# ITTC Quality System Manual

# Recommended Procedures and Guidelines

## Procedure

# Resistance Tests in Ice

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# Resistance Tests in Ice

## 1. PURPOSE OF PROCEDURE

The purpose of the procedure is to ensure consistent methodology for ice towing tank tests and the acquisition of correct results for ice resistance.

Resistance tests can be performed in several types of ice features as described in guideline 7.5-02-04-01. These features include:

- Level ice
- Pack ice
- Broken channels (incl. brash ice)
- Rubble ice fields

The main purpose of ship resistance tests in ice is to measure the ice resistance at given ice/ ship conditions and to evaluate the effectiveness of the hull-form in ice-breaking and ice-clearing.

The specific results from these tests include:

- Ice resistance at certain speeds and ice thicknesses
- The ship performance diagram (i.e. speed versus ice thickness)
- Limiting ice thickness for a continuous ice breaking
- Maximum force on the ship when breaking through an ice ridge.

## 2. ICE RESISTANCE TESTS

### 2.1 Test methods

#### 2.1.1 Test Set up

The ice resistance tests are carried out by towing the model at a constant speed through the ice sheet using a tow-post, a pulling rod or wire. When performing constant speed tests with a towing wire instead of a tow-post or pulling rod, a counterweight must be used to provide the required tension in the towing wire.

Two alternative test setups are described below:

- The model is fixed to the towing carriage (1) as shown in Figure 1. A dynamometer (2) is located inside the model usually at or near the LCB and in the line of the propeller shaft.

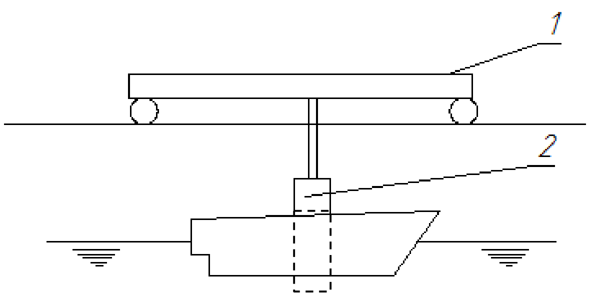



Figure 1: Resistance setup alternative 1

- The model is fixed to the towing carriage (1) as shown in Figure 2. A dynamometer and (or) load cell (2) is located on the bow or inside the model. The model can be pulled either by a wire or a rod. If a wire was used, it should be pre-tensioned to avoid going slack during ice breaking.

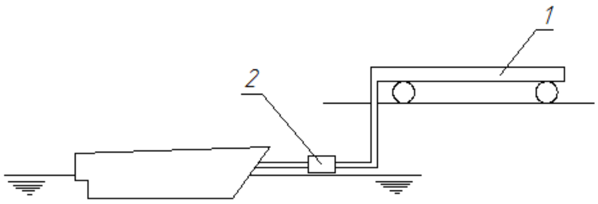



Figure 2: Resistance setup alternative 2

In both test setups, the model should be free to roll, pitch and heave while constrained in surge, sway and yaw.

When space permits, the towing tests can be done in parallel channels. In these cases, it is possible that cracks propagate from the second channel to the previously broken channel and may reduce the ice resistance. To prevent release cracks and the sideway drifting of the ice plates, it is strongly recommended to support the existing channel, when those are relatively close to each other.

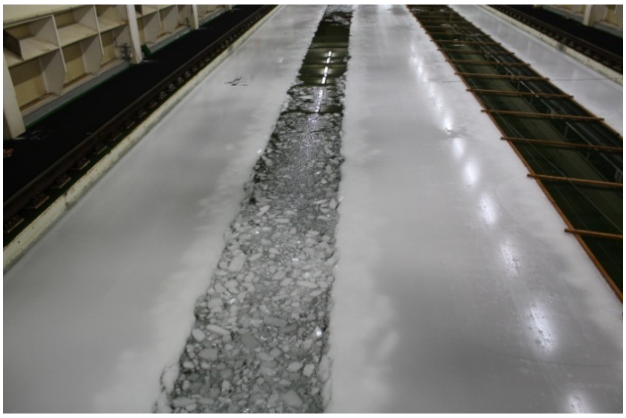


Figure 3: Example of two-track arrangement showing support of first channel (right side)

Figure 3 shows a multiple track arrangement in ice model basin. Once the first channel was used, the channel should have support to maintain the rest of ice in place (shown in the right side in the Figure). The support arrangements, as well as any visible cracks between the channels that occur, need to be reported.

### 2.1.2 Resistance Tests in Intact Level Ice

For the resistance tests in intact level ice, the towing force from intact level ice is the primary measurement. As shown in Figure 4, there are three forces acting on the model. It is noted that open water resistance should be measured before or after ice tests.

- $F_x$ towing force acting in ships longitudinal direction measured by a dynamometer
- $R_I$ net ice resistance
- $R_{IW}$ water resistance in ice conditions

When a rigid towing system is used, the total resistance is the measured towing force, $F_x$.

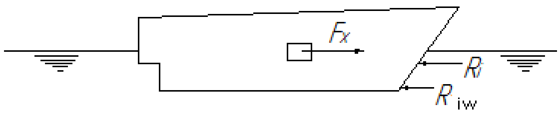



Figure 4: Forces acting on a model in a towing resistance test

The towing method and arrangement should be documented sufficiently to permit reproduction of the experiment.

The velocity of the model and the towing force are the main parameters and the main result from a resistance test. The total ice resistance is defined as the time average of the longitudinal force resisting the motion of the ship.

$$R_{IT} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} F_x(t)\, dt \qquad (1)$$

where $t_1$ and $t_2$ are, respectively, time to start and finish analysis recording of dynamometer readings.

The time interval has to be of sufficient length to achieve a steady state, with transient effects minimized and the flow of the ice around the hull is fully developed. This state is usually established after 1 (one) model length. It is recommended to allow the ship model to move at least another 1.5 model lengths in the level ice of uniform thickness to get a reliable resistance value in the steady state.

The analysis starting time ($t_1$) has to be selected by the researcher based on the experiment conditions. The analysis of the measurements shall start as soon as the flow of ice pieces around the model is fully developed. Therefore, the above time dependent equation can be presented in a distance dependent form:

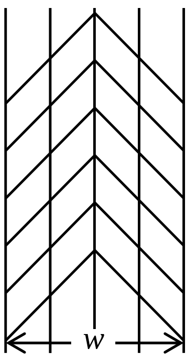
$$R_{IT} = \frac{1}{x_2 - x_1} \int_{x_1}^{x_2} F_x\left(\frac{x}{v}\right) dx \qquad (2)$$

where $v$ is the towing speed, $x_1$ and $x_2$ are, respectively, the start and end positions of the test section, and the minimum run length is given by:

$$x_2 - x_1 > 1.5L_{\mathrm{WL}} \qquad (3)$$

where $L_{WL}$ is the model waterline length.

2.1.3 Resistance tests in Intact and Pre-sawn Level Ice




| | |
|---|---|
| $w$ | channel width (m) w=B +α $h_I$ |
| $B$ | ship breadth (m) |
| $\alpha$ | 2 to 3 |
| $h_I$ | ice thickness (m) |

Figure 5: An example of pre-sawn cutting pattern

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 5). Once those forces are measured, the breakdown ice resistance components addressed in Equation (4) can be identified.

$$\begin{aligned} R_{IT} &= R_{br} + R_c + R_b + R_{IW} \\ R_I &= R_{br} + R_c + R_b \end{aligned} \qquad (4)$$

where,

| | |
|---|---|
| $R_{IT}$ | total resistance in ice (N) |
| $R_{br}$ | resistance due to breaking the ice |
| $R_c$ | resistance due to clearing the ice |
| $R_b$ | resistance due to buoyancy/static clearing the ice |
| $R_{IW}$ | water resistance in ice conditions |
| $R_I$ | 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 the 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 (4), and all components will be determined.

## 2.2 Analysis of results

### 2.2.1 Analysis of Tests in Intact Level Ice

The net ice resistance is defined as the difference between the total resistance in ice and the open water resistance, for the same speed:

$$R_I = R_{IT} - R_{IW} \tag{5}$$

where $R_I$ is the net ice resistance and $R_{IW}$ the water resistance in ice conditions. This quantity should be determined as per *ITTC 7.5-02-02-01 Resistance Test*. It should be noted that there is practically no wave-making component in water resistance when the model is moving in ice conditions.

The difference between the total and net ice resistance is small at low speeds, but may be significantly larger for higher speeds.

2.2.1.1 Correction to target ice conditions

The ice resistance tests commonly have a target ice flexural strength and ice thickness; both are design parameters of the vessel. The actual ice properties, measured according to *ITTC 7.5-02-04-02.1 Test Methods for Model Ice Properties*, may deviate from the target values of the ice thickness or strength. Therefore, the experimental results need to be modified by corrections unless using non-dimensional coefficient methods.

The test data correction methods described below primarily refers to towing tests in level ice.

The test results are usually corrected in terms of ice thickness, ice flexural strength and the ice-hull friction coefficient. The range of applicability for the corrections is to be determined by each model test basin individually.

2.2.1.2 Correction of minor deviations in ice thickness.

The following formula shall be used to correct the ice resistance for ice thickness deviations:

$$R_I = R_{I,\text{meas}} \left( \frac{h_{I,\text{target}}}{h_{I,\text{meas}}} \right)^x \tag{6}$$

where,

| | |
|---|---|
| $R_{I,\text{meas}}$ | measured ice resistance, |
| $h_{I,\text{meas}}$ | measured ice thickness |
| $h_{I,\text{target}}$ | target ice thickness, |
| x | correctional exponent. |

The exponent in Equation (6) may typically vary within 1.0 and 2.0. The definite value of the exponent needs to be determined by each individual model test basin.

If the ice resistance is measured in two clearly different ice thicknesses, the exponent may be calculated as:

$$x = \frac{\ln\left(\frac{R_{I1}}{R_{I2}}\right)}{\ln\left(\frac{h_{I1}}{h_{I2}}\right)} \tag{7}$$

where,

| | |
|---|---|
| $R_{I1}$ | ice resistance obtained in ice field thickness of $h_{I1}$, and |
| $R_{I2}$ | ice resistance obtained in ice field thickness of $h_{I2}$. |

The resistances $R_{I1}$ and $R_{I2}$ are found at the same towing speed of the model and ice strength of the ice sheet.

2.2.1.3 Correction of minor deviations in flexural strength

The classic way to do the corrections is to use a component breakdown of the ice resistance:

$$R_I = R_{br} + R_R \tag{8}$$

where,

$R_{br}$ ice breaking resistance component, which is associated with the mechanical failure of the ice and

$R_R$ rest resistance which contains i.e. submerging, clearing, etc.

$R_{br}$ component can be determined in pre-sawn ice (please see 2.1.3). When $R_{br}$ is found Equation (8) can be rewritten as follows:

$$R_I = R_R + \frac{\sigma_{f,\text{target}}}{\sigma_{f,\text{meas}}} R_{br} \quad (9)$$

where $\sigma_f$ is the ice flexural strength.

2.2.1.4 Friction coefficient correction.

Allowance for friction coefficient is usually introduced for the net ice resistance with the formula:

$$R_{I,corr} = C_{sf} R_I \quad (10)$$

where $C_{sf}$ is the friction correction coefficient.

As each model basin is using different coatings resulting in different ice-hull friction, individual correction coefficients have to be determined / applied.

2.2.2 Analysis of Tests in Intact and Pre-sawn Level Ice

The resistance components in Equation (4) may be made non-dimensional form based on model beam, model speed, model draft, ice thickness, ice flexural strength and ice/water density. The non-dimensional coefficients of each resistance components with ice strength number and ice Froude number are used to determine the factors and exponents of a resistance prediction equation to obtain the net ice resistance.

The advantage of this method is to identify the influence of each component such as breaking term, dynamic and static clearing terms on the net ice resistance. It also provides the net ice resistance prediction for a range of flexural strength, ice thickness, ice density and ship speed. This method, however, does not include a friction term so the friction correction should be done differently. Detailed equations and procedures are addressed in 28th ITTC 2017 final report.

### 2.3 Full scale extrapolation

Finally, the extrapolation from the model scale net ice resistance to full scale is achieved by applying Froude scaling according to Equation (11):

$$R_{I,p} = \lambda^3 R_I \quad (11)$$

where $R_{I,p}$ is the full-scale ship resistance and $\lambda$ is the scale factor.

## 3. REQUIRED TEST DOCUMENTATION

### 3.1 Ice parameters to be measured

- Ice thickness
- Elastic modulus
- Flexural strength
- Friction coefficient
- Ice/water density

### 3.2 Experiment setup

- towing arrangement
- measurement equipment

### 3.3 Experiment results

- Towing velocity
- Towing Force

## 4. BENCHMARK TESTS

Report of Committee on Ships in Ice Covered Water (16th ITTC 1981 pp. 363-372). Catalogue of Available Model and Full Scale Test Data (16th ITTC 1981 pp. 370-371)

a) Standard Model Tests (17th ITTC 1984)
b) Model Tests with R-Class Icebreaker
c) Propulsion Tests
d) Full Scale Prediction

Reanalysis of Full Scale R-Class Icebreaker Trial Results (18th ITTC 1987 - pp.528-531) to Get Reliable Full-Scale R-Class Data CCGS "Pierre Radisson“ and CCGS “Franklin“

Retest of R-Class Icebreaker Model at a Different Friction Level (18th ITTC 1987, pp.532-543)

a) Resistance Tests (18th 1987 pp.532-540)
b) Self Propulsion Test (18th ITTC 1987 pp.540-543)

Comparative Test Program with R-Class Model (19th ITTC 1990 pp.526-531)

Comparative Test Program with Basic Off shore Model Structure (19th ITTC 1990 pp.534-540) and Basic Cylinder Tests (20th ITTC - 1993 pp.470-481)

Repeatability Tests for Quality Control (20th ITTC 1993 pp.488-490)