ITTC Quality System Manual

Recommended Procedures and Guidelines

Guideline

Guidelines for Modelling of Complex Ice Environments

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Updated / Edited by	Approved
Specialist Committee on Ice of the 28th ITTC	28th ITTC 2017
Date: 03/2017	Date: 09/2017

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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. FIRST YEAR 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.

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 objective is 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 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.

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 constant 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 1: Ice sheet cut free at the sides

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.

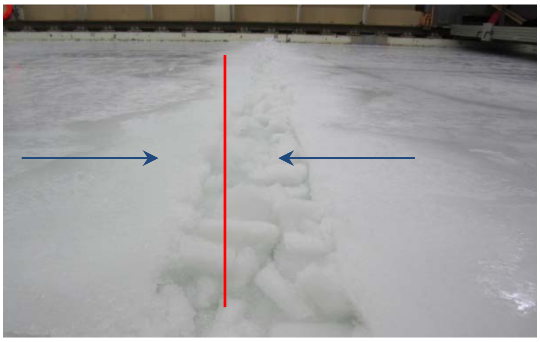

Figure 3: Piled up ridge sail surrounded by unbroken ice sheets

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:

a) Grow level ice sheet to required thickness.
b) Cut ice sheet across the tank in the required width and location of the ridges.
c) Break ice between the cuts into floes, and leave them in place.
d) 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.
e) 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 and Lensu (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)).
The geometric definition of an idealized first year ice ridge is given in Figure 5 (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 and keel height is around 1:4.85 (Strub-Klein and Sudom. 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% of the overall volume of the ice ridge is ice, and 30% is void space / porosity.

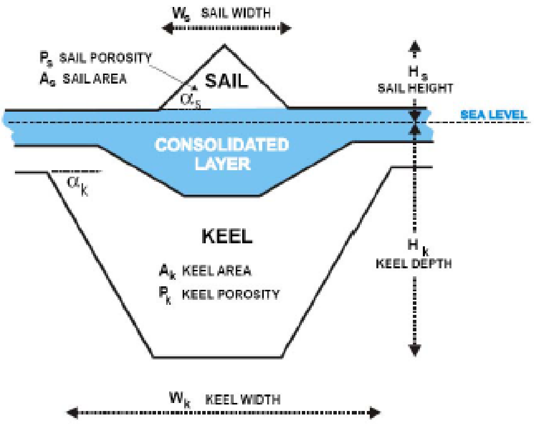

Figure 4: Idealized first year ridge geometry

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.

$$p = 1 - \frac{Vice}{Vtot} \qquad 1$$

Here, p is the porosity and $Vice$ is the ice volume of the parent ice sheet which is used to form ridges, but also rubbles or brash ice. Vtot 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 6). 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 is the speed over time, the penetration depth into the ridge and the ship motions

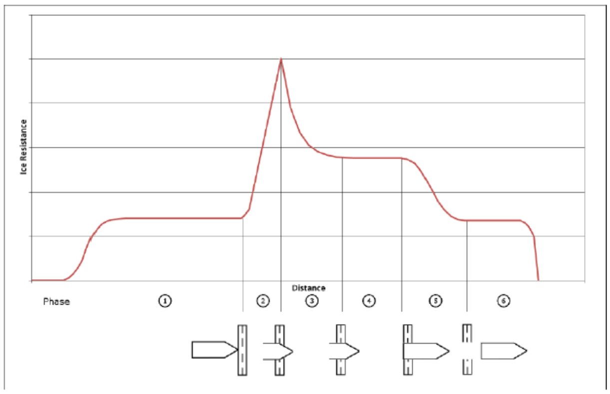

Figure 5: Qualitative illustration of the resistance of ship model penetrating a ridge. With the ship resistance plotted over the ship position.

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.

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. Thereafter, the ice pieces in the channel are compacted to increase the brash density 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. These planes or plates preferably unfold after piercing through the channel to reduce the created disturbance in the channel.

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 bending 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 Equation 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 Equation 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 7.5-02-04-02 "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 level 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 7, the managed ice should 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. Figure 7 shows the managed ice in full scale (Hamilton et al., 2011).

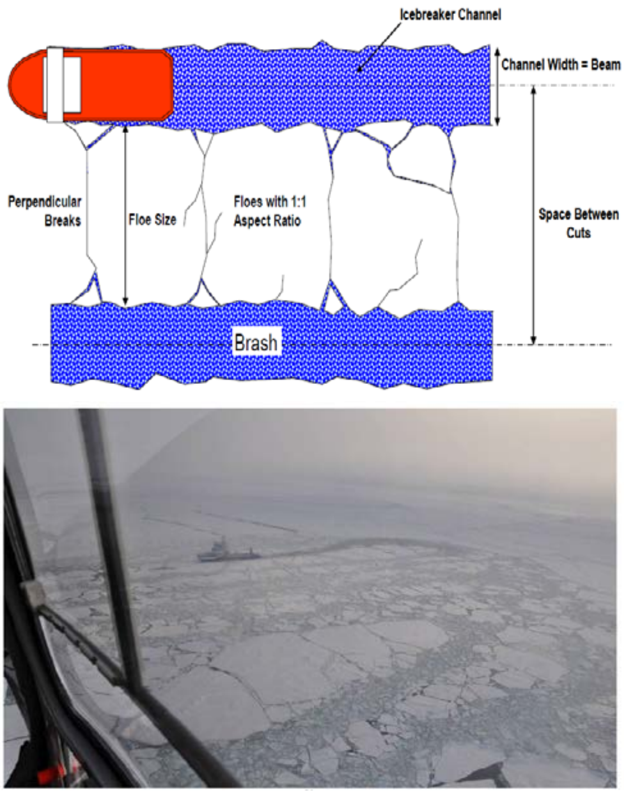

Figure 6: Managed ice in full scale (Hamilton et al., 2011)

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.

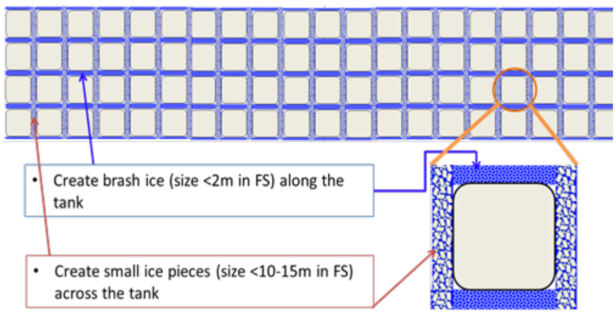

Figure 7: First stage of ice preparation (100 m floes) in the model basin

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).

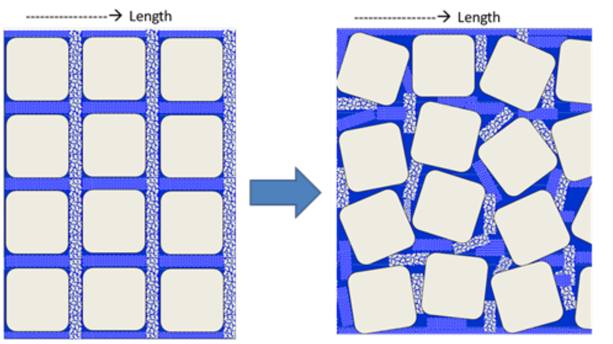

Figure 8: Second stage of ice preparation in the model basin

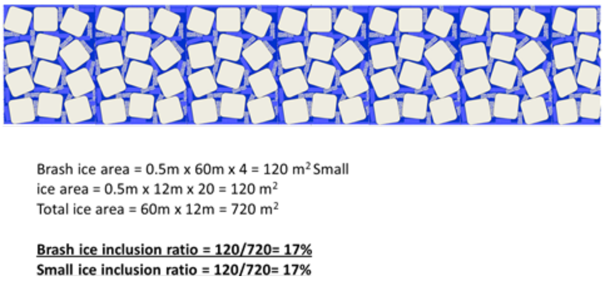

Figure 9: Sketch of the managed ice field in the model basin (60 m long and 12 m wide basin as an example)

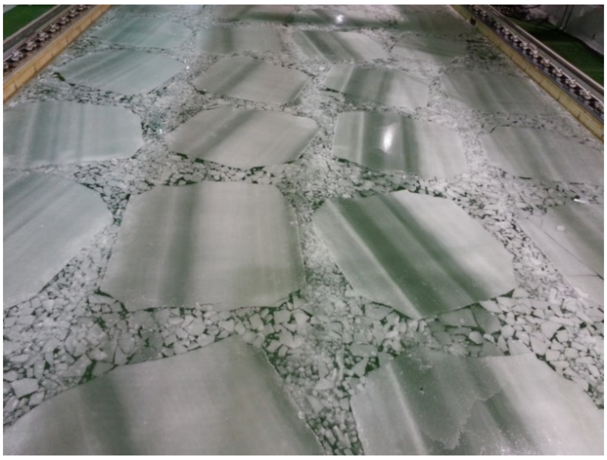

Figure 10: managed ice field in the model basin (60 m long and 12 m wide basin as an example)

Figure 11: A mixture of floe size in the model basin

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 in managed ice conditions as it affects the vessel’s behaviour so that it should be measured during the model test each day if tests are more than one days.

6.2.4 Control Parameters for Pack Ice in the Model Basin

Pack ice is considered as "naturally managed ice." Since there is no icebreaker’s action, a mixture of brash ice and small ice pieces should be excluded in the modelling. The pack 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. REFERENCES

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