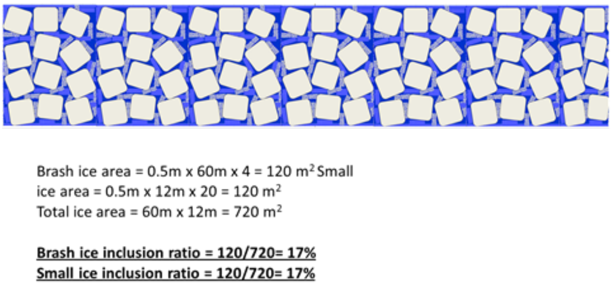

Figure 10: Sketch of the managed ice field in the model basin (60 m long and 12 m wide basin as an example)

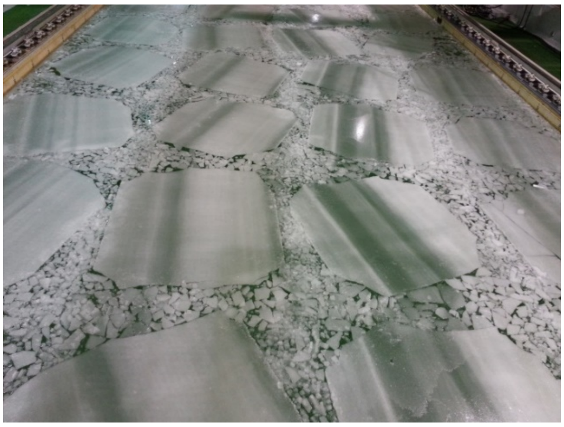

Figure 11: managed ice field in the model basin (60 m long and 12 m wide basin as an example)

Figure 4: A mixture of floe size in the model basin

Figure 8 shows the first stage of ice preparation. Parental level ice should be cut longitudinally and transversely based on the target floe size. Figure 9 shows that ice pieces are rotated and moved to simulate a natural looking ice field. Figure 10 shows the sketch of the managed ice field in the model basin with brash ice/small ice piece inclusion. Figure 11 shows the final managed ice field for the largest floe size. After tests with the largest floe size, the ice pieces can be broken as half sizes for small floe size tests. Figure 12 shows a mixed floe field by reserving some large floes from the previous tests. More details can be found in Wang et al., 2016.

6.2.3 Control Parameters for Managed Ice in the Model Basin

There are several parameters to be considered for the model tests in managed ice as follows:

- Ice floe size;
- Ice thickness;
- Ice concentration;
- Initial ice distribution;
- Ice drift speed;
- Ice drift angle;
- Ice strength;
- Brash ice;
- Small ice pieces;
- Hull ice friction;
- Ridge fragment.

The parameters such as ice floe size, thickness, concentration, speed, strength and mixture of brash/small ice pieces depend on the objectives and operating region of the projects. Hull ice friction plays a significant role in managed ice conditions, as it affects the vessel's behaviour, it should be measured during each test series.

6.2.4 Difference between Managed Ice and Pack Ice in Modelling

Pack ice is considered as "naturally managed ice." Since there is no icebreaker's action, a mixture of brash ice and small ice pieces can be excluded case-vice in the modelling. The pack or managed ice field can be prepared by cutting the target size of ice and adjusting them manually based on the concentration. It can be done with the same procedure of the managed ice field except brash ice/small ice pieces which are removed and replaced to the open water.

6.3 Experiments and Testing

Resistance and propulsion tests can be performed in managed ice, see 7.5-02-04-02.1 "Resistance Test in Ice" and 7.5-02-04-02.2 "Propulsion Test in Ice." Due to the rationale behind the managed ice, a dynamic positioning algorithm equipped model or a moored model is often used to evaluate their performance in given ice conditions.

7. COMPRESSIVE ICE

7.1 Background

The term compression in an ice cover refers to a situation where wind and/or current exert drag force on ice cover and the ice starts to drift.

When wind drag acts on open pack ice, the ice floes start to move. If the ice motion is restricted by an obstacle like a shoreline, the ice cover starts to compact. First all the open water area closes. This is followed by rafting of ice at the contact points between ice floes. The rafting is followed by ridging. When the force required to ridging is larger than the driving forces, the ice drift stops and stresses i.e. compression in the immobile ice cover will be present.

Figure 13: A ship stuck in compressive ice

There is a definite relationship between the compression level the closing speed of the channel (Sazonov, 2010) on the basis of the full-scale tests processing, which can be presented as approximation:

$$V_{\mathrm{C}} = 0.005 S_{\mathrm{IC}} + 0.3762 S_{\mathrm{IC}}^2 \; m/s \qquad (2)$$

where V_{C} – the closing speed of the channel; S_{IC} – ice compression level measuring in numbers from 0 to 3. An ice compression from 0 to 3 on this scale can be described as:

0 – The ice is not compressed. There are channels, unclosed cracks and patches of ice-free water among the close ice;

1 – The ice is weakly compressed. In the compression zone separate patches of ice-free water and fresh cracks are observed. The brash ice between the ice floes is consolidated. There are rafted nilas and grey ice. There ice ridges among grey/white ice.

2 – The ice is distinctly compressed. In the compression zone only a few small patches of ice-free water and narrow cracks of variable width are preserved. This is an evidence of ice drift. The brash ice is partly extruded onto the ice channel edges. Fresh ice ridges are observed.

3 – The ice is strongly compressed. Open water and cracks are completely absent. Young ice is completely formed into ridges. The brash ice is completely extruded onto/under the ice channel edges. The channel is closed behind the icebreaker at once. There are ice ridges at the junctions of first-year and multi-year ice.

7.2 Method for Modelling Compressive Ice

An ice feature approximating a natural rubble field can be created by compressing ice floes within the tank, into a single- or multi-layered rubble field. The steps in this method are as follows:

a b

Figure 14: Towing tests of ship in compressive ice (a – the model towing with a winch across the KSRC basin during the pushing of ice sheet; b – the pushing plates lowered to the water level in AALTO basin)

The tests are performed with a self-propelled model or by towing the model with a winch across the basin. A ship model is driven or pulled through an open channel and one side of the ice field is pushed perpendicular towards the heading of the model (Fig. 14). The model can be towed by a carriage only if the both side of ice can compress the model symmetrically. The compression level is determined based on the closing speed of the channel in relation to the ship speed.

Added resistance in relation to the level ice resistance and open channel resistance determined with tests in these features without a compression.

7.3 Experiments and Testing

Resistance and propulsion tests can be performed in compressive level ice and closing channel see 7.5-02-04-02.1 “Resistance Test in Ice” and 7.5-02-04-02.2 “Propulsion Test in Ice”.

8. SNOW-COVERED ICE

8.1 General

Snow cover can have a significant effect on ice resistance and can increase the friction on a vessel's hull. It also provides an easily compressible layer, which consumes energy prior to fracturing the underlying ice, and entraps air which increases the buoyancy component. Such effects have been demonstrated through full-scale trials and model tests.

The results of full-scale sea trials provide conclusive evidences that snow cover on ice has significant effect on the ship’s ice resistance. Traditionally, this effect is taken into account by assuming some effective ice thickness so that the ship’s resistance in this effective ice thickness is equal to that in ice covered with snow.

8.2 Preparation

There are 3 main approaches that could be used for preparing snow in model basin: modeling as an additional thickness to the ice sheet, artificially generating snow in basin (Huang 2018) and imitation by special chemical composition.

A so-called effective ice thickness h_I', which is commonly introduced to include the snow effect on the ship's performance in ice, is defined as the ice thickness h_I plus some allowance for the snow-covered ice properties, primarily snow thickness h_{SN}. In this case it is assumed that the ice resistance of ship moving through continuous snow-free ice of thickness h_I' is equal to the ice resistance of the same ship moving through snow-covered ice of thickness h_I plus snow thickness h_{SN}. Calculations are performed using the following formula:

$$h_I' = h_I + k_e h_{SN} \quad (3)$$

where k_e is a certain empirical coefficient.

Different researchers suggested different values for this coefficient k_e based on scanty results obtained in full-scale trials. According to Ref. (Buzuev A.Ya., 1981) based on the analysis of the studies conducted by various researchers the values of this coefficient are in the range of 0.5 to 1.5, while A.Ya. Buzuev suggested it's equal to 1. Alternative suggestion was made by (Nyman, 1999 & Riska, 2001) to use a value of k_e equal to 1/3. For a fresh snow cover this coefficient could be assumed to be $k_e = 0$ (Belyashov, V.A., 2008 & Appolonov, E.M., 2011).

In Ref. (Ryvlin, Heisin, 1980), also based on full-scale results, it is shown that the value of this coefficient should depend on the snow density. These authors suggested the following formula for k_e:

$$k_e = k_e' \frac{\rho_{SN}}{\rho_I} \quad (4)$$

where ρ_{SN}, ρ_I– snow and ice density, respectively; k_e' – empirical coefficient (in the opinion of the authors, equal to 4.2 for icebreakers). The authors used the linear dependence as the first approximation. This dependence is apparently applicable to snow densities up to 400 kg/m^3.

The semi-empirical approach was further developed in Ref. (Gramuzov, 2011) that suggested the following formula for estimation of the coefficient k_e in eq. (3):

$$k_e = 0{,}284 + 0{,}575 \cdot 10^{-3} \cdot S_{WB} - 0{,}164 \cdot h_I - 0{,}048 \cdot V \quad (5)$$

Where V– ship speed, S_{WB}– wetted bottom area, m^2.

This formula was derived based on numerical calculations of the ship's ice resistance using the method of B.P. Ionov and E.M. Gramuzov (Ionov, 2001). In these calculations the snow thickness h_{SN} and some initial ice thickness h_I were assumed. The resistance due to snow-covered ice was calculated based on the data of Ref. (Gramuzov, 1986). Then the effective ice thickness h_I' was calculated to meet the equal resistance condition.

The technique of artificially generating snow included in this method is forcing water vapor flowing over a cold snow surface to accelerate the formation of coarse-grained snow ice. A layer of snow ice is firstly produced on the model ice sheet by performing the two-order water pulverization procedure.

Then a layer of coarse-grained snow ice with big crystal size (2–3 mm) is made by spraying the water vapour on the surface of new snow layer directly. As the wet snow particles are completely refrozen, another new snow layer is sprayed on this base layer subsequently. In the next step, water vapour is driven to horizontally flow over the new snow surface to accelerate the formation of depth hoar (Fig. 15).

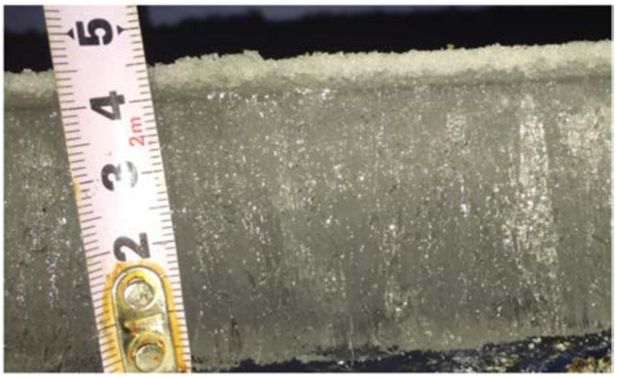

Figure 15: Artificially produced middle layer of depth hoar on model ice sheet (Huang, 2018)

Then a layer of dense and close-grained depth hoar is quickly developed on the base snow ice layer. The last step of the layered snow cover generation is spraying a layer of new snow over the middle layer of depth hoar (Huang et al, 2016).

8.3 Experiments and Testing

Resistance and propulsion tests can be performed in snow cover ice see 7.5-02-04-02.1 “Resistance Test in Ice” and 7.5-02-04-02.2 “Propulsion Test in Ice”.

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