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Resistance Test in Level Ice

1. PURPOSE OF PROCEDURE

The main reason for the towed resistance tests for ships in level ice is to determine the effectiveness of the hull-form in breaking ice and progressing through it. The specific results from these tests include:

- Ice resistance at certain speeds and ice thickness
- The ship performance diagram (i.e. speed versus ice thickness)
- Limiting ice thickness for a continuous motion.

2. ICE RESISTANCE TESTS IN LEVEL ICE

Ice resistance tests are not always sufficient for the above tasks and additional propulsion tests are required. The propulsion tests, described in procedure 7.5-02-04-02.2, are needed to obtain a more complete view of the ship’s performance in ice. However, the level ice resistance remains the basic element in describing the ship operability in ice.

The ice resistance tests may be carried out either by towing the model with a constant towing force or at constant speed through ice. The use of constant force is more realistic in view of the constant thrust given by the propeller in full scale. The constant force tests are very difficult to perform and are susceptible to vibrations in the towing system originating from the variation in ice resistance due to the breaking pattern of ice. Also the speed cannot be set exactly in advance in constant force tests. For this reason the constant speed test is the common ice resistance test. When performing constant speed tests, a counterweight is sometimes used in order to keep the towing wire in tension.

There are four forces acting on the model (Fig. 1). The use of the counterweight eliminates oscillations of the model in the ice-free areas where the resistance is very low. The total resistance of the vessel is:

$$R_{IT} = F_x - W \tag{1}$$

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

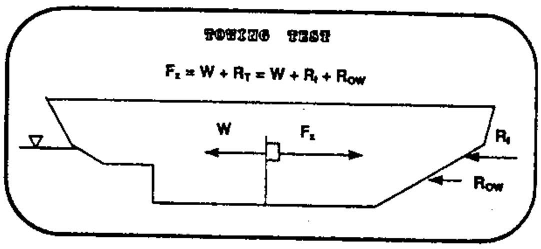

Fig. 1 Forces acting on a model in a resistance test.

The towing method and arrangement should be recorded to ensure a repeatability of the tests. The parameters which need to be measured in an ice resistance test, with their associated priority, are given below.

The velocity of the model and the towing force are the main parameters and the main result from a resistance test. When reporting ice resistance model tests, the entire instrumentation should be described. The digital sampling rate should be high enough to capture variations in ice breaking.

The total ice resistance is defined as the time average of the longitudinal force resisting the forward (or astern) motion of the ship, see Fig. 2:

$$R_{\mathrm{IT}} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} F_x(t)\,dt \qquad (2)$$

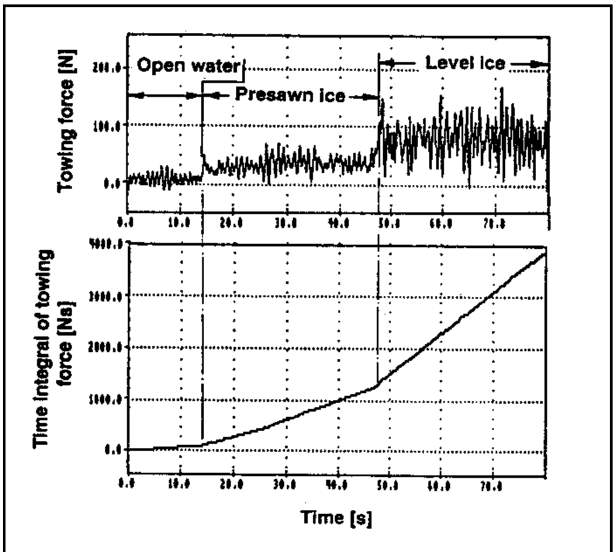

Fig. 2 The measured towing force and its integral

Due to the quasi-steady nature of ice resistance, the time interval has to be long enough. The time when the test begins should be the time when the aft end of the vessel enters the level ice sheet. The integral of the towing force is a straight line when the resistance does not include any transient effects.

Usually, it is recommended to allow the ship to proceed at least two ship lengths in level ice of uniform thickness to get a reliable resistance value. Therefore the above time dependent equation can be presented in a distance dependent form

$$R_{\mathrm{IT}} = \frac{1}{x_2 - x_1} \int_{x_1/\mathrm{v}}^{x_2/\mathrm{v}} F_x\left(\frac{x}{V}\right) dx \qquad (3)$$

where V = the towing speed.

The conventional rule (rule of thumb) for the minimum test length is:

$x_2 - x_1 > 2L_{\mathrm{WL}}$.

The total ice resistance is divided into components for the purposes of correcting small deviations of ice parameters from the target values. The net ice resistance is defined as the difference between the total ice resistance and the open water resistance, for the same speed:

$$R_{\mathrm{I}} = R_{\mathrm{IT}} - R_{\mathrm{OW}} \qquad (4)$$

The difference between the total and net ice resistance is small in low speeds but increases very quickly with increasing speeds. Therefore, at higher speeds the difference between total and net ice resistance can be substantial. Note that sometimes the open water resistance is determined in the track left in ice when the broken ice pieces are removed from it. In this case, the surrounding ice influences the resistance and the resistance is called, resistance in ice free water. This resistance differs from open water resistance, but the distinction is small and usually can be ignored.

Often the velocities used in ice model tests are low, and consequently, the open water resistance is low. In this case, wave-making resistance is small, and the open water resistance can be as approximated by the viscous drag. Sometimes, the open water resistance is measured in the ice-free section before the model enters the ice. This method should be avoided if the speed is high enough to make wave-making resistance noticeable.

The ice resistance tests commonly have a target ice flexural strength and ice thickness; they are design parameters of the vessel. The model ice preparation process may result in small deviations from the target values of ice thickness or strength. The results obtained from the slightly different ice sheet are then corrected to the target values. A relationship for ice resistance, ice thickness and ice strength is available. Some tanks use for the ice thickness correction the following simple equation:

$$R_{\mathrm{I}} \approx H_{\mathrm{I}}^{1.5} \qquad (5)$$

Another methodology to obtain corrections is to assume that the ice resistance is dependent on the strength and the thickness of the ice:

$$R_{\mathrm{I}} = a(\mathrm{v})\sigma_i H_{\mathrm{I}}^2 + b(\mathrm{v})\rho_i H_{\mathrm{I}}.$$

(6)

where the speed dependent constants (a and b) are determined by regression analysis.

Similar equations have been presented (see e.g. Alekseev & Sasonov 1994) but the drawback of these methods is that usually not many measurement points are available. Some insight into the parametric dependence is usually required.

The classic way to do the corrections is to use a component breakdown of the ice resistance. (Jones & al. 1994, Riska & al. 1994, Izumiyama & Uto 1995)

$$R_{\mathrm{I}} = R_{\mathrm{B}} + R_V \qquad (7)$$

where R_{B} is the breaking component and R_V is usually termed as the speed dependent part of the ice resistance. This division is not strictly correct, as the breaking part is also somewhat speed - dependent. Further, the speed dependent part is sometimes divided into submergence part and frictional part. A better way to do the division could be given by the division into components due to tangential and normal forces but this has not been widely applied yet.

The breaking component can be determined by means of a test in presawn ice. In this type of test ice is cut beforehand in a similar pattern as can be observed in the level ice test. This way R_{B} is eliminated from the total resistance, and therefore, R_{B} can be defined as the difference between the resistances measured in level ice and in the presawn ice, for the same speed:

$$R_{\mathrm{B}} = R_{\mathrm{IT.levelice}} - R_{\mathrm{IT.presawnice}} = R_{\mathrm{I}} - R_{V.} \qquad (8)$$

The speed of the model was considered constant in all of the above equations (3.3 to 3.8). If tests in level ice and presawn ice are performed at several speeds, the effect of speed on R_{B} can be determined. Two speeds in presawn ice suffice as the resistance in presawn ice may be considered linear with speed Fig. 3 shows that $F_H = V/\sqrt{gH_{\mathrm{I}}}$.

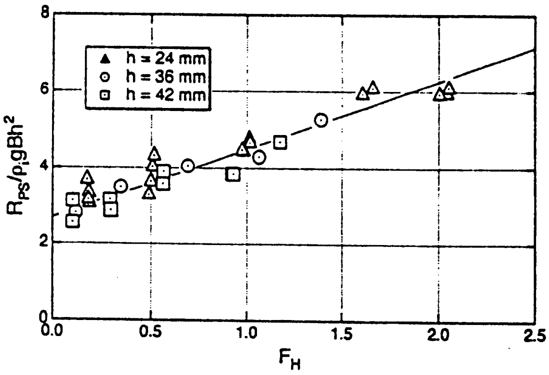

Fig. 3 The resistance in presawn ice versus the ice thickness based Froude Number.

The pattern of ice pieces in the presawn ice field should resemble the real breaking pattern. Some compromises are, however, usually made and a typical pattern shown in procedure 7.5-02-04-02.2. The centreline of the model should coincide with the centreline of the presawn ice field. The recommendation for the length of the presawn area is the same as for the level ice section. It is important that the presawn area is slightly broader than the waterline breadth of the model ship. The breadth of the presawn area may be defined by the formula:

$$B_{\mathrm{PS}} = B_{\mathrm{WL}} + nH_I \tag{9}$$

where the constant n should be between 3 and 4. If the air temperature is below the freezing point, or the ice is very cold, the ice pieces may freeze together. Therefore it is important to minimise the time lag between the tests and preparation of the presawn field.

An adjustment (correction) of the results to the targeted ice strength and ice thickness may be needed. The ice resistance is assumed to depend on the ice thickness according to a power law. Thus the corrected resistance is:

$$R_{\mathrm{I}} = R_{\mathrm{I,meas}} \left(\frac{H_{\mathrm{I}}}{H_{\mathrm{I,meas}}} \right)^x \tag{10}$$

where the exponent depends on the hull shape and the model ice. In most cases, x=1.5 to 2.0. If the ice resistance is measured in two clearly different ice thicknesses, the exponent can be calculated as:

$$x = \frac{\ln\left(R_{\mathrm{I2}}/R_{\mathrm{I1}}\right)}{\ln\left(H_{\mathrm{I2}}/H_{\mathrm{I1}}\right)} \tag{11}$$

Experience has shown that the exponent may be different in level ice and in presawn ice.

Moderate deviations in ice flexural strength from target values can be corrected by assuming that the breaking resistance depends linearly on the flexural strength. Thus, the final corrected ice resistance is:

$$R_{\mathrm{I}} = \left(R_{V,\mathrm{meas}} + R_{\mathrm{B,meas}} \frac{\sigma_{\mathrm{f}}}{\sigma_{\mathrm{f,meas}}} \right) \left(\frac{H_{\mathrm{I}}}{H_{\mathrm{I,meas}}} \right)^x \tag{12}$$

Finally, the extrapolation from model scale results to full scale is achieved by the formula:

$$R_{\mathrm{I,p}} = \lambda^3 . R_{\mathrm{I}} \tag{13}$$

where λ is the geometric scale factor and the subscript p refers to the prototype.

The friction coefficient is important for the ice resistance. If the surface treatment of the model does not result in a desired friction between the model and the ice, some further corrections are needed. The best correction is to repaint the model to the desired surface roughness. However, if the difference between the measured friction coefficient and the target value is small, instead of a new surface treatment, a friction correction coefficient may be applied. The friction coefficient may be taken into account by the following equation:

$$R_{\mathrm{I,corr}} = C_{\mu}.R_{\mathrm{I,p}} \tag{14}$$

The friction correction coefficient can be based on the coefficient of the measured model ice friction and a comparison between full-scale tests results and model tests with different model/ice-friction coefficients.

Actual test results (Fig. 4) can be used to derive the friction correction coefficient. If the correction is assumed to be linearly proportional to the coefficient of friction, then from Fig. 4 the following formula is obtained:

$$\frac{\lambda^3 R_{\mathrm{I,m}}}{R_{\mathrm{I,p}}} = \frac{1}{C_{\mu}} = a + f_{\mathrm{ID}}.b \tag{15}$$

where f_{ID} is the dynamic model ice friction coefficient and a and b are empirical coefficients (From Fig. 4, a = 0.8 and b = 5.8). This formula is valid for a new ship with a hull surface in good condition.

Resistance tests can be performed with or without appendages, but in the former case all appendages have to be mentioned (reported). If consecutive tests are performed, it is recommended to remove all ice pieces that are remaining under the model before the next test. Ice removal is impossible, if the tests are run by increasing the speed stepwise. In some cases large ice floes, resulting especially from low speed tests, may get trapped (e.g. between two rudders) and may cause additional resistance. If this kind of situation has taken place, it should be reported.

The above equations present just one type of correction procedure, which is based on the division of resistance in ice into different components. As long as no ideal model ice material exists, some kind of correction methods is needed to handle the differences between measured and target values of ice thickness, flexural strength, buoyancy and other parameters that are substantial in ice breaking. If any kind of data correction method is used, it is very important to present the detailed principles of the method.

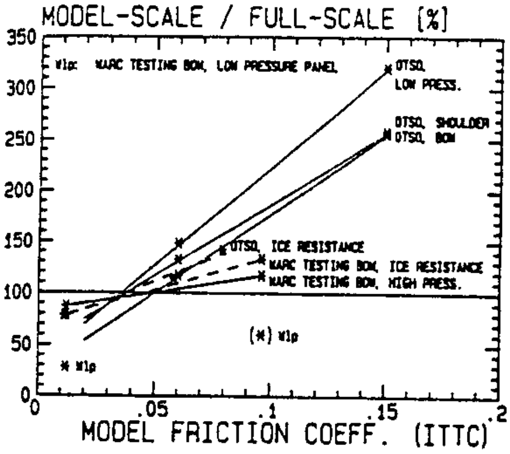

Fig. 4 The ratio between extrapolated model scale ice resistance and measured full scale ice resistance plotted versus the coefficient of friction in model scale (Liukkonen 1989).

3. PARAMETERS

3.1 Ship model parameters

Parameter	Priority
Towing velocity	1
Type of restraints	1
Towing Force	1
Location of towing point	1
Pitch angle	2
Roll angle	2
Heave	2
Natural frequency of the towing system	2

3.2 Ice parameters to be measured

Parameter	Priority
Ice thickness	1
Broken channel width	1
Piece size, breaking pattern	1
Model ice type	1
Elastic modulus	1
Flexural strength	1
Compressive strength	1
Underwater photography	1
Ice density	1
Ice crystal structure	2
Fracture toughness	2
Water density	2

4. VALIDATION

4.1 Uncertainty Analysis

See ITTC Procedure 7.5-02-04-02.5.

4.2 Benchmark Tests

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

(2) 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“

(3) 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 1987 pp.540-543)

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

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

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

5. REFERENCES

Alekseev & Sasonov 1994: An Investigation into the Effects of Ice Cover Parameters upon Ship Resistance. Proc. of POLARTECH 94, 22-25 March, 1994, Lulea, Sweden pp 49-55.

Izumiyama & Uto 1995: Ice Resistance of Three Bow Forms for the NSR Cargo Ship. Proc. of INSROP Symposium, Tokyo 95: 1-6 Oct. 1995, Tokyo, Japan

Jones & al. 1994: Icebreaking Performance from Model Scale Tests. Proc. of ICETECH 94, paper H, SNAME, Calgary, March 1994

Riska & al. 1994: Assessment of Ice Model Testing Techniques. Proc. of ICETECH 94, SNAME, Calgary, March 1994