REPORT OF COMMITTEE ON SHIPS IN ICE-COVERED WATERS

I. General, Membership, Meetings

The Committee on Ships in Ice-Covered Waters was established at the 15th ITTC, The Hague, 1978. The Ice Committee, as it is commonly referred to, was created as a result of the many problems of testing in ice as discussed in the ice panel report of the 15th Conference and continued with the original work of the ice panel which was initiated at the 14th ITCC, Ottawa, 1975. The ice panel discussed ships in ice for the first time at the 15th ITTC,

Members of the Committee:

J. Alekseyev
G. Frankenstein (Chairman)
E. Makinen
D. Maksutov
S. Mathews
J. Schwarz
H. Takahashi
G. Vance (Secretary)

Dr. H. Takahashi was replaced on the committee by H. Kitagawa in September 1979. Dr. Takahashi was forced to resign from the committee because of other commitments to ITTC that unexpectedly arose. The committee met on five occasions. The first meeting was held at HSVA, Hamburg, Germany on 18 and 19 January 1979; the second at NRC, Ottawa, Canada on 27 and 28 September 1979; the third at A.A.R.I., Leningrad, USSR on 25 and 26 March 1980; and the fourth at S.R.I. Tokyo, Japan on 2, 3 and 4 October 1980. The final meeting was held at Wartsila, Helsinki, Finland on 19 and 20 February 1981.

Recommendations of the 15th ITTC:

1. That the specific procedures and techniques recommended in this report be adopted for international use.
2. That model and full scale testing in ice (including properties and ice conditions) should be continued and every opportunity be take to make careful correlation analysis between the model and full scale results.
3. That continued investigations be made into the testing of models and ships in all ice conditions with the view of eventual adoption of standard techniques.
4. That the development of model ice be continued in order to better satisfy the laws of similitude.
5. Consider circulating at least one test model for comparative ice towing tests in various establishments.
6. Investigate in detail existing and develop new techniques for ice model testing with a view to recommending standard procedures.
7. Review existing ice terminology and symbols with a view to adding additional items if necessary to the existing ITTC standards.
8. That the development of analytical prediction methods for the performance of vessels and structures in ice be continued and that the ice committee review and report on these methods at the next ITTC.
9. That ship owners and/or builders allow for model and full scale testing of all vessels that have been designed for ice-transiting.
10. That ship owners and/or operators of ice-transiting vessels be encouraged to collect reliable ice voyage data during operational voyages.

II. Review of Research on Modeling in Ice of Importance to the ITTC

General Introduction

The modeling of ships and structures in ice began many years ago but the science has advanced greatly the past ten years. The Ice Committee has attempted to review the past and present modeling techniques, and to hopefully establish standard test procedures and analysis of the model test data.

The Ice Committee was requested by Melville Shipping (MSL) to review the results of model tests which MSL had carried out at three different test facilities. This was a rare opportunity for the committee so they accepted the challenge. The committee was to review the reports from the three facilities and then recommend to MSL the best state-of-the-art prediction methods based on these test results. A discussion of this work is included in the report.

A number of facilities and/or organizations have conducted both model and full scale experiments on the same vessel. The committee felt that all existing and available data should be catalogued and published. A list of the catalog to date is presented in the report.

The contents of this report are as follows:

(a) The procedures and techniques for Resistance and Propulsion model testing which have been developed for the standard model experiment.

(b) A discussion of model ice emphasizing any developments since the 15th ITTC.

(c) Review of Melville Shipping model experiments.

(d) The standardization of symbols to be utilized in ice model testing.

(e) The progress that has been made to date in the analytical approaches to predicting ice resistance of ships.

(f) The state-of-the-art of model testing of offshore structures in ice.

(g) Catalog of available Model and Full Scale data.

a. <u>The procedures and techniques for resistance and propulsion testing that have been developed for the standard model experiment</u>.

One of the most important objectives of the Ice Committee is to eventually recommend a standardized procedure for conducting model tests in ice. One of the ice panel's recommendations to the 15th ITTC Congress stated that continued investigations be made into the testing of models and ships in all ice conditions with the view of eventual adoption of standard techniques.

The present test facilities that are using artificial and/or natural ice to test resistance of vessels in ice utilize different methods of testing and the application of the results to predict ice breaking capabilities. Because of this the Ice Committee at its first meeting discussed the possibilities of developing a test program for a test model that would be circulated to all participating organizations. This program would be a giant step in the development of standardized techniques. The Ice Committee therefore concentrated their efforts in the development of this program.

Mr. Sidney Mathews of National Research Council, Canada (NRC) generously offered to provide models of the new Canadian R-Class icebreaking cargo vessel. The R-Class vessel was designed for arctic ice, has a twin screw, fixed pitch, propulsion system and has undergone extensive full scale trial tests. It was an excellent choice for the model test program. Mr. Mathews agreed to have six (6) models built, three to a scale of 1:20 and three to a scale of 1:40. NRC would provide the propellers for the 1:20 model for the propulsion tests that would be conducted in North America and Japan; HSVA would provide them for the tests conducted in Europe. No propellers would be made for the 1:40 models because propulsion tests for such a small model would not produce meaningful results.

Letters of invitation were sent to all ITTC members who had ice testing capabilities (synthetic or ice) to participate in the model test program. A tentative schedule was prepared after the replies were received. Each participant was informed that resistance and propulsion tests were required of the 1:20 models and only resistance tests of the 1:40 models. NRC will supply all the baseline data for the R-class as well as the results of the full scale tests.

Each participating facility will conduct their tests according to ITTC standards using their own techniques. The parameters to be measured are those that were recommended as high priority in the 15th ITTC ice panel report. In addition if a dopant or synthetic ice is used, the chemical makeup must be reported. The committee recommends that the modulus of elasticity and bending strength be determined from cantilever beams. In model testing technques requiring a correction for lack of simulation of the E/σ ratio, the full scale ratio utilized should be 6000. In any case the actual model values should be quoted. It was emphasized that it is necessary to consider the plate deflection and the angle of rotation at the root of the beam when using the cantilever beam technique to determine E.

The following requirements were established for determining the friction factor for the model:

Location:	On standard board provided by NRC (required)
Condition:	Submerged ice and board (required) Surface ice and board (required)
Temperature:	Test temperature (required) -0.5°C (required)
Velocity:	10 cm/sec
Normal Load:	Equivalent to 400 KPa full scale
Ice Surface:	Top surface (required) Other surfaces (optional)

The resistance and propulsion tests of the 1:20 model have either been or are being conducted at NRC, Wartsilä, HSVA, and CRREL. Resistance tests that will be conducted at SRI, Norway, and AARI will be 1:40 scale. The experiments will be carried out according to the following conditions as far as possible:

Resistance Tests

Run No.	f	h(m)	σ(KPa)	V(m/sec)
1	As supplied	.45	400	0.5
2	"	.45	400	2.5
3	"	.45	400	5.5
4	"	.70	400	0.5
5	"	.70	400	1.5
6	"	.70	400	5.5
7	"	.45	800	0.5
8	"	.45	800	2.5
9	"	.45	800	5.5
10	"	.70	800	0.5
11	"	.70	800	1.5
12	"	.70	800	2.5

Self-Propelled Tests

	Run No.	f	h(m)	σ(KPa)	RPM
Required	1	As supplied	.45	400	0.85 Nm
	2	"	.45	400	1.15 Nm
	3	"	.45	400	1.00 Nm
	4	"	.70	400	1.15 Nm
	5	"	.70	400	0.85 Nm
	6	"	.70	400	1.00 Nm
Optional	7	"	.45	800	
	8	"	.45	800	
	9	"	.45	800	
	10	"	.70	800	
	11	"	.70	800	
	12	"	.70	800	

f = friction factor
h = ice thickness
σ = bending strength
V = velocity
Nm = normal mode

Propulsion tests are very important because the results can be compared directly to full scale. Therefore, they are required for the facilities that are participating in the standard model experiment. The comparisons will be made for the given test condition for the average full scale thrust, T_{AI}, torque, Q_A, rate of revolution of the propellers, n_A, and the delivered power at the propellers, P_{DI}. In order to achieve this each participating facility may use its own test technique. The results should be given as Q_A, T_{AI}, n_A, C_{IT}, and P_{DI} as a function of velocity, V. Predictions of the icebreaking capability of a ship, in general, can be made from model propulsion tests in ice at full power where the prediction is given as a function of thickness and speed.

b. A discussion of model ice.

The first attempts by towing tanks to model ship resistance in ice used a synthetic material as the model ice. This was usually a wax-type material. The major problem associated with synthetic materials is that they have a very high coefficient of friction compared to real ice.

It has been well established that when modeling vessels in towing tanks it is very important to accurately scale according to the Froude Law. In modeling icebreaking ships it is important also to simulate the breaking characteristics of the ice. It then becomes important to satisfy the Cauchy scaling criteria. This requires that the flexural strength and the elastic modulus be scaled by the scale factor, i.e., reduced by a factor equal to the length scaling factor. This means that the E/σ ratio of model ice be that of natural ice, which is usually equal to or greater than 2,000. Saline ice is most commonly used to satisfy this requirement but is only good for large scale ratios. Most synthetic material can meet the Cauchy similarity requirement but cannot maintain the coefficient of friction. The Ship Re-

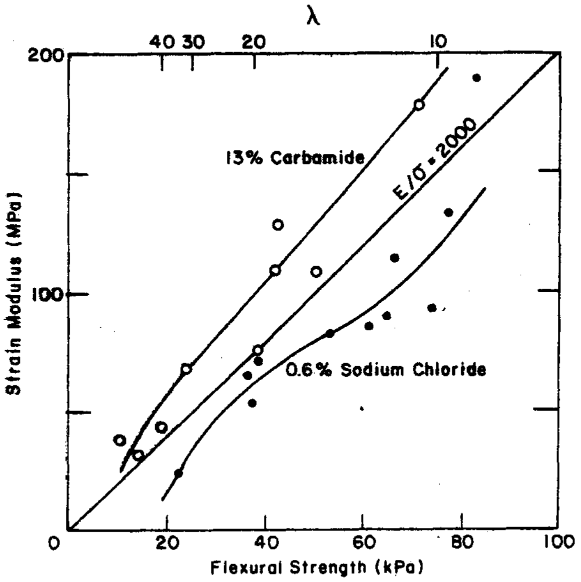

Fig.I

search Institute of Norway is the only tank that has used synthetic ice for their tests on the ITTC Ice Committee standard model test experiment.

Recently, G. Timco of the National Research Council of Canada initiated a program to see if a dopant could be added which would produce an ice sheet that could meet the Chauchy scaling critieria. The study by Timco found that a seeded ice sheet containing 1.3% carbamide (NH_2CONH_2), commonly referred to as urea, would meet the requirement (Fig. 1). A number of towing tanks have experimented with urea-ice with various results. The experiments conducted at USACRREL produced very positive results.[13]

It should be noted that to produce successful model ice sheets special care and detailed techniques must be used. In general the initial strength of a model ice plate depends on the following variables:

$$\sigma_{fm} = f(C, Q, t_w, t_A)$$

where

σ_{fm} = ultimate flexural strength
C = Dopant concentration
Q = the quantity of crystals per unit surface area injected during seeding. An increase in Q causes a decrease in ice strength, provided the other conditions remain constant.
t_w = temperature of the water
t_A = temperature of the air

The Ice Committee would encourage other towing tanks and laboratories to experiment with dopants to hopefully find one that would satisfy all of the scaling criteria and be easily and economically produced.

c. Melville Shipping LNG Carrier Model Experiments

Melville Shipping Co. of Canada graciously provided the committee with the results of resistance tests in ice on a LNG carrier model carried out in three establishments: Arctec (U.S), HSVA, and Wartsila. The data were for the scientific information of the committee and in return Melville Shipping requested a statement on apparent differences between the results. The committee found the results most useful in its work in comparing test procedures and techniques from the different establishments and in return were able to supply Melville Shipping with a statement to their satisfaction.

The work carried out and findings are summarized here. Apart from leading to a useful comparison of techniques, the reports from the different establishments allowed a first comparison of results carried out in different tanks.

Each committee member prepared a critique on the results and it was clearly evident that the main reason for the apparent differences in the results was the fact that different model ice friction coefficient values (f) were used. As part of its discussion the Arctic and Antarctic Institute (AARI) of Leningrad in cooperation with Kryloff Institute also presented resistance results carried out on a model (λ = 100) of the ship at AARI. To illustrate the comparitive results Figure 2, transposed from the AARI report, shows ship speed versus ice thickness (using normalized scales) for the four establishments which tested models. The effect of the different friction coefficients used in the four tanks, for the most part, indicates an increase in resistance with an increase in friction factor.

Corrections to a standard friction coefficient, as made by various committee members, indicated that resistance prediction variations

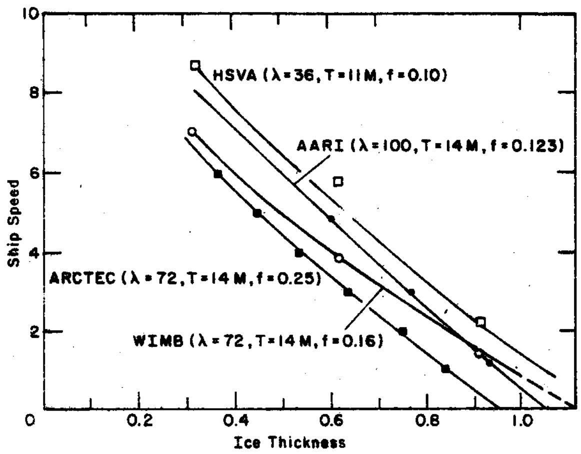

Fig.2

for the same ice thickness, ice strength and speed were of the order of 10 percent. It should be noted that apart from friction coefficient differences, the various establishments used different values of other important parameters such as model scales, ice strengths (σ) and E/σ values. The different values reflected the different test techniques and prediction methods of the tanks involved. These differences emphasized the need for the standard model program of the committee which not only will enable comparisons of techniques and model results but will also be used in making ship/model correlations.

It should be noted that the different values of the parameters used in the four tanks involved are also associated with generally different approaches to ship predictions. The Committee has been able to make the following joint statement:

Committee Statement on Level Ice Conditions

1. An important part of the work of each ice tank is the comparison of different forms, tested under the same conditions, leading to best form.
2. Predicted ice total resistance results for the four tanks which have here presented data compare reasonably well when the differences in prediction friction coefficients for the results are considered, and where the other prediction parameters of E, σ and h are the same with each tank using its present methods.
3. There are two fundamentally different prediction methods used, both based on experience with model/ship correlations.
   a) From Ice Resistance Tests:
      This method is based on a large amount of correlation experience. The open water thrusts, for given powers and speeds are compared with predicted ice resistance data.
   b) From Propulsion Tests:
      Recently prediction methods based on detailed model propulsion tests in ice have been used in order to more accurately take account of the effects of broken ice on the propulsion factors. Only a few correlations have been made so far using this method. The method involves using true prediction hull/ice friction values, appropriate to the conditions, and equating thrust data corrected for the in ice thrust deduction from propulsion tests to the ice total resistance.
4. Both of the above prediction methods may be used at present with some confidence, the second test method is more detailed and yields more data related to the performance of the propulsion system.

d. Standardization of Symbols

In review of the ITTC recommended List of Symbols the Ice Committee noted that the subsection on ice needed revision. The committee therefore developed a revised list for utilization in ice testing. The list will be continually updated as needed. The list as it appears in the appendix will be presented to the Information Committee for approval. In addition the committee has requested that the subscript capital "I" be reserved for ice model testing.

e. Theoretical Approaches to Predict the Resistance of Icebreaking Ships

1. Introduction

Several methods exist to predict the resistance of icebreaking ships in level ice by theoretical or mathematical models. Most of these methods are either semi-theoretical or imperical. We can distinguish between three different types of prediction methods in use at the present:

(1) Icebreaking prediction equations which have been established on the basis of model tests by regression analysis. These equations can predict the resistance for only

that ship which has been model tested.

(2) Semi-theoretical approach which uses a standard knowledge of mechanics and hydrodynamics for the prediction of portions of the total icebreaking resistance. Unknown effects of the complicated icebreaking process are taken care of by use of coefficients which are determined from model or full-scale tests.

(3) Theoretical formulations of the icebreaking problem which predict the icebreaking resistance for different hull forms as well as for different ice conditions. These theoretical formulations are under continuous development.

The following discussion of available prediction methods of the icebreaking resistance will concentrate on methods (2) and (3) only.

2. Semi-Theoretical Approach

Semi-theoretical methods to predict the icebreaking resistance of ships have been developed by Kashteljan (1968) and by several commercial firms.

The Kashteljan method for predicting the resistance of icebreakers in level ice is based on theoretical, full scale and model investigations with the icebreaker ERMAK (1898). This method can be used for the calculation of the resistance of icebreakers, the form of which even differs from that of ERMAK. The Kashteljan method is restricted to ice thickness of 0.3 to 1.5 m and speeds ranging from 1 to 5 knots.

The prediction methods of commercial firms are not published in detail. Therefore evaluation is difficult. These methods are partly based on theory and in addition contain factors so that their predictions will match that of model and full scale test results. These factors have no general applicability. Therefore, the general validity of these prediction methods of the icebreaking resistance has yet to be shown.

3. Theoretical Approach

In 1973 Milano published his purely theoretical method to predict the resistance of ships when moving continuously through level ice. Milano has developed a mathematical method to describe the physical interactions at the ship's forebody-ice interface which contribute to the resistance of the ship when continuously breaking a level ice cover. Milano's analysis is based on an energy approach, in which the total energy lost by the moving ship when it breaks the level ice cover is calculated. Milano just considers one icebreaking cycle.

The total resistance to motion in ice is taken as that average force acting throughout the breaking distance which gives rise to the energy level lost during this cycle.

a) Motion Through Broken Ice - Energy E_1

As the ship moves through the ice field, it encounters a concentration of broken ice pieces floating on the surface which must be forced aside to allow passage of the ship. The ship does not break such ice. Rather, it pushes the ice aside and generally, under the broken shelf. The effect on ship resistance is a direct function of ice concentration and ship broken ice is taken as equal to the thickness of the unbroken field. Ice particle interaction has been ignored as small.

Since the buoyancy effects are considered as a part of energy loss E5, this component of resistance has been approached as due solely to inertia and friction effects.

b) Impact With the Ice Field - Energy E_2

In considering the impact between a ship's hull and an ice field, it is assumed that the loss of energy by the ship due to the impact is completely absorbed in local crushing and subsequently bending of the ice sheet as the ship rides up onto the ice. The extent of crushing is a direct function of the ultimate crushing strength of the ice, σ_c, and the area of contact between the ship and the ice.

c) Ship Motion Onto the Ice - Energy E_3

When the ice deformation due to crushing has progressed to the point where the ship/ice contact area $A_c = P_V/\sigma_c$, forward motion due to crushing will cease and the ship will be forced onto the ice due to the inclined stem and cheeks of the bow. This sliding motion with an associated change in ship draft and trim will continue until all the ship's kinetic energy is expended, or until the vertical force generated against the ice face causes failure of the ice wedge or slab. In the continuous mode of icebreaking, the first alternative is discarded as trivial.

d) Ship Motion After Ice Failure - Energy E_4

When the ship has moved forward onto the ice such that the ice wedges fail, the ship will fall, tending to return to the original draft and trim. The motion is taken as two-dimensional pitching superimposed on a fixed forward velocity.

e) Effects of Ice Submergence - Energy E_5

The ship falling and moving forward after failure will cause the broken ice pieces to be driven down and aft under the ship. A buoyant force will act which is a function of ice geometry and which will increase as the ice pieces are driven down, until immersion is complete, at which point it is constant.

By superimposing all five portions of energy and dividing the sum by the distance of advance the total resistance is established.

Milano has shown recently by comparison between theoretically predicted and experimentally established resistances in level ice that his analytical method is capable of predicting the resistance of icebreakers as well as of large icebreaking merchant ships. Milano indicates that improvements still have to be made in order to describe the complicated icebreaking process by theory to full satisfaction.

Some areas in which the theories can be improved are:

(a) the interaction of broken ice floes

(b) secondary cracking of broken ice

(c) strain rate effects on the crushing strength of ice

(d) the failure model of level ice by considering multiaxial failure criteria

(e) the effect of shear and adhesive friction between hull and ice in the various stages of contact.

Milano and others have compared their theoretically predicted ship resistance in ice with full-scale measurements. In full-scale, just the propeller thrust can be measured. A conversion of thrust into resistance is possible using results from model propulsion tests.

Since in many comparisons, propulsion tests have not been carried out, the theories have yet to be validated.

The above mentioned prediction methods consider only the resistance in level ice. Milano (1975) and Kashteljan (1968) have presented theories for the prediction of resistance in mush/brash ice. The viscous properties of this type of ice are unknown and therefore were not included. At the present, there is no data available to validate either theory.

The resistance of ships moving through ridged ice fields has been studied by Keinonen (1979). His results were used for the development of a theory on ship performance in one-year ice. His theory considers the geometry and the degree of consolidation of ridges, the shear stresses between the broken ice pieces as well as the ship's data.

The theory and full scale correlation of this prediction method is not as advanced as for level ice. This is due of difficulties in obtaining good ridge property data and the fact that these properties vary widely in full scale.

f. State-of-the-Art of Model Testing of Offshore Structures in Ice

With the discovery of hydrocarbons in the offshore environment in ice-covered waters interest has grown in testing potential exploratory and production drilling structures in refrigerated model test basins. Such tests have been undertaken for the past ten years or so. Unfortunately a majority, if not all, of these tests are proprietary and therefore the data and techniques utilized have not been subjected to the same intense scrutiny and analysis as the ship model tests. In addition, there have been no reported full scale tests to verify or vindicate the results of the model tests.

The tests were carried out in indoor refrigerated basins as well as in outdoor naturally frozen basins. The testing medium varied from saline water to carbamide ice and proprietary solutions. In some tests the ice sheet was pulled to the model, in other tests the model was pulled through the ice sheet. Scale ratios varied from 1/5 to about 1/50. Some ice properties were measured in most tests, however, the standard techniques now being recommended by the ITTC were not utilized. In many cases the ice beam was removed from the test basin and tested

TABLE 1. MODEL TESTS CONDUCTED ON OFFSHORE STRUCTURES IN ICE

Testing Facility	Type of Structure	Approx. Date	App.Tank size L(m)xW(m)xD(m)	Scale Factor	Test Material	Remarks
Chevron Offshore LaHabra, CA	Arctic Mobile Drill St (45° to 60° Cones)	1975	6.0x2.5x1.2	1:50	Proprietary Aqueous sol	Uniform Ice Submerged SS Beam Tests
ARCTEC, USA Columbia, MD	30° and 60° Cones	1976	27.5x3.6x1.2	1:36	Saline Sol	Uniform Ice Canti+SS Beam InSitu
Imperial Oil Calgary, Canada	30° and 45° Cones	1976-78	55.0x30.5x3.0	1:5	Saline Sol	Outdoor Tank, Ridge Test SS Beam Test InSitu
ARCTEC, USA Columbia, MD	Multi-Legged Jackup	1977	27.5x3.6x1.2	1:24	Saline Sol	Uniform Ice Canti+SS beam Test InSitu
ARCTEC, USA Columbia, MD	Four-Legged Steel	1978	27.5x3.6x1.2	1:36	Saline Sol	Uniform Ice Canti+SS Beam Test InSitu
USACRREL Hanover, NH	Thin Steel Mono Pod	1979-81	36.5x9.1x2.5	1:10	Carbamide Sol Saline Sol	Uniform Ice Canti Beam Test InSitu
HSVA Hamburg, GERMANY	Tethered Invert Cone	1980	30.5x6.0x1.2	1:20	Saline Sol	Uniform Ice Canti Beam Test InSitu
ARCTEC, USA Columbia, MD	Gravel Island	1981	27.5x3.6x1.2	1:30	Saline Sol	Uniform Ice Canti Beam Test InSitu
WÄRTSILÄ Helsinki, Finland	Drill Ships	1973-79	50x4.8x1.1	1:50	Saline Sol	Flow Ice
WÄRTSILÄ Helsinki, Finland	Series of Monohull Structures	1975	50x4.8x1.1	1:50	Saline Sol	Level Ice
IHI, Japan	Columns and 5°-10° Cones	1980	Low Salinity Lake	--	Brackish	Level Lake Ice
MITSUI ZOSEN Japan	Large Inclined Pile	1978-81	HARBOR	—	Sea Ice	
HSVA, Hamburg Germany	Oscillating Cone and Vertical Columns	1976	30.5x6.0x1.2	1:20	Saline Sol	Off Shore-Monbetsu, Japan
HSVA, Hamburg Germany	Upward + Downward breaking fixed cones and downward breaking moored floating cones	1979-80	30.5x6.0x1.2	1:20	Saline Sol	Level and Ridged Ice
HSVA, Hamburg Germany	Monopod in Ice	1980	30.5x6.0x1.2	1:20	Saline Sol	Level and Ridged Ice
UNIVERSITY of Iowa	Ice Forces on Vertical Piles	1974	7.0x1.0x0.6	--	Freshwater Ice	Level Ice

on a simply supported testing apparatus. In some cases the beam was completely submerged during the test.

A majority, if not all of the tests were on simple shaped structures such as monocones, monopods or gravel islands. As far as can be ascertained no tests were conducted on complicated floating structures such as a semi-submersible.

It is unfortunate that the results and techniques cannot be made public so that the methods can be evaluated and standardized. However, much of the ITTC Ice Committee work now being carried out will apply to the testing of these offshore structures and may eventually be adopted by the institutions conducting the tests.

Table I is a summary of the known tests that have been conducted in both the laboratory and the field.

g. Catalog of Available Model and Full Scale Test Data

The individual committee members usually referred to model and full scale tests with which they have been involved. In the discussion of their results many questions were presented by the other members. It was therefore recommended that the committee begin to develop a catalog of all available model and full scale data. The data would be maintained by the Chairman and copies could be requested by all ITTC members. No attempt has been made as yet by the committee to analyze any of the data. A list of the vessels where such data is available, who performed the tests, date, location, and test friction factor is listed below:

1. Ermak - (1898) Model and Full Scale Test Data

Model Scale Test Performed by: AARI
Date: 1955
Model Scale: 1/50
Friction Factor: 0.15 (assumed)

Full Scale Test Performed by: AARI
Date: 1941
Location: Baltic Sea
Friction Factor: 0.15 (assumed)

2. Wind Class - Model and Full Scale Test Data

Model Scale Test Performed by: Arctec, Inc.
Date: 1971
Model Scale: 1/36
Friction Factor: 0.15 (assumed)

Full Scale Tests Performed by: USCG
Date: 1969
Location: Bering Sea
Friction Factor: 0.15 (assumed)

3. Mackinaw - Model and Full Scale Test Data

Model Scale Test Performed by: Arctec, Inc.
Date: 1972
Model Scale: 1/48
Friction Factor: 0.15 (assumed)

Full Scale Tests Performed by: Arctec, Inc.
Date: 1971
Location: Great Lakes
Friction Factor: 0.15

4. Jelppari - Model and Full Scale Test Data

Model Scale Test Performed by: Wartsila
Date: 1971
Model Scale: 1/5
Friction Factor: 0.15

Full Scale Tests Performed by: Wartsila
Date: 1971
Location: Gulf of Finland
Friction Factor: 0.15

5. Finncarrier - Model and Full Scale Test Data

Model Scale Tests Performed by: Wartsila
Date: 1972
Model Scale: 1/20
Friction Factor: 0.20

Full Scale Tests Performed by: Wartsila
Date: 1970
Location: Gulf of Finland
Friction Factor: 0.25

6. Moskow - Model and Full Scale Test Data

Model Scale Tests Performed by: Wartsila
Date: 1972
Model Scale: 1/25
Friction Factor: 0.2

Full Scale Test Performed by: AARI
Date: 1964
Location: Arctic
Friction Factor: 0.2-0.4 (from model tests)

7. Polar Star - Model and Full Scale Test Data

Model Scale Tests Performed by: Arctec, Inc.
Date: Nov. 1976
Model Scale: 1/48 (Dual Model Tests)
Friction Factor: 0.061-0.478

Full Scale Tests Performed by: USCG R&DC
Date: Dec. 1977
Location: McMurdo Sound
Friction Factor: 0.44-0.54

8. Katmai Bay - Model and Full Scale Test Data

Model Scale Tests Performed by: Arctec, Inc.
Date: Sep. 1975
Model Scale: 1/24 (Dual Model Tests)
Friction Factor: 0.021-0.68

Full Scale Tests Performed by: US Army CRREL/ US Navy NSRDC
Date: Feb 1979
Location: Great Lakes
Friction Factor: 0.15 Avg.

9. WERDERTOR - Model and Full Scale Data

Model Scale Tests Performed by HSVA:
Date: 1977
Model Scale: 1:16.6
Friction Factor: 0.10

Full Scale Tests Performed by: HSVA
Date: 1978
Location: Arctic (Spitzbergen)
Friction Factor: 0.13

10. Fuji II - Model Test Data

Model Tests Performed by: HSVA
Date: 1977
Model Scale: 1:20
Friction Factor: 0:10

Acknowledgments

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APPENDIX A

RECOMMENDED LIST OF SYMBOLS FOR RESISTANCE AND PROPULSION TESTS IN ICE

Symbol	C.C Symbol	Title	Definition	Dimension
1	2	3	4	5
C_I	CI	Coefficient of net ice resistance		-
C_{IB}	CIB	Coefficient of resistance due to breaking of ice		-
C_{II}	CII	Coefficient of inertial resistance due to velocity of ship		-
C_{IS}	CIS	Coefficient of resistance due to submersion of ice		-
C_{IT}	CIT	Coefficient of total resistence in ice		-
C_{IW}	CIW	Coefficient of water resistence in the presence of ice		-
C_{TI}	CTI	Relative time of propeller-ice interaction	Ratio of time of ice-propeller interaction to time of measurement	-
C_{IF}	CIF	Coefficient of friction due to ice		-
d_{cr}	DCR	Diameter of ice crystals		L
F_{NI}	FNI	Froude ice depth number	$F_{NI} = V/\sqrt{gh_I}$	-
F_{IN}	FIN	Normal ice force on a body		LMT^{-2}
F_{XI}	FXI	Components of the local ice force		LMT^{-2}
F_{YI}	FYI			LMT^{-2}
F_{ZI}	FZI			LMT^{-2}
F_{ID}	CFRD	Coefficient of friction between surface of body and ice (dynamic)	Ratio of tangential force to normal force between two sliding bodies	-
f_{IS}	CFRS	Coefficient of friction between surface and ice (static)		-
h_I	HI	Thickness of ice sheet		L
h_{sn}	HSNOW	Thickness of snow cover		L
K_{QA}	KQA	Average coefficient of torque in ice conditions	$K_{QA}=Q_A/\rho_W n_A^2 D^5$	-
K_{QIW}	KQIW	Coefficient of torque without ice propeller interaction	$K_{QIW}= Q_{IW}/\rho_W N_{IW}^2 D^5$	-

KK_Q	KKQ	Correlation coefficient of torque	$KK_Q=QS_{AI}/QM_{AI}\lambda^4$	-
K_{TA}	KTA	Average coefficient of thrust in ice condition	$K_{TA}=T_{AI}/\rho_W n_A^2 D^4$	-
K_{TIW}	KTIW	Coefficient of thrust without ice-propeller interaction	$K_{TIW}=T_{IW}/\rho_W n_{IW}^2 D^4$	-
KK_T	KKT	Correlation coefficient of thrust	$KK_T= TS_{AI}/TM_{AI}\lambda^3$	-
l_{cr}	LCR	Length of crystals		L
n_A	NA	Average rate of propeller revolution in ice		REVS T^{-1}
n_I	NI	Rate of propeller revolution while interacting with ice		REVS T^{-1}
n_{IW}	niw	Rate of revolution without ice-propeller interaction		REVS T^{-1}
P_{DI}	PDI	Delivered power at propeller in ice	$2\pi Q_A n_A$	L^2MT^{-3}
Q_A	QA	Average torque in ice condition	$Q_A=Q_{IW}(1-C_{TI})+$	L^2MT^2
Q_I	QI	Ice torque	$+Q_I C_{TI}$	L^2MT^2
Q_{IW}	QIW	Torque without ice-propeller interaction		L^2MT^2
R_I	RI	Net ice resistance		LMT^{-2}
R_{IB}	RIB	Resistance due to breaking of ice		LMT^{-2}
R_{IC}	RICR	Resistance independent of velocity		LMT^{-2}
R_{IF}	RIF	Resistance due to friction in ice		LMT^{-2}
R_{II}	RII	Inertial resistance due to velocity	Arising from acceleration force caused by ice pressure on the body	LMT^{-2}
R_{IS}	RIS	Resistance due to submersion of ice		LMT^{-2}
R_{IT}	RIT	Total resistance of ice		LMT^{-2}
R_{IV}	RIV	Resistance due to velocity of ship		LMT^{-2}
R_{IW}	RIW	Hydrodynamic resistance		LMT^{-2}
S_I	SALTI	Salinity of ice		
S_W	SALTW	Salinity of ice	Weight of the salt dissolved divided by the total weight of the salt water	
t°_A	TEMA	Temperature of air		
t°_I	TEMI	Temperature of ice		
t°_{IT}	TEMIT	Temperature of upper ice layer		

t°_{IB}	TEMIB	Temperature in bottom ice layer		
t°_S	TEMS	Temperature of snow		
t°_W	TEMW	Temperature of water		
T_{AI}	TAI	Average thrust in ice condition	$T_{AI}=T_{IW}(1-C_{TT})+T_I\cdot C_{TI}$	LMT^{-2}
T_I	TI	Ice thrust		LMT^{-2}
T_{IW}	TIW	Thrust without ice-propeller interaction		LMT^{-2}
X_I	FIX	Ice force components		LMT^{-2}
Y_I	FIY	On body relative to		LMT^{-2}
Z_I	FIZ.	Body axes		LMT^{-2}
γ_I	GAMSI	Ice strain, shear		-
δ_I	DELI	Deflection of ice sheet		
ε_I	STI	Ice strain, normal	Elongation per unit length	-
$\dot{\varepsilon}_I$	STRAT	Strain rate, normal		T^{-1}
η_{ID}	ETAI	Propulsive efficiency in ice	$\eta_{ID}=R_{IT}/P_{ID}=(2\pi\ N_I Q_I)$	
μ_I	POISI	Poisson's ratio of ice	The ratio of transverse strain of ice to longitudinal strain	-
ν_A	NUA	Air volume in ice		-
ν_B	NUB	Brine volume of dopant		-
ν_o	NUO	Total porosity	$\nu_o=\nu_A+\nu_B$	-
ρ_S	RHOI	Mass density of ice		ML^{-3}
ρ_W	RHOW	Mass density of water		ML^{-3}
ρ_Δ	RHOD	Ice mass density loss	ρ_Δ	ML^{-3}
σ	SIGS	Stress, normal		$L^{-1}MT^{-2}$
σ_c	SIGCO	Compression strength		$L^{-1}MT^{-2}$
σ_f	SIGFL	Flexural strength		$L^{-1}MT^{-2}$
σ_N	SIGN	Normal to centerplane component of ice pressure		$L^{-1}MT^{-2}$
σ_{PI}	SIGPI	Pressure in compressed ice sheet		$L^{-1}MT^{-2}$
σ_T	SIGT	Tensile strength		$L^{-1}MT^{-2}$
τ_S	TAUS	Stress, shear		$L^{-1}MT^{-2}$

III. Recommendations of the Committee

1. That the symbols listed in Appendix A be used until approved by the Information Committee.
2. That testing of the ITTC Ice Committee's standard model be continued and the comparison of test results and full-scale predictions be reviewed and reported.
3. Investigate the fundamental effects of friction in ice-breaking. This is to be achieved by re-testing the standard model at other friction values which are to be determined by the new Committee.
4. That the development of analytical prediction methods for the performance of vessels and structures in ice be continued.
5. Investigations on modeling the performance of ships and structures in ice ridges initiated.
6. That the development of model ice be continued and encouraged.
7. Review the present techniques used in propulsion testing.
8. That model and full scale testing in ice (including ice properties and ice conditions) should be continued and every opportunity be taken to make careful correlation analysis between the model and full scale results.
9. That continued investigations be made into the testing of models and ships in all ice conditions with the view of eventual adoption of standard techniques.