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SHIP MODEL TESTING IN ICE. POSSIBILITIES AND RELIABILITY

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1 BACKGROUND

The formulation of the model scale laws about a hundred years ago led to dramatic advances in the modelling of ship movement in open water. The first attempts to elucidate the problems of navigation in ice-covered waters were made at about the same time, but, since navigation in ice was necessary only in limited areas, the need for ship model testing in ice was not particularly urgent.

Today, the world-wide shortage of energy and raw materials has increased the importance of the oil, ore, etc. stored near the polar regions of the earth, and the necessity of transporting these materials through icy waters has created a new demand for ice-going ships.

The greater number of ships required for ice-covered waters will obviously increase the need for model testing; the technical problems connected with navigation in different types of ice fields cannot be solved by full-scale tests alone, since this would be far too expensive and time-consuming.

The first succesful attempt to simulate natural sea ice in a laboratory for ship model tests was made at the Arctic and Antarctic Scientific Research Institute (here abbreviated as AAI) in the U.S.S.R. in the fifties of this century. The Russian scientists employed so called "high salinity" model ice for scaling the properties of sea ice. Attempts to simulate sea ice with wax or other artificial materials have so far been unsuccessful.

Since the pioneering work at AAI, three more laboratories have been built for testing the behaviour of ships and other semisubmersible icebreaking structures in various ice conditions. The laboratories and their dimensions are shown in fig. 1.

Some other institutes have occasionally performed ship model tests in ice but only the laboratories which have concentrated upon ship research are included here.

This paper will deal with model tests performed in laboratory ice in general, and in particular with the testing and analysing methods and the progress made at the research institute represented by the author, the Wärtsilä Icebreaking Model Basin (WIMB) of the Wärtsilä Helsinki Shipyard, Finland.

Attention will be restricted to the mobility of ships in ice-covered waters, i.e. to the resistance offered to ships by various ice formations. The present work at WIMB does not include the investigation of the effect of ice loads on ship structures.

2 SCOPE OF THE TASK

The aim of the tests is to investigate the performance of all kinds of ice-going ships in all ice conditions permitting navigation. In addition to natural ice conditions, some "artificial" conditions must be considered, such as a channel broken by an icebreaker etc. The work can be divided into three parts, which can be performed independently of each other.

2.1 Definition of ice conditions

There are countless different types of ice cover and also countless different parameters determining the prevailing conditions. The definition of ice conditions is not usually made by naval architects but by geophysicists, who are interested in ice as a material but not in its effect on ships, so that ice formations are seldom considered from the point of view of ship-ice interaction. Ice conditions are also often difficult to observe, as in most ice formations the most interesting part lies below the surface of the water.

The Soviet scientists (ref. 3) define ice conditions that are difficult to determine by a "ball scale". This is justifiable as a first attempt to assess the conditions in some way but it does not give a quantitative determination. The next step will be to define the conditions by means of certain physical variables as exactly as in the case of level ice.

An example of a certain kind of ice cover is shown in fig. 2, in which ridges are photographed above the water level. This ice looks "rather smooth" and easy to penetrate above the water level, but blocks of ice may extend to a depth of 20-30 m below the ice surface, pressing together to form a very serious obstacle to navigation.

2.2 Modelling the ice conditions

The lack of satisfactory definitions of ice conditions in nature makes it impossible to model them completely. It is also difficult to simulate exactly certain situations existing in nature. For example level ice with a snow cover, which is certainly one of the simplest conditions, cannot be simulated completely, and even greater difficulties are encountered in modelling more complicated conditions. A further problem is the choice of parameters, which should give as accurate a description as possible of the ice conditions involved, and also be satisfactory from the point of view of the influence exerted on the progress of the ship. Fig. 3 shows an underwater picture of a simulated ridge.

2.3 Modelling of ship-ice interaction

The final task, after the desired ice conditions have been satisfactorily defined and simulated in the laboratory is to model the ship and simulate its movement in such a way that the desired measurements can be made, and that they can be scaled reliably up to ship size.

The complete modelling of ship behaviour in open water ("open water" = ice-free water) has not been achieved, and the various components of resistance must be determined in different ways, by tests (residuary resistance) or calculations (frictional resistance).

Since complete scaling is not possible for ships in open water it is improbable that it can be accomplished for ships in different types of ice, where the conditions are much more complicated.

We can be satisfied that the scale laws have now been found out (ref. 3), and that we have arrived at the point reached a century ago for ship model testing in open water.

3 PARAMETERS INVOLVED

The problems encountered here will often be compared with those experienced in modelling ships in open water because there are certain similarities between the tests in these two different environments.

The parameters can be divided into three groups:

- ship parameters
- environmental parameters, i.e. parameters defining the type of ice cover
- "intermediate parameters".

3.1 Ship parameters

This group of parameters is essentially the same for navigation in ice-covered waters as for navigation in open water. However, the parameters, which have the greatest influence on resistance are somewhat different. According to ref. 7, the following parameters are the most important for the resistance encountered in level ice:

- Ship beam, especially maximum beam at actual waterline
- Ship length, especially length of entrance and parallel middle body
- The form of the fore body, represented by the slope of the waterlines, buttocks (including stem), frames etc. is of great importance.

- Ship draught and trim. Owing to the limited amount of test results, the influence of these parameters is not well known.
- The dimensions and form of the afterbody have less significance in forward motion than the other parameters listed above.

3.2 Environmental parameters

The parameters chosen are those that represent as adequately as possible the properties of a certain type of ice formation, and that influence the progress of the ship. For practical reasons, it is desirable to define the ice properties with as few parameters as possible, only the most important being chosen from the countless variables involved. Some of the environmental parameters are:

- ice thickness or thickness of ice blocks
- ice strength
- ice elasticity
- ridge depth
- depth of snow cover
- ice coverage (for example in clogged channel).

Naturally, none of these parameters need be considered in open water tests.

3.3 "Intermediate parameters"

There is also a group of parameters with an intermediate position between the ship and environmental parameters. This group comprises ship speed and the friction properties between the ice and the surface of the ship or model. Usually these properties are described with a dynamic friction coefficient.

4 THE WÄRTSILÄ ICEBREAKING MODEL BASIN

The model basin is a department of the design drawing office of Wärtsilä's Helsinki Shipyard. The shipyard is especially known for the design and production of icebreakers of many different types. The opportunity to use full-scale trials in ice with ships built by the shipyard as a source of feedback is a great advantage for the research department.

4.1 Data on model basin

The model basin has been in operation about 3 1/2 years. Some technical data on the tank and instrumentation:

- main dimensions as in fig. 1
- normal freezing cycle, one ice cover per day
- maximum ice thickness 65 mm
- windows for underwater observation
- salinity of water normally 10-20 $^{o}/oo$
- the scales used range from 1:5 to 1:50. The upper limit for the model beam is about 1.2 m.

About 230 ice-fields can be frozen and broken in one year.

Fig. 4 shows the general arrangement of the laboratory, which was constructed in a former air-raid shelter. Fig. 5 gives a general view of the basin.

4.2 Range of possible test conditions

The following ice conditions and types of tests are possible in WIMB today.

Ice conditions:
- level ice
- ice ridges
- broken channel

The extension of the range of ice formations would necessitate the collection of detailed data on the corresponding conditions in nature.

Types of tests:
- towing tests at constant speed
- towing tests at constant force
- self-propulsion tests
- starting and backing (extraction) tests
- manoeuvring tests
- tests of the effect of special devices, such as bow screws, pitching systems, the Wärtsilä Air Bubbling System.

4.3 Measurements and treatment of test results

During the tests measurements of the following can be recorded:

- towing force
- acceleration in longitudinal and vertical directions
- pitch in bow and stern
- model speed
- propeller revolutions
- rudder angle
- measurements relating to the special devices.

The properties of the ice, i.e. thickness, strength, elasticity and salinity will be measured for each ice field. Since the measured ice resistance values have a relatively large scatter, there is no sense in treating the measured points individually, and an average expression should be calculated. An example of the variation in the measurements of towing force is given in fig. 6.

The total ice resistance in level ice is divided into three components: those relating to the breaking of ice and the submersion of broken blocks, and a velocity-dependent component. All the components include friction. The separate components must be known for the conversion of the model values to full-scale resistance in natural sea ice.

The results are scaled up to ship size according to the scale laws presented in refs 1 and 3. The following points may be noted:

1. Since pure ice resistance is treated, the open-water resistance measured in WIMB is subtracted from the measured total resistance.

2. In the calculation of the breaking resistance, which is dependent on the strength of the ice, a correction must be made for the difference in the properties of natural sea ice and model ice. The elasticity of the "high salinity" model ice is too low, when its strength is in scale, so that, when scaled to ship size, the energy for breaking the model ice is much higher than that required for breaking sea ice (fig. 7). The correction is made by multiplying the upscaled breaking component with a constant which takes into account the difference in ice properties.

It is this difference in ice properties that necessitates separate tests for determining the different ice resistance components.

This correction is necessary only for ice conditions in which breaking occurs.

Ref. 8 presents a new method developed by Soviet scientists to improve the properties of model ice so that this correction becomes unnecessary.

3. The results from model tests will correlate with full-scale measurements if the surface of the model is treated in a certain way, giving a certain friction coefficient between the ice and the model surface. The treatment of the surfaces of the models at WIMB has been chosen so that model tests give resistance values equal to the full-scale measurements for certain "calibration ships" used by the yard in both full-scale and model tests. The friction coefficient used to obtain the correct full-scale values is found empirically and thus the roughness of the ship surface is not scaled down to the model.

4.4 Test series performed at WIMB

The most significant test series performed at WIMB are those relating to:

- the Esso Arctic tanker designs
- five ships for the calibration of the analysing methods
- nine hull forms of Great Lakes bulk carriers. This series was ordered by the U.S. Maritime Administration, and was the first ice resistance test series with systematically varying parameters (fig. 8).
- three hulls for the German EOS study
- two hulls for Imperial Oil Ltd, Canada.

Most of the tests have been resistance tests in level, snow-free ice, an ice cover that seldom occurs in nature. Correspondingly, in open water research, tests are mostly performed in still water, although the sea is seldom completely calm.

In addition to these test series, tests have been undertaken to investigate the performance in ice of single ships or to examine the effect of some special device intended to improve icebreaking performance.

5 FULL-SCALE TRIALS

Full-scale measurements made during ship trials in ice (figs. 9 and 10) are, of course, essential for full-scale predictions based on model tests. These empirical data are used to obtain the empirical coefficients employed in the predictions. Empirical coefficients are still in use today in predictions of open water resistance, and the complexity of the icebreaking process makes them even more important for ice resistance predictions.

Today WIMB has the necessary full-scale resistance data for 6 different types of ships tested in the laboratory. Most of the data are from tests in level ice but some measurements have been made in ridges, too. If next winter (1973-74) is suitable for ice trials in the Baltic 4 new types of vessels will be tested in level ice and some of them will also be tried in ridges and clogged channels. In addition, some special devices and the influence of the quality of the hull surface will be tested.

Progress in ice model testing is closely dependent on the amount of full-scale data available. The store of full-scale measurements can be built up only very slowly; during the winter icegoing ships are seldom available for tests as they are generally required throughout the season for their usual duties. There are also very mild winters, like winter 1972-73, when it is impossible to perform useful trials in the areas in which the ships normally run.

6 RELIABILITY OF MODEL TEST RESULTS

The value of the work performed in a model basin is naturally largely dependent on the reliability with which full-scale predictions can be made from the model-scale measurements.

6.1 Full-scale - model-scale correlation

Experience gained from comparisons between full-scale and model-scale results shows that a value of about 0.3 should be taken as the dynamic friction coefficient in predictions of resistance in level ice. The friction coefficients were obtained from measurements made by the standard method of WIMB (ref. 1); the testing methods are known to influence the values obtained. The comparison between full-scale and model-scale results was made using five ships of different type ranging from a small tug to a large cargo ship.

The beam of the models used for determining the friction coefficient for the full-scale prediction ranged from 0.825 to 1.18 m and the scale factor ranged from 1:5 to 1:50.

Experience from tests with models of different size - beam 0.4 - 1.2 m - has proved that the larger model the better are the results and the smaller the scatter. In WIMB the most suitable model beam range is 0.8 to 1.2 m. The beam is the most important main dimension of a ship from the point of view of ice resistance and can thus suitably be used to determine model size and scale.

The following two examples of the model-scale - full-scale correlation from tests in level ice may be given here:

- Icebreaker of Moskva type.

The full-scale measurements made at AAI in the U.S.S.R. (ref. 4) and at WIMB (ref. 9) correspond well to the predictions based on model-scale measurements (fig. 11). It should be noted that two different ships of this type were used in the full-scale tests. Nothing is known regarding possible differences in the quality of their hull surfaces, but both the ships were fairly new at the time of the tests (ref. 5).

- Two small cutters.

These tests gave a very interesting illustration of the influence of the quality of the hull surface on ice resistance (fig. 12).

Ship No. 1 was in service for its first winter; a friction coefficient slightly above 0.3 gives good correlation between its results and those of the model tests. The main dimensions and body form of ship No. 2 were the same as those of ship No. 1, with a few small, insignificant exceptions, but it was nine years old when tested. The ice resistance of the older ship is almost double that of the newer one (ref. 6).

Other results also indicate the importance of surface smoothness. Fig. 13 shows the level-ice resistance encountered by a small icebreaking tug with a) a normal ship steel surface and b) the fore body covered with stainless steel plates. The difference is large and increases with decreasing speed. Since friction, and thus the ship age, seem to be very significant, the quality of the hull and the model surface are variables that must be taken into account.

In open water, there is no economic reason for attempting to reduce resistance by using a material smoother than normal painted ship steel. In ice the friction seems to be of such importance that it might be economically sound to cover the ship hull with a particularly smooth, hard-wearing material, or to manufacture the whole hull from a material with a smoother surface than normal ship steel has.

The importance of friction is illustrated by fig. 14, which shows its influence in model tests. Fig. 15 presents photos of the surfaces of some ships, all taken of the ice belt in the fore body.

Comprehensive investigations are in progress at WIMB in respect of the influence of friction and materials suitable for improving the surfaces of existing ships and newbuildings.

6.2 Scatter in model test results

The relatively large scatter in model test results is mainly due to the nature of the icebreaking process. This process is not stationary, as is the case in open water; the breaking of the ice blocks occurs discontinuously and irregularly, owing to the heterogeneity of the ice. If absolute homogeneity could be achieved, which is impossible, even in the laboratory, the process would still not be stationary although periodical and thus regular.

An example of the scatter of the test results is shown in fig. 16. In this case the scatter increases with increasing speed. The magnitude of the total scatter is ± 10 %.

Owing to the scatter, replicate tests are necessary.

7 SUMMARY

The number of model basins for testing ships in ice has increased sharply within the last four years.

Owing to the global shortage of raw materials, access must be obtained to areas lying beyond ice-covered waters, and navigation in ice may be expected to increase rapidly. Model tests are necessary for investigating the icebreaking properties of the ships, discovering the optimum hull form and developing special devices for reducing ice resistance.

Many difficulties are encountered in the simulation of ice conditions, and it is not yet possible to simulate all the existing types of ice cover. These limitations must be kept in mind when a test series is planned.

Owing to the great quantity of parameters involved, and the relatively large scatter of the test results, the advances made in the field of ice resistance research cannot yet be considered comparable to those in open water research. Progress in ice model testing is slowed down by the time needed for freezing and the limited opportunities for checking the results with full-scale tests.

At present, ice resistance in level ice can be predicted satisfactorily by means of model tests, whereas prediction under other ice conditions is hampered by the lack of full-scale measurements. The greater the number of full-scale trials, the more reliable will be predictions based on model tests.

It is now time to begin systematic tests, instead of studying particular cases, e.g. a certain ship in a certain type of ice cover. The first attempt at this was made when nine icebreaking ore carrier hulls were tested in WIMB for the U.S. Maritime Administration (ref. 2).

Testing in ice is expensive compared with corresponding testing work in open water, although simpler and cheaper testing methods will be developed.

Today there is no regular communication between the laboratories listed in fig. 1. It would be desirable for persons engaged in ship-ice research to have opportunities to get together at smaller, more intimate, meetings than those arranged by POAC. Which of the possible organizations listed below would be able to take charge of the item "Ship Model Testing in Ice"?

POAC	Port and Ocean Engineering under Arctic Conditions
IAHR	International Association for Hydraulic Research
ITTC	International Towing Tank Conference
? ?	International Conference for Ship Model Testing in Ice, a new organization

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4. Kashteljan, V.I., Ryvlin, A.Ja.: "The Influence of Natural Characteristics of Solid Ice in Evaluation of its Resistance

to Icebreaker Passage". Problemy Arktiki i Antarktiki. Vol. 22, p. 75 (1966).

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6. WIMB Test Report No. A 25, 1973. Unpublished.

7. Soininen, H.: "Analysis of Certain Ship Model Tests in Ice" (in Finnish). Helsinki University of Technology 1973. (Thesis under the supervision of prof. V. Kostilainen).

8. "Icebreaking Properties of Ships" (in Russian). Trudy. Vol. 309. Gidrometeoizdat. Leningrad 1973.

9. WIMB Report No. B 2. "Report on Full Scale Icebreaking Tests with Varma and Vladivostok on the Gulf of Finland, March 1969". Unpublished.

BUILT IN	LOCATION	OWNER	LENGTH (m)	WIDTH (m)	DEPTH (m)
1955	LENINGRAD USSR	ARCTIC AND ANTARCTIC SCIENTIFIC RESEARCH INSTITUTE	13.4	1.85	1.1
1969	HELSINKI FINLAND	WÄRTSILÄ HELSINKI SHIPYARD	50	4.8	1.15
1970	COLUMBIA USA	ARCTEC INC.	18.3	2.4	1.2
1971	HAMBURG W-GERMANY	HAMBURGISCHE SCHIFFBAU-VERSUCHSANSTALT	30	6.0	1.2

Fig. 1. List of ice model basins.

Fig. 2. Ice ridges above water level.

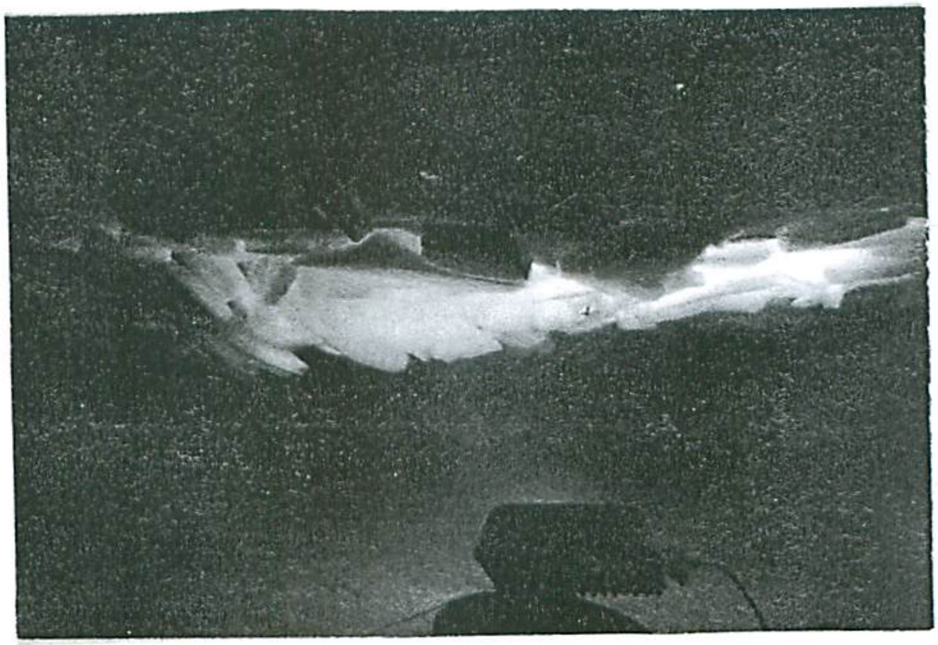

Fig. 3. Underwater photograph of a simulated ridge.

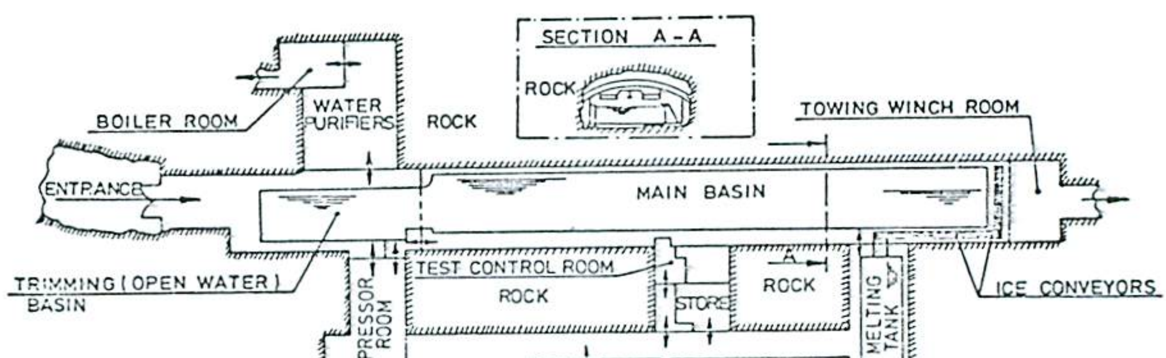

Fig. 4. General arrangement of the Wärtsilä Icebreaking Model Basin (WIMB).

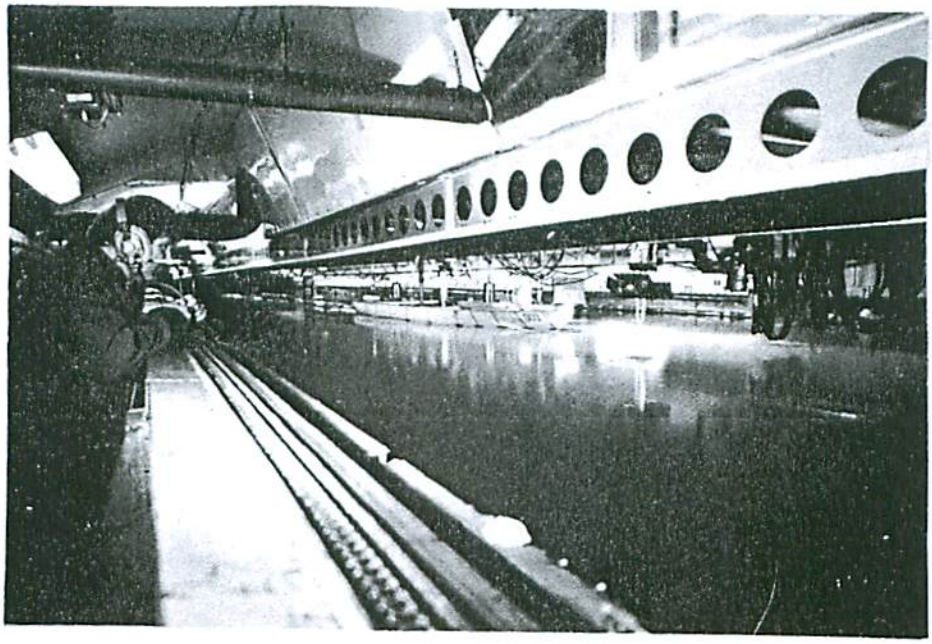

Fig. 5. A general view of the Wärtsilä Icebreaking Model Basin (WIMB).

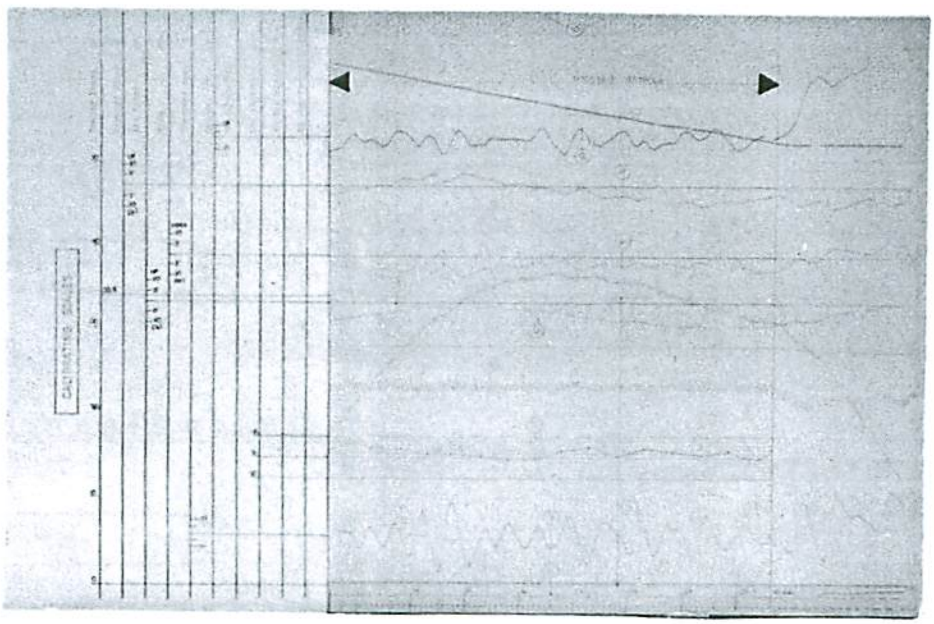

Fig. 6. Recordings made in a constant speed test in level ice. (2) = towing force.

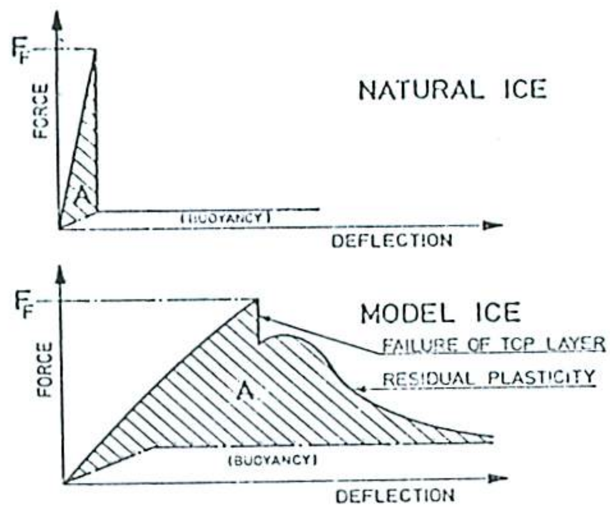

Fig. 7. Schematic force-deflection curves for natural and model ice cantilever beams.

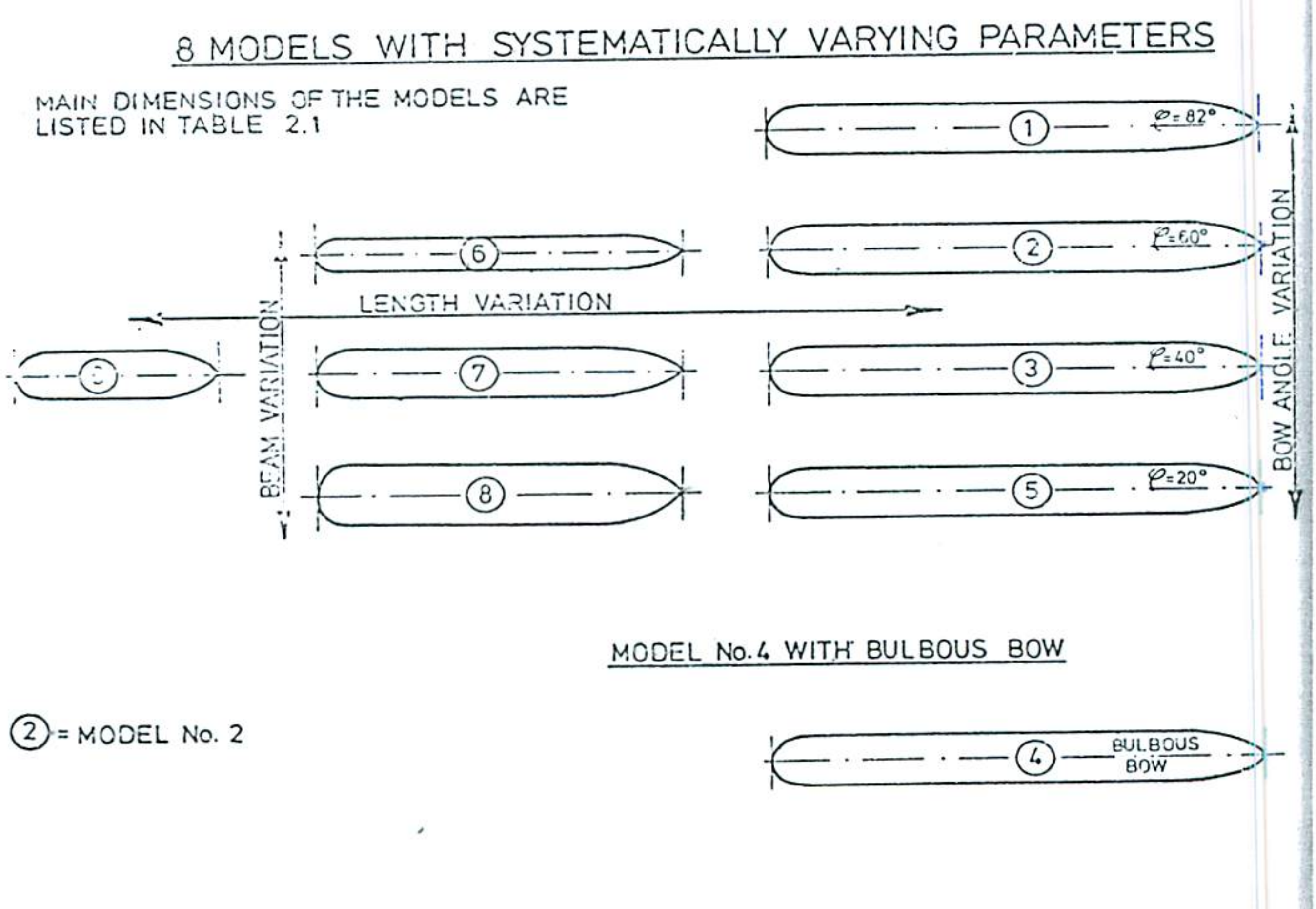

Fig. 8. A schematic drawing of the Great Laker models tested for the U.S. Maritime Administration.

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Fig. 9. Ro-ro-ferry FINNCARRIER in ice trial.

Fig. 10. VLADIVOSTOK, a polar icebreaker of Moskva type, in ice trial.

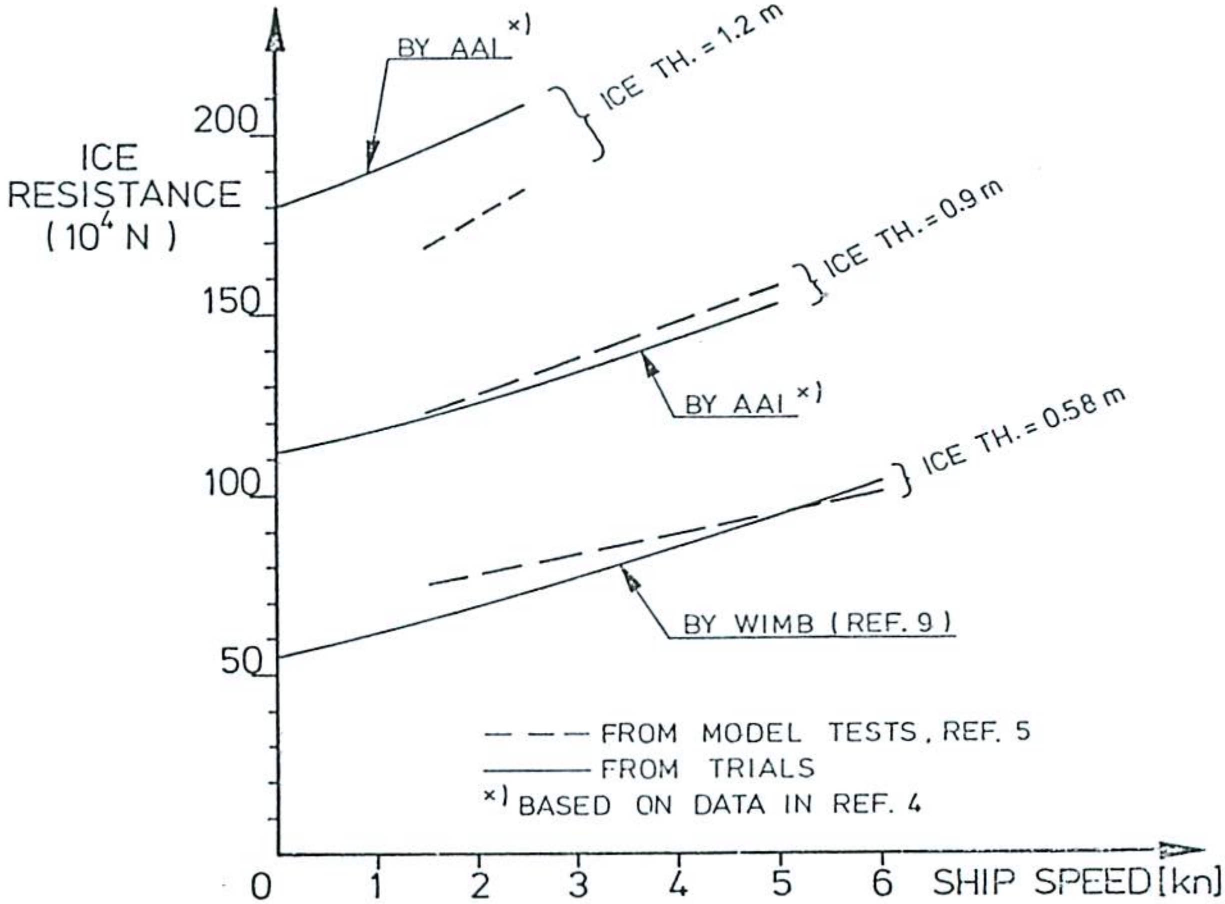

Fig. 11. Moskva type, model test and full scale test results in level ice.

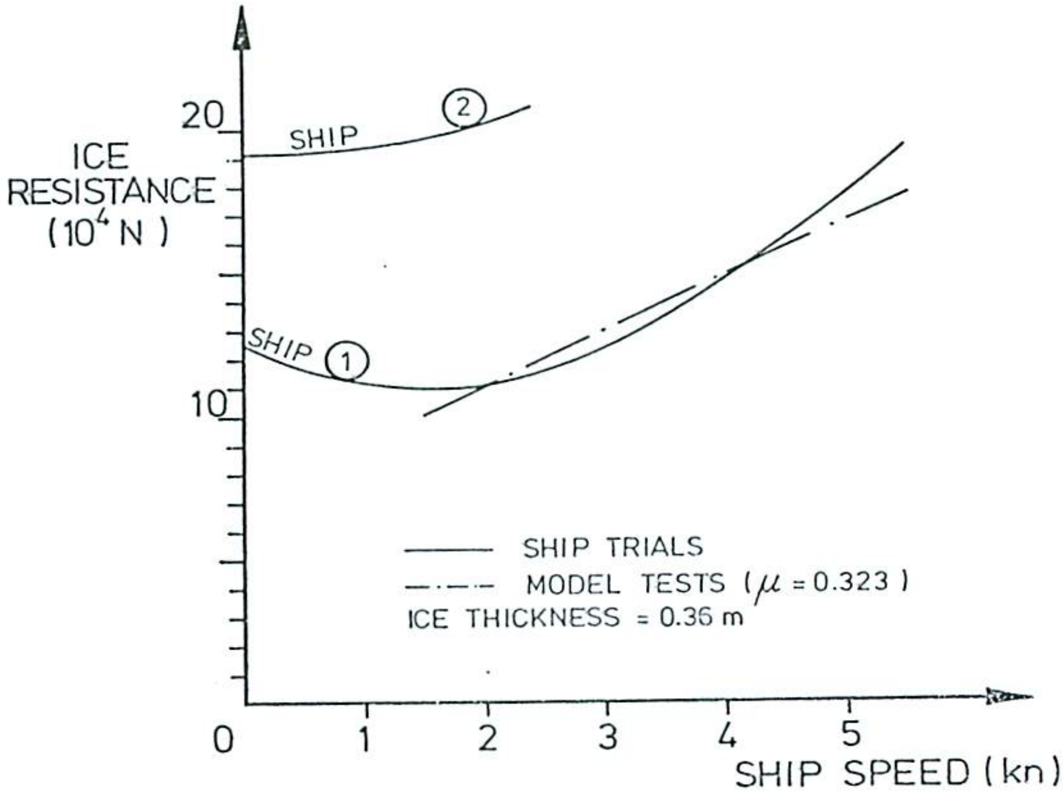

Fig. 12. Test results of two small cutters. Influence of hull surface quality on ice resistance in level ice.

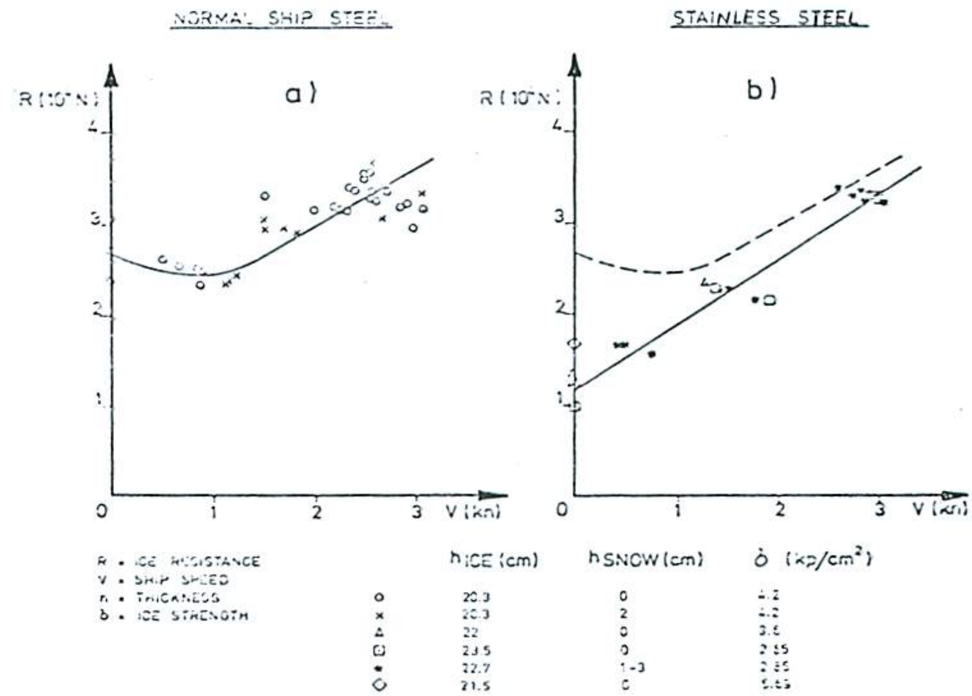

Fig. 13. Test results of the icebreaking tug JELPPARI. Influence of hull surface quality on ice resistance in level ice.

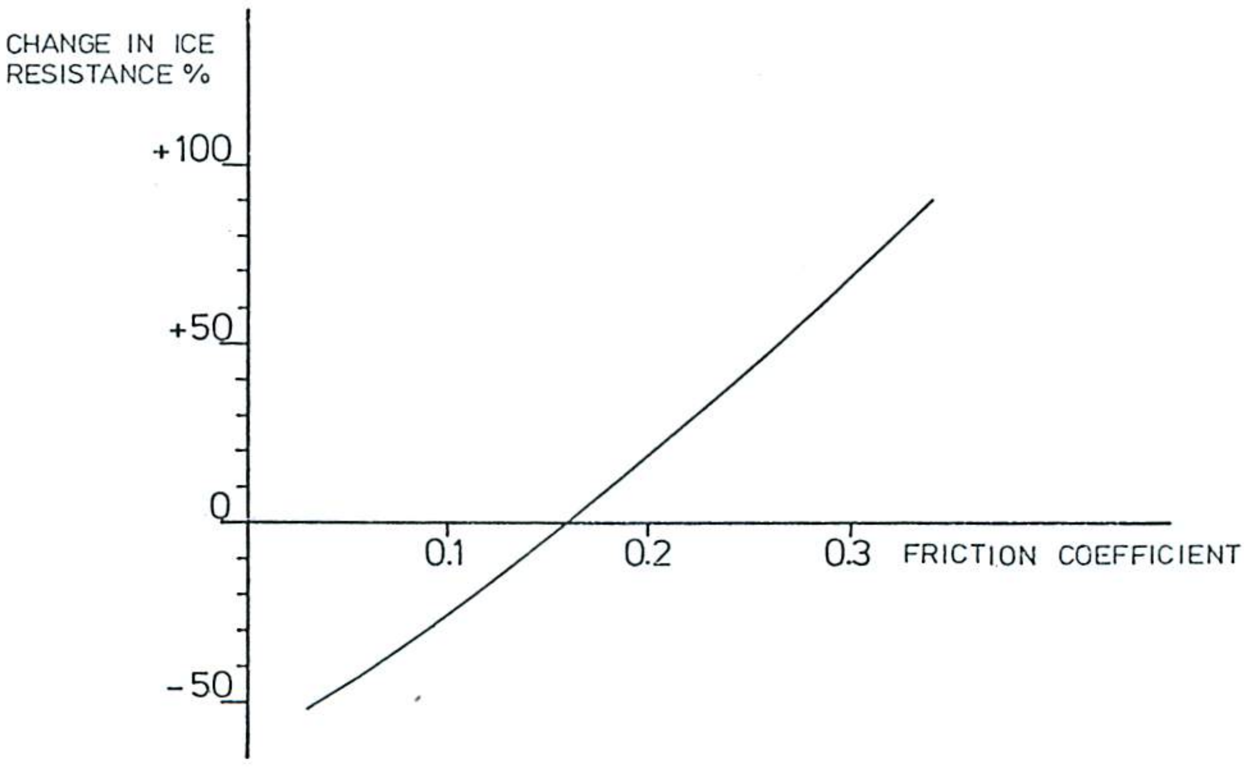

Fig. 14. Influence of friction on ice resistance in model tests.

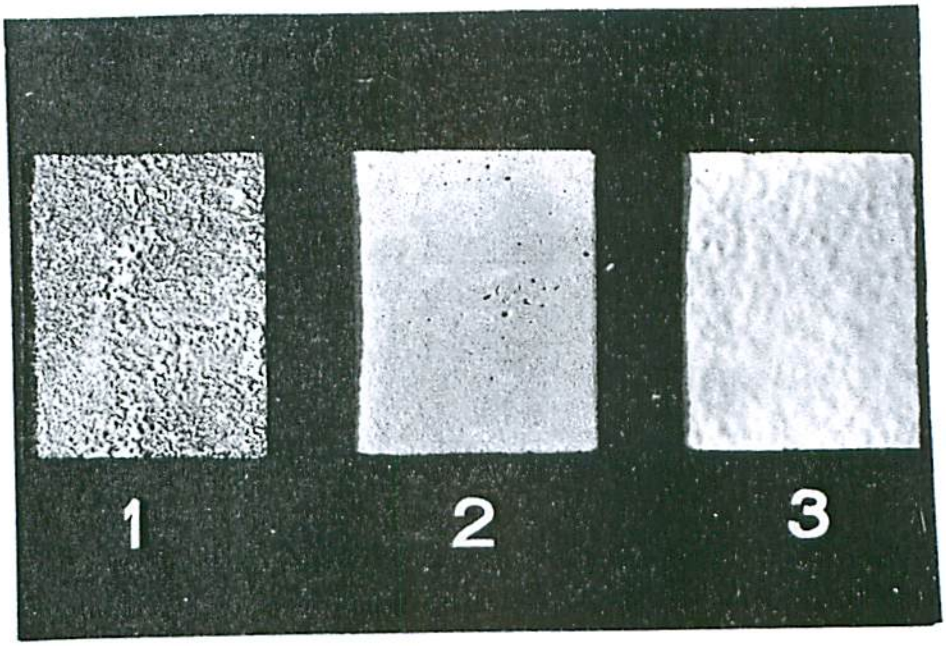

Fig. 15. Example of differences in hull surface quality.

1. Polar icebreaker after two seasons in service.
2. A small cutter after one season in service.
3. A small nine-year-old cutter immediately after coating with epoxy paint.

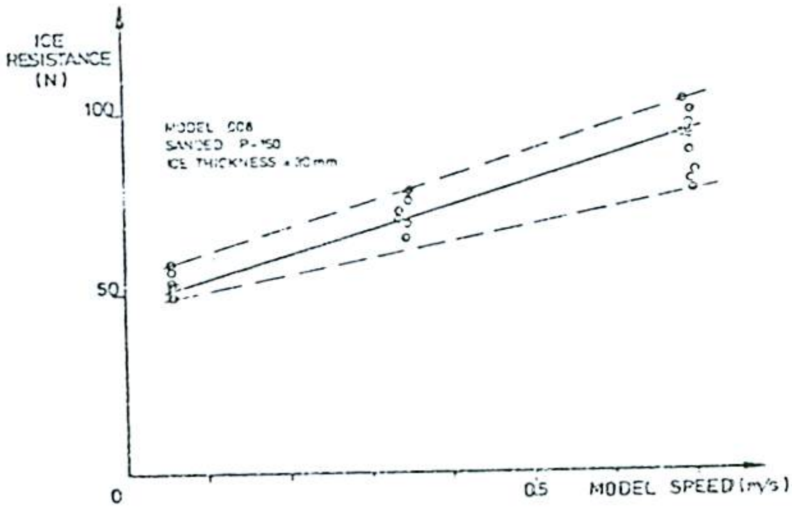

Fig. 16. Example of the scatter in model test results.