The Specialist Committee on Ice

Final Report and
Recommendations to the 22nd ITTC

1. GENERAL

The Ice Committee appointed by the 21st ITTC consisted of:

Dr. Kazuyuki Kato, Japan (chairman)
Dr. Wilfrid Nixon, USA (secretary)
Dr. Stephen Jones, Canada
Mr. Goran Wilkman, Finland
Mr. Koh Izumiyama, Japan
Mr. Krill Sazanov, Russia

The committee met four times:

April 10, 1997	Yokohama (Japan)
October 23, 1997	Helsinki (Finland)
July 24, 1998	Potsdam (USA)
December 7-8, 1998	Iowa City (USA)

Recommendations of The 21st ITTC.

1. Review the ITTC recommended procedures, benchmark data, and test cases for validation and uncertainty analysis and update as required. Pass the information to the Quality Systems Group for publication in 1999.
2. Prepare an up-to-date bibliography of relevant papers and reports.
3. carry out tests in different tanks to clarify ice loads and also the performance of an open propeller in level ice. The test should improve the modelling practice in the field of propeller/ice interaction.
4. Continue work to achieve common guidelines for the measurement of model ice properties. Also develop procedures to conduct and analyze model and full-scale tests.
5. Develop model test procedures in deformed ice and the measurement of the properties of deformed ice.
6. Analyze methods to correct ice resistance for small deviation from target values of ice thickness, ice strength, and hull friction.
7. Analyze methods for conducting tests involving offshore structures and moored vessels in ice in view of the results obtained in the comparative cylinder tests.

The present Ice Committee was constituted as a specialist technical committee. The committee decided to concentrate its efforts on recommended test procedures and to drop the task associated with propeller/ice interaction from the recommendations. This was because of little interest from the member organizations, and because it was felt that recommended methods for test procedures was more important. The committee agreed to add a task on the model test procedures for offshore structure and updating a list of ice tank facilities. Therefore, the committee decided to deal with the tasks listed below:-

1. Guidelines for measuring model ice properties. In this task, three sub tasks

2. were set, namely, (a) recommendations of standard measurement procedure, (b) a round robin test on the floating uniaxial compressive test, and (c) reviewing testing methods on the fracture toughness of model ice.
3. Reviewing testing procedures for ridges and deformed ice.
4. Reviewing testing procedures for offshore structures in ice.
5. Updating the list of ice tank facilities.
6. Updating the bibliography on ship and structure in ice.
7. Discussion on revising direction for the proposed “ITTC Recommended Procedures”.

2. MEASUREMENT PROCEDURES FOR MODEL ICE PROPERTIES

2.1 Recommended Procedures For Model Ice Properties

For a long time, the Ice Committee of the International Towing Tank Conference (ITTC) has been attempting to standardize measurement procedures for the mechanical properties of model ice. The rationale for this is that the mechanical properties are specified when a model experiment is conducted, and results obtained from the model tests are normalized by the mechanical properties of the model ice sheet used in the experiments. However, the mechanical properties of model ice are, to some extent, "method dependent". That is, the property being measured may vary depending on the test method used. This means that test results obtained by different ice tanks may not be entirely comparable. Therefore, the Ice Committee decided to develop recommended measurement procedures for the mechanical properties of model ice.

The ITTC Ice Committee has decided to recommend three measurement procedures described below:-

a) The measurement procedure for elastic modulus of model ice.
b) The measurement procedure for flexural strength of model ice.
c) The measurement procedure for specific weight of model ice.

These were chosen because they are important measurements which are usually made for all ice basin tests, and general agreement has been obtained on the recommended procedures. Other properties, compressive strength, fracture toughness, etc. are important but general agreement on a standard method has not yet been obtained.

General Remarks On Selecting The Measurement Procedures. Before describing the three procedures, some general remarks on the nature of model ice is necessary. In nature, at the normal speed of interaction of a ship with sea ice, the ice behaves as a brittle solid with little, if any, plastic deformation. The compressive strength of sea ice depends principally on the strain-rate (or speed) of the interaction, the temperature, and the salinity of the ice. The flexural strength is independent of strain-rate in this range, but does depend on temperature and salinity. Ideally, if we follow Froude scaling laws, model ice should behave in the same manner, but with the strengths reduced by the linear scale factor of the model test, λ. Much effort has gone into finding the perfect material over the last 30 years, but none of the model ices used today can claim to be perfect. The methods, and analyses, used to measure many mechanical properties of model ice in an ice tank are associated with homogeneous linear elastic materials. While model ice is not such an ideal substance, the Ice Committee recognizes that, sometimes, we can only measure an “index value” to represent a mechanical property of the model ice. However, whether it is an index value, or a fundamental mechanical property, any measurement procedure should be standardized.

Any model ice is generally quite weak and temperature sensitive. A model ice specimen can easily fail by its own self-weight if it is taken out of a tank. Even if it does not break, brine will drain out of the ice sample when it is removed from the tank, thus changing its properties. It is preferable, therefore, to test model ice while it is still in the tank. The ambient air temperature in an ice tank is usually well-controlled. However, it is possible for the temperature of the tank water to change with time. Since the tank water temperature will greatly influence the strength of the model ice, measurements should be made as quickly as possible to minimize any effects due to changing temperatures. Also, any measurement procedure should be relatively simple to conduct in the time available during a model test program, and give reproducible and unambiguous results.

Elastic Modulus- Plate Deflection Method

The Committee has agreed to recommend the plate deflection method (Sodhi et al, 1981) to measure the elastic modulus of a model ice sheet. This procedure is now described.

A model ice sheet is loaded uniformly over a circular area of radius, r, by placing dead weights in discrete increments (ΔP). The deflection at the centre of the load is then measured by a displacement measuring device. An example of the test equipment is shown in Figure 1. The loads (dead weights) should be as small as possible in order not to cause any plastic deformation in the model ice sheet. Also, the loads should not remain on the ice sheet long enough to cause large creep deformation of the ice sheet. Since the loads are small, the deflection measuring device must have good resolution, and should not itself put any extra load on the ice sheet. Thus, the choice of measurement device is important. The load should be applied at least four characteristic lengths, l, of the ice sheet from the tank walls. The tank water must be still, so care must be taken not to slam doors or generate other vibrations in the tank while making the measurement.

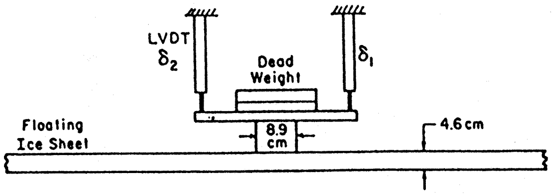

Figure 1 An example of test set-up (after Sodhi, et al., 1981)

An example of deflection curves obtained by the above procedure is shown in Figure 2. The discontinuities in the deflection curves (Δ w) are due to the elastic response to the sudden application of the load increments. The sudden load application creates vibrations of the ice sheet, which decay after a short time. The steady increase in the deflection after the application of the load is due to creep of the ice. The effect of creep can also be seen in the permanent deformation of the ice sheet after removal of the load.

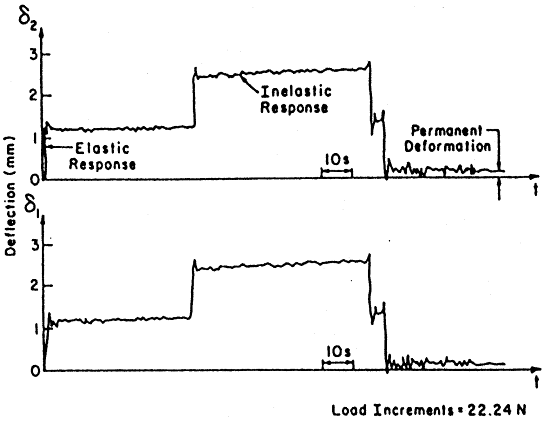

Figure 2. An example of the resulting deflection curve (after Sodhi, et al., 1981)

The average value of the ratio of ($\Delta P/\Delta w$) for increasing load increment, and for decreasing load increment, is used to calculate the characteristic length using an equation from the theory of an infinite elastic plate on an elastic foundation. From (ΔP/Δw) at the centre of the plate, the characteristic length of the ice sheet can be calculated by the equation described below.

$$l^2 = \left| \frac{\Delta P}{\Delta w} \right| \frac{1}{8k} Z \qquad (1)$$

where

$$Z = 1 + \frac{\alpha^2}{2\pi} \left| \ln \frac{\gamma\alpha}{2} - 5/4 \right|$$

(2)

where l is the characteristic length, k the specific weight of water, $\alpha = r/l$ and $\ln\gamma = 0.57721$ (Euler′s constant). It should be noted that Z is approximately equal to 1.0 for low values of α (<0.2).

The elastic modulus, E, of a model ice sheet is then obtained from the equation below:-

$$l = \sqrt[4]{\frac{Eh^3}{12\left(1-\nu^2\right)k}}$$

(3)

where h is the ice thickness. The Poisson′s ratio, ν, is assumed to be 0.3.

Quantities to be Reported. The Ice Committee recommends that the following be reported:-

(a) Thickness of model ice sheet
(b) Weight(s) used.
(c) Location in tank where loaded.
(d) Time-deflection curves (if possible)
(e) Calculated characteristic length and elastic modulus
(f) Time of day when measured

In applying the plate deflection method, there are two points that one should remember. The load, i.e. the weights, must be small enough not to cause any plastic deformation. And the loading point must be at a distance of at least four characteristic lengths from the tank walls. Discussions on the above mentioned cautions are seen in the ATTC′98 paper (ITTC Ice Committee, 1998)

Flexural Strength - Procedure. An in-situ cantilever beam method is recommended to measure the flexural strength of an ice sheet. Other methods such as three point bending method do not meet the requirements described above as well as the cantilever beam method.

A sketch of a test specimen is shown in Figure 3. A floating cantilever beam having length, L, and width, B, is cut in-situ. The tip of the beam is then loaded at a constant speed until the beam fails. The loading direction can be either upward or downward, which will be in the same bending direction as is anticipated in the scheduled model test.

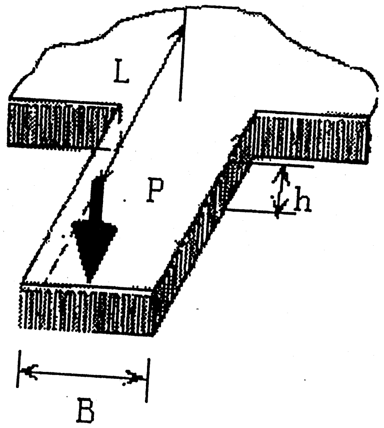

Figure 3. A sketch of cantilever test specimen

A typical time versus load plot for an in-situ cantilever beam bending test is shown in Figure 4. From this time versus load plot, the flexural strength σ_f is calculated from the following equation,

$$\sigma_f = \frac{6PL}{Bh^2} \tag{4}$$

where P the failure load, and h is the ice thickness.

The dimensions of a beam are recommended to be:-

$$L = (5 - 7)h \qquad B \approx 2h. \tag{5}$$

The loading speed, i.e. the displacement rate at the tip, is recommended to be about 1mm/sec. Too low a displacement rate may cause visco-plastic deformation, and too high a displacement rate may introduce an inertia effect.

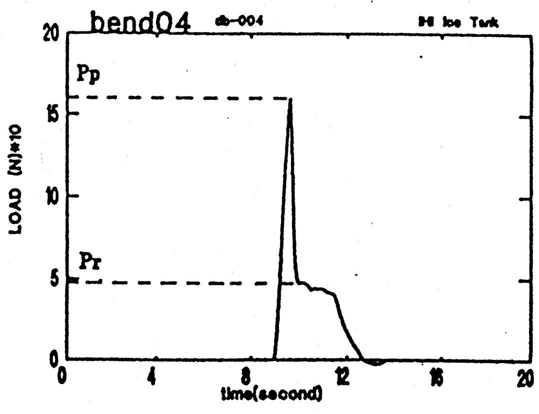

Figure 4. A typical time versus load plot for an in-situ cantilever beam bending test

Quantities to be Reported. The Ice Committee recommends that the following be reported:

(a) Dimensions of the beam, i.e. thickness, width and length (length should be the distance from the loading point to beam root).
(b) Failure load (Pp in Figure 4).
(c) Flexural strength calculated by equation (4) using Pp
(d) Time-deflection curves (if possible)
(e) Residual load (Pr in Figure 4) and associated stress (if needed)
(f) Time of day when measured

The in-situ cantilever beam test is based on the beam on a elastic foundation theory. The theoretical background and the care to be taken for applying this method is briefly described in the ATTC'98 paper (ITTC Ice Committee, 1998).

Specific Weight - Procedure. The procedure involved in the recommended procedure for measuring specific weight is, in principle, simple. Measuring the force necessary to just submerge a piece of model ice of known mass or volume is all that is required. The sketch of an appropriate apparatus is shown in Figure 5.

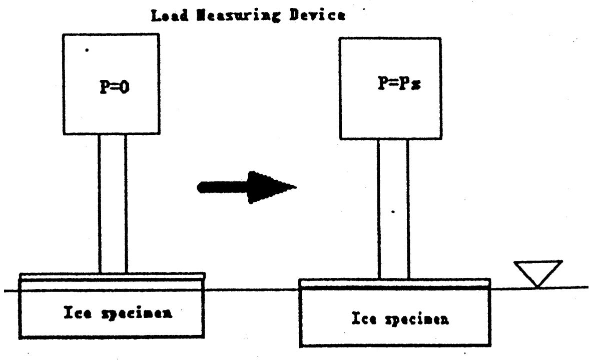

Figure 5. Sketch of an appropriate apparatus for measuring specific weight

The force, P_s, necessary to just submerge an ice piece is given by

$$P_s = (\rho_w g - \rho_i g)V \tag{6}$$

where ρ_i is the specific weight of ice, ρ_w is the specific weight of the tank water and V is the volume of the ice piece. This equation can be re-written as

$$\rho_i = \rho_w - \frac{P_s}{gV} \tag{7}$$

or, eliminating V,

$$\rho_i = \frac{M_i \rho_w}{M_i + P_s / g}, \qquad (8)$$

where M_i is the mass of the ice piece of volume, V. It can be seen from these two equations that one must measure either V or M_i as well as P_s in order to calculate ρ_i. It is also necessary to know the density of the tank water, ρ_w. In principle, it should be more accurate to use equation (8) and measure M_i rather than V. However, because of the weak nature of model ice, and the fact that brine drains out of it while being handled, thus changing M_i it is preferable to measure V and use equation (7).

Quantities to be Reported The Ice Committee recommends to report those quantities described below.

(a) Dimensions of the ice piece tested, i.e. its thickness, width and length. From these dimensions the volume is calculated
(b) Measured submergence load
(c) Specific weight of the tank water used, and the calculated specific weight of the model ice.

The theoretical background and some discussions are given in the ATTC'98 paper (ITTC Ice Committee, 1998).

2.2 Floating Compression Test (FC test)

Background. As mentioned in the previous section, there is no agreement on the standard testing method for compressive strength of model ice. Several methods have been proposed. The followings methods are most frequently used:-

a) in-situ compression test of unconfined cantilever beams
b) compression test using standard compression tester, which is used for materials such as steel or concrete.
c) indentation test of ice sheet

The Ice Committee of the 21st ITTC examined the above methods and concluded that each had shortcomings. In view of this, the Committee proposed a new method to measure compressive strength of model ice. The method was expected to be free of the shortcomings in the previous methods.

In the new test method, ice samples are cut out of an ice sheet and tested in-situ by a uni-axial compression tester. The test is performed without taking the ice samples out of the tank water, thus avoiding both possible damage and brine drainage from the specimen. The new test method was named the “floating uni-axial compressive strength test” (hereinafter called the FC test). Some trial tests were performed at the ice model basin of the Ishikawajima-Harima Heavy Industries, Ltd. (IHI) during the 21st ITTC term and those results were reported at the 21st ITTC (Performance in Ice-Covered Waters Committee, 1996).

At the second meeting of the present committee in Helsinki in October 1997, it was agreed to perform a "round robin" experiment of the FC test using the same apparatus at the different ice model basins of the committee members. Other ice model basins were also encouraged to join the round robin test.

Round Robin Test Description. Since the FC test requires special equipment, it was decided to circulate the tester used at IHI among the ice model basins. It was circulated to Ship Research Institute, Japan (SRIJ), NKK cooperation, Japan (NKK) and Institute for Marine Dynamics, Canada (IMD). The model ice used at the three basins was different. SRI used columnar-structured model ice doped with propylene glycol. NKK used urea doped granular model ice. IMD used columnar-structured EG/AD/S ice. They tested both Controllable-Density (CD) ice and non-CD ice.

Figure 6 shows the FC tester schematically. The tester is composed of two compression platens, a load cell, an electric motor and a rigid supporting frame. The tester is fixed to a carriage so that the platens are submerged midway. The motor drives one of them. An ice sample placed between the platens is compressed horizontally. The load exerted on the sample is measured by the load cell which has a capacity of 500 N.

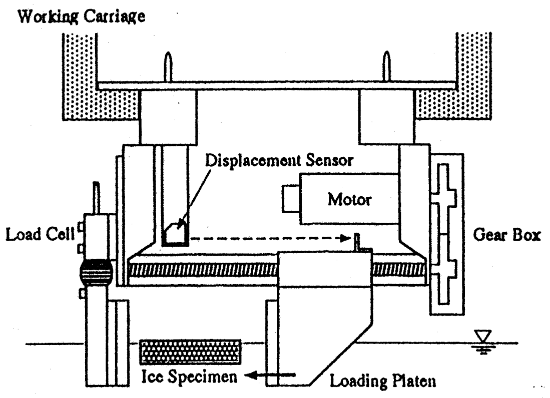

Figure 6 FC tester

In addition to the FC test, a compression test using another method was also performed for comparison. In the trial test at IHI, method (a) above was used. In the present "round robin" test, compression test using method (b) above (hereinafter named the on-land test) was performed as the comparative test at the three basins. To distinguish compressive strengths measured with the different methods, the following symbols are used;

σ_{CF}: compressive strength from FC test

σ_{CI}: compressive strength from indentation of ice sheet, method (c).

σ_{CL}: compressive strength by way of on-land test, method (b).

Test program was slightly different between the three basins. At SRIJ and IMD, tests were made for ice at different stages of tempering. The on-land tests were performed at a fixed strain-rate. On the other hand, tests at NKK were made over a short period of time so that the effects of tempering were not included in the test results. The on-land tests were, however, performed for a wide range of strain-rate so that they match those of FC test. This allows a direct comparison of the two testing methods.

Results. It is generally known that the compressive strength of ice is rate-dependent with the strength increasing with strain-rate. Results of the trial test at IHI, however, showed the compressive strength decreased as the strain rate increased up to 10^{-2} s^{-1} and then remained constant for higher rates. Figure 7 shows the effects of strain-rate on the test results at NKK together with those at IHI. Although the range of strain-rates used at the two tanks was different, it is seen that the NKK results do not show as clear a dependence on the strain-rate as seen in the results at IHI.

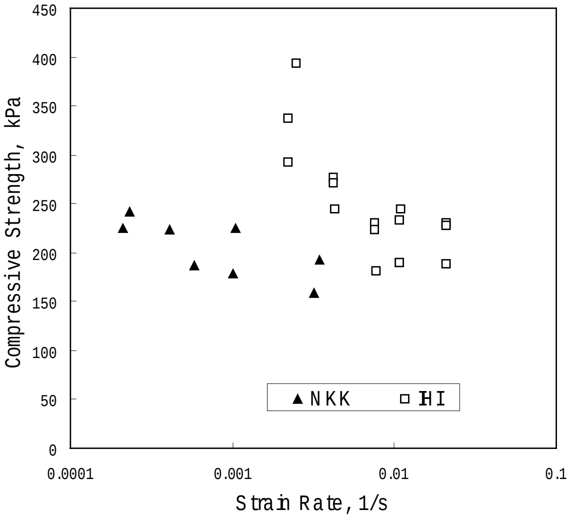

Figure 7 Strain-Rate Dependence of FC test

Figure 8 also shows strain-rate dependence of the compressive strength obtained at SRIJ and IMD. Since tests at these two tanks were performed at different times during the tempering, or warming up, of the ice, it would be misleading if the results were directly plotted as in Figure 7. To eliminate the effects of warm-up time in the results of the FC test, results of the on-land test were used as a reference strength, because the test was performed for a fixed strain-rate, which was 2.5×10^{-2} and 2.0×10^{-2} s^{-1} at SRIJ and IMD, respectively. The FC tests were performed for strain-rates

$3.0x10^{-3}$, $6.0x10^{-3}$ and $1.2x10^{-2}$ s^{-1} at SRIJ, and for $4.0x10^{-3}$, $1.0x10^{-2}$ and $2.0x10^{-2}$ s^{-1} at IMD. Figure 9 shows the ratio of σ_{CF}/σ_{CL}. Average values at each strain-rate are shown. In general, there is a slight decreasing trend of strength ratio with increasing strain-rate. The trend, however, is not so clear as that obtained at IHI. It must also be remembered that the range of strain-rates used in all the tests was quite small.

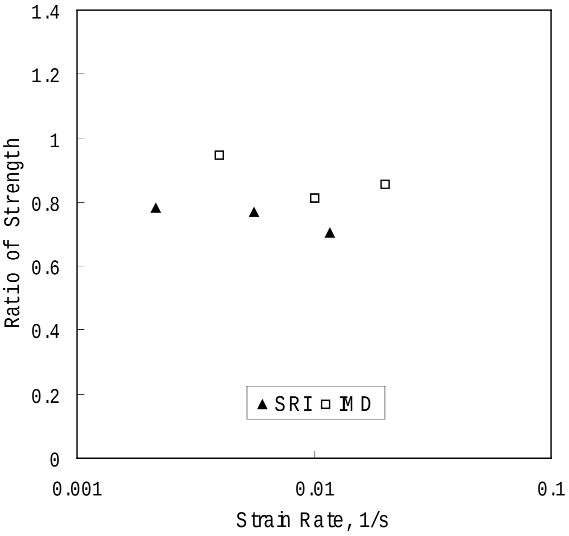

Figure 8 Strain Rate Dependence of FC test

From a practical point of view of model testing in ice, it is of interest to compare the results of the FC test with other methods of measuring compressive strength. The trial tests at IHI gave a correlation $\sigma_{CI} = 0.6\sigma_{CF}$ between the results of FC test and an indentation test. Figure 9 shows the correlation between σ_{CF} and σ_{CL} obtained at NKK and IMD. In plotting IMD's data, results of the FC test only at the strain-rate of $2.0x10^{-2}$ s^{-1}, which is equivalent to that of the on-land test, were used. The figure shows that result of FC test is higher than that of on-land test at NKK, while IMD gives an opposite result. The ratios of σ_{CF}/σ_{CL} are about 1.5 and 0.8 for NKK and IMD, respectively. There is no data available to include in Figure 9 from test results of SRIJ, because the range of strain-rate for FC test did not include that of the on-land test. If the trend shown in Figure 8 is extrapolated to a strain rate of $2.5x10^{-2}$ s^{-1}, however, a ratio of $\sigma_{CF}/\sigma_{CL} = 0.7$ would be obtained.

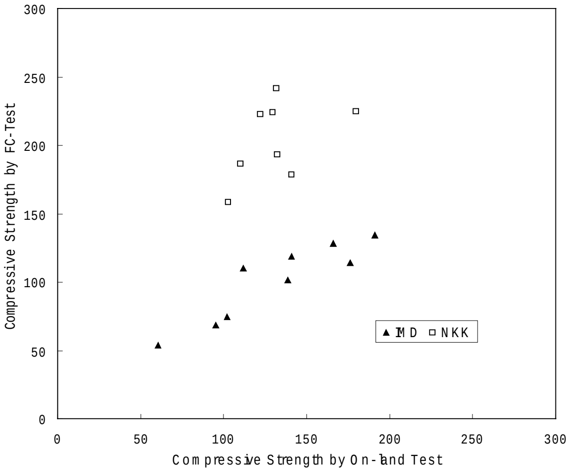

Figure 9 Comparison of Testing Methods

<u>Summary</u> Since test results from only four ice tanks are available at present, it is premature to make an evaluation of the FC test as a method for the compression testing of model ice. It is hoped that the comparative study will be continued at other ice tanks. However, it is felt that the FC test is technically more difficult to perform than other compression tests such as the on-land test. In a compression test, for instance, great care should be taken in shaping the loading surfaces of the specimen so that they are smooth and parallel each other. It is very difficult to achieve this, however, when the ice sample is cut while in the water. Imperfect loading surfaces will affect the result. The idea of the FC test is a promising one as a new method of compression test at ice tanks. It is felt, however, that improvements are required in the devices and techniques associated with the test method to obtain more reliable and consistent results. At this stage the Committee does not feel that the FC test should be recommended as a standard testing method for compressive strength

of model ice.

2.3 Fracture Toughness Similitude Requirements for Model Ice Testing

Atkins (1995) showed that to achieve similitude between model and prototype for the fracture of ice, the following equation must be satisfied:

$$\frac{v_p^2 \rho_p \sqrt{L_p}}{K_{Cp}} = \frac{v_m^2 \rho_m \sqrt{L_m}}{K_{Cm}} \qquad (9)$$

where the subscripts p and m refer to prototype and model values respectively, ν is the velocity of interaction, ρ is the density of the ice, L is the length scale, and K_C is the fracture toughness. Accordingly, to satisfy the fracture similitude, the toughness of the model ice is easily related to that of the prototype fracture toughness by the following relation:

$$K_{Cm} = \left| \frac{v_m}{v_p} \right|^2 \left(\frac{\rho_m}{\rho_p} \right) \sqrt{\frac{L_m}{L_p}} K_{Cp} \qquad (10)$$

Thus, to use fracture toughness as a model scaling parameter, it is necessary to know both the prototype and the model values of fracture toughness. This raises a number of problems.

First, measuring fracture toughness of sea ice is rather difficult. A series of large scale experiments by Dempsey and co-workers (Mulmule et al., 1995; Adamson et al., 1995; Adamson et al., 1997; Bentley et al., 1988; Dempsey, 1991) has shown that the fracture toughness is scale dependent. They also demonstrated that considerable care must be taken to get representative values of toughness. The existing database of fracture toughness values from prototype scales is very limited, and no great confidence in existing values exists.

Second, only limited use of the fracture toughness test has been tried with model ice (Parsons and Snellen, 1985; Timco, 1986). As can be seen elsewhere in the report, developing good test techniques for such simple tests as cantilever beam tests is not straightforward. Extending this to obtain recommended procedures for the far more complex fracture toughness test would be difficult.

However, while the use of fracture toughness as a scaling parameter for ice towing tank tests is at present very limited, there is good reason to believe that this may be crucial for certain types of tests in which ice fracture (and especially floe splitting) is a dominant process.

It appears at this time that the most suitable type of specimen geometry for in-situ fracture tests would be a centre or edge cracked plate (see Figure 10) that is loaded in displacement control (Vincent and Dempsey, 1999). This will provide a reasonable measure of crack resistance for a vertically oriented crack propagating in a horizontal direction through an ice sheet.

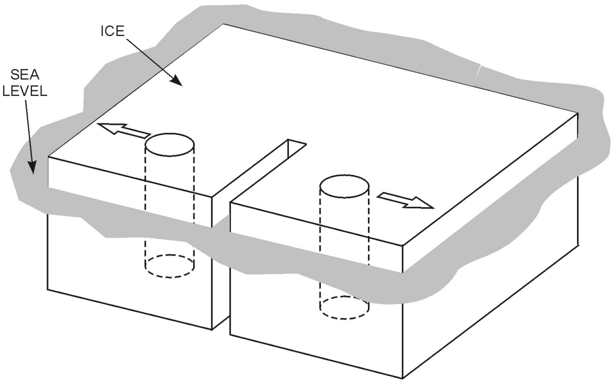

Figure 10 An example of a suitable fracture toughness specimen - the edge cracked plate

However, it should be noted that considerable care is needed in choosing the size of such a sample. The size requirements at full scale given by Mulmule and Dempsey (1998) are:

$L / d_{av} \geq 200$ (Homogeneity Requirement)
$L \geq 10\ l_{ch}$ (Process Zone Requirement)

Where d_{av} and l_{ch} are the average grain size and characteristic length respectively, and L is the specimen size in the cracking direction.

In addition to the size issue there is also concern about the orientation of the crack. The work of Dempsey and others has concentrated on a vertically oriented crack that has fully penetrated the ice sheet and is propagating in a horizontal direction (see Figure 11). There are two other cracking orientations which must be considered. A crack may be oriented horizontally and propagating in an essentially horizontal direction (see Figure 12). This sort of cracking is a necessary part of any spalling process, which is often a critical failure mechanism in certain interactions. A crack may also be oriented vertically and propagating in a vertical direction (see Figure 13). This happens when an ice sheet fails in bending.

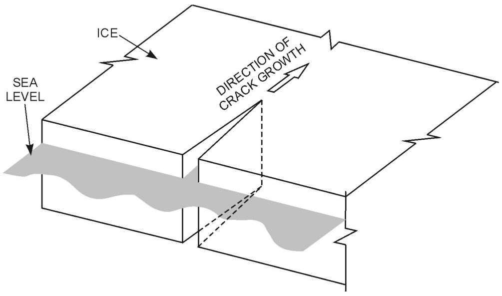

Figure 11 A vertical crack in an ice sheet, propagating horizontally

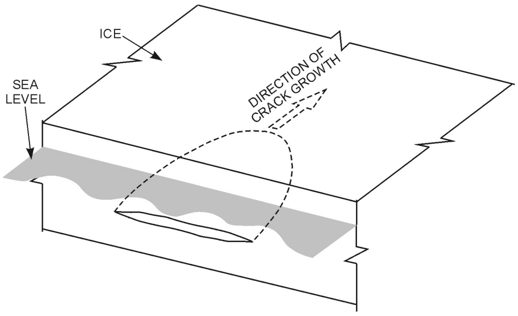

Figure 12 A horizontal crack, propagating horizontally

At present there are no data available for either of these other crack orientations, and until such time as both a reliable measurement method, and an appropriate database of full-scale values have been developed for such orientations, it will not be possible to scale such fracture processes. Accordingly, the committee recommends that effort be expended to advance this area of knowledge and to develop appropriate methodologies that would allow fracture toughness testing to become more common.

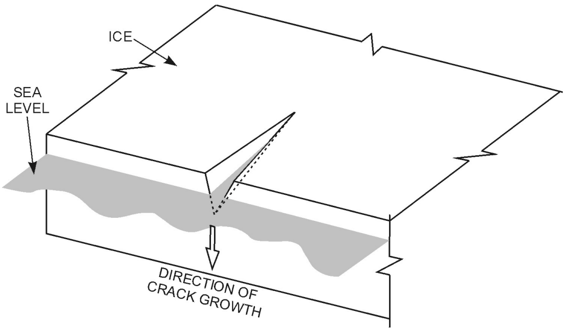

Figure 13 A vertical crack, propagating vertically

2.4 Mechanical Properties of Ridges

In model tests in ice, the normal well defined ice condition is the uniform smooth level flat ice, which in practice only exists in nature in areas where there are restrictions to ice movement, such as in archipelagos, rivers and lakes. In open sea areas such well defined ice condition are unlikely to be met. More likely the ice conditions at sea are a mixture of all possible types of ice, and thus very difficult to define in a simple way. In the real world the ice conditions may consist of, for instance, the following different ice types: ridges (first year or multi-year), rubble fields (“uniform” thick rubble with large horizontal dimensions), pack ice (a mixture of ice floes with different coverage concentration) and rafted ice (two or several layers of flat ice piled on top of each other).

A vessel route, or an ice field drifting against an offshore structure, will typically consists of many of the above ice conditions. To be able to predict the behaviour of a whole transportation chain, the capability of an individual vessel in each of the ice conditions must be defined as well as possible.

The use of ice model tests in solving these questions is becoming more and more practical. Each piece in the transportation chain has its own requirements, and design basis. In each ice condition the parameters needed for the design basis are different. In the case of ice ridges the following main parameters can be used for helping the design work:-

- thickness of level ice
- total thickness of the ridge
- thickness of the consolidated (ice blocks frozen together) layer in the ridge
- strength of the consolidated layer
- longitudinal profile of the ridge
- size of ice blocks in the ridge (distribution)
- porosity
- ridge shape (sail, keel)

Keeping the above in mind, a questionnaire was sent to fourteen (14) laboratories. The tabulated results are presented in Table 1 on the following page. A short summary of the results is in the following:

<u>Q1: What kind of ridges do you simulate in your basin?</u>

- Thirteen (13) laboratories simulate first year ridges.
- Seven (7) simulate also multi-year ridges and eight (8) rubble fields. Also one (1) laboratory reported simulating thick non-uniform ice.

In this basic definition the laboratories seem to be in the same direction. Of course some of the differences are related to the size of the facilities and line of testing performed.

<u>Q2: How do you build the ridges?</u>

- Almost all the laboratories (12) use the same methods for ridge/rubble building: Crush ice into pieces and collect them together.
- Also compressing the broken ice pieces against a rubble generator (1 laboratory) is an alternative for building a ridge.
- Use of thick beams (1 laboratory).
- Build the ridge out of two basic ice thicknesses (1 laboratory).
- Push a weakened ice sheet against an transverse beam to form rubble (1 laboratory).

<u>Q3: What are the typical properties of the sheet ice you use for ridge building, you define /measure?</u>

- All the laboratories measure the ice thickness and block size of the basic ice.
- Majority (10-12) measure also the flexural strength, elasticity and density of ice.
- compressive strength of the basic ice is not paid much attention (5).

<u>Q4: What measurements of the ridge properties you perform?</u>

- A thickness profile across the ridge is measured by all laboratories. Profile along the sail of the ridge is not measured by all laboratories (10).
- Most of the laboratories (9-10) measure the properties of the consolidated layer of the ridge.
- Porosity is defined by (10) laboratories.

A group of parameters defined as the inner properties of a ridge is not normally measured as standard procedure by any laboratory. Only three laboratories pay attention to these, which basically give answers to the behaviour of the ice outside the consolidated layer of the ridge.

Table 1 Summary of response to model ridge property questionnaire

		-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14	COUNT
1. What kind of ridges do you simulate in your basin?																
-first year		X	X	X	X	X	X	X	X	X	X	X	X		X	13
-multiyear		X	X	X	X				X			X	(X)			7
-rubble field		X		X			X				X	X	X	X	X	8
-other												X				1
2. How do you build the ridges?																
-Crush ice to pieces and collect them together			X	X	X	X	X	X	X	X	X	X	X	X		12
-Cut the ice sheet into long stripes and pile them on top of each other				X							X					2
-Other method		X			X		X								X	4
3. What are the typical properties of the sheet ice you use for ridge building you define/measure?																
- block size		X	X	X	X	X	X	X	X	X	X	X	X	X	X	14
- ice thickness		X	X	X	X	X	X	X	X	X	X	X	X	X	X	14
- flexural strength of ice sheet		X	X	X	X		X	X	X	X	X	X	X		X	12
- compression strenth of ice sheet		R	X				X	X		X			R			6
- density of ice		R	X	X	X		X	X		X		X	X	X		10
- elasticity of ice sheet		R	X	X	X		X	X		X	X		X		X	10
- other					X								R			2
4. What measurements of the ridge properties you use?																
- thickness profile	* longitudinal	R		X	X	X		X	X		X		X	X	X	10
	* transverse	X	X	X	X	X	X	X	X	X		X	X	X	X	13
- degree of consolidation		X	X				X	X	X	X	X	X	X		X	10
- strength of consolidation layer		X	X	X		X		X	X			X	X		X	8
- porosity		X	X			X	X	X		X	X		X	X	X	10
- inner properties of ridge							X	X					X			3
R = on request		-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14	COUNT

This brief questionnaire did not reveal any substantial differences in the methods of the different laboratories. There are some minor differences because of the different model ices used at the different laboratories. The conclusion of the questionnaire can be put into the following frame:

- Building of the ridges is done using similar methods at different ice tanks.
- Basic ice property measurements are also similar at the different tanks.
- The measurement of properties of the ridges themselves has the most potential for development. There still seems to be some lack of understanding of the importance of the properties of the consolidated layer, and even more so for the properties of the inner part of the ridge.

3. MODEL TEST PROCEDURES FOR DEFORMED ICE

Ice model tests are mostly done in well defined conditions, and less attention has been paid to conditions that are practically prevailing in ice covered seas. In addition to smooth level ice the following conditions are met, all of which consist of deformed ice:

- ridges (rubble fields)
- pack ice
- channels of different types
- rafted ice
- ice under pressure

A questionnaire was sent to fourteen (14) laboratories. The results are presented in Table 2 on the following page. A short summary of the results follows:

<u>Q 1: What kind of deformed ice do you simulate?</u>

- Thirteen (13) laboratories simulate ridges/rubble fields.
- Eleven (11) simulate pack ice.
- Seven (7) also rafted ice and ice under pressure.

The focus has been more on difficult open sea conditions rather than in the channels which are in many cases located in areas of restricted water ways, and thus may be one of the design criteria. However, those laboratories which do not perform tests in channels have concentrated more in work with offshore structures.

<u>Q 2.1: Pack ice/ice field: Do you define ice properties?</u>

- Almost all the laboratories (9), which conduct tests in pack ice measure the degree of coverage and seven (7) measure the piece size of ice blocks.

<u>Q 2.2: Pack ice/Tests: What tests do you perform in pack ice fields?</u>

- All the laboratories (9) perform towing tests in pack ice.
- Propulsion tests are conducted by five (5), towed propulsion, and seven (7), self propulsion.
- Other type of tests like manoeuvring are done by four (4) laboratories.

<u>Q 3.1: Channels/fresh new: What ice properties you define?</u>

- All the (9), which conduct tests in fresh new channels measure ice properties in the parent ice sheet..
- Eight (8) define the degree of ice coverage in the channel.
- The governing factor in the channel, the piece size of the ice blocks is measured by only six (6) laboratories.

<u>Q 3.2: Channels/fresh new: What kind of tests do you perform in a fresh new channel?</u>

- All the (9) laboratories, which conduct tests in fresh new channels make towing tests.

- Five (5) use the self propulsion test method while (6) the towed propulsion method.

Q 3.3: Channels/old: What ice properties do you define?

- All the (4), which conduct tests in old channels, measure ice properties in the parent ice sheet.
- Three (3) define the piece size in the channel.
- Four (4) define also the age of the channel.

Making tests in old channels is not as common as in fresh new channels. This is due to the difficulty of building of the channel and lack of proper scaling factors for full-scale predictions.

Q 3.4: Channels/old: What kind of tests do you perform in an old channel?

- All (4) the laboratories, which conduct tests in old channels make towing tests. Two (2) use the self propulsion test method and (3) the towed propulsion method.

Q 4.1: Rafted ice: How do you prepare a rafted ice field?

- All (7) the laboratories, which conduct tests in rafted ice put level ice layers on top of each other. Two (2) laboratories also grow level ice to double thickness.

One possibility is to make a level ice sheet of two different thicknesses. This is of course dependent on the ice making procedure used in the tank.

Q 4.2: Rafted ice: What properties do you define in a rafted ice field?

- All (7) the laboratories, which conduct tests in rafted ice define the basic ice properties as in level ice.

Q4.2: Rafted ice: What tests do you conduct in a rafted ice field?

- Five (5) laboratories conduct towing tests and self propulsion tests in rafted ice.
- Four (4) use the towed propulsion method as well.
- Other type of tests like ramming are conducted by three (3) laboratories

Q5: Ice under compression: Do you conduct tests in ice under compression?

- Four (4) laboratories conduct tests in level ice under pressure
- Three (3) laboratories conduct tests in pack ice fields and ridges under pressure.
- Only one (1) laboratory has made tests in both ice channels and rafted ice.

This brief questionnaire did not reveal any substantial differences in the testing practices of the different laboratories. The more undefined is the full-scale ice condition, the more uncertain is the modelling. Perhaps the lack of full-scale information is one reason for not making tests in these difficult conditions. Test results in these ice conditions have a large scatter and, therefore, definite conclusions are difficult to make. However, the committee wishes to encourage the development of testing methods for these more realistic ice conditions, in order to better understand the complexity of the interaction between ice and ships or structures.

The conclusion of the questionnaire can be summarized as follows:-

- Ice conditions more complicated than level ice and ridges are not simulated very often. The building and controlling of the model ice for such conditions is difficult.
- Tests in these uncommonly simulated conditions are mostly simple towing tests.

Table 2 Summary of response to model test in deformed ice questionnaire

		-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	COUN
1. What kind of deformed ice do you simulate?															
	Ridges	X	X	X	X	X	X	X	X	X	X	X		X	12
	Pack Ice	X	X	X		X	X	X	X	X	X	X			10
	Channels	X	X				X	X		X		X		X	7
	Rafted Ice	X	X		X		X	X				X		X	7
	Ice Under Pressure	X		X			X			X		X			5
	Other	X													1
2. Pack Ice															
2.1. Ice Field	Ice Properties	X	X	X		X	X	X		X	X	X			9
	Degree of Coverage	X		X		X	X	X	X	X	X	X			9
	Piece Size			X		X	X	X		X	X	X			7
2.2. Tests in Pack Ice	Towing Tests	X	X	X		X	X	X	X	X		X			9
	Towed Propulsion	X	X	X					X			X			5
	Self propulsion	X	X	X				X	X	X		X			7
	Other		X	X					X		X	X			5
3. Channels															
3.1. New Channel	Ice Properties	X	X	X			X	X		X		X	X	X	9
	Degree of Coverage	X	X	X			X	X				X	X	X	8
	Piece Size in Channel	X		X				X				X	X	X	6
3.2. Tests in New Channel	Towing Tests	X	X	X			X	X		X		X	X	X	9
	Towed Propulsion	X	X	X			X					X		X	6
	Self propulsion	X	X	X				X				X			5
	Other		X									X			2
3.3. Old Channel	Ice Properties	X					X					X	X		4
	Piece Size in Channel	X										X	X		3
	Age of Channel	X					X					X	X		4
3.4. Tests in Old Channel	Towing Tests	X					X					X	X		4
	Towed Propulsion	X					X					X			3
	Self propulsion	X										X			2
	Other											X			1
4. Rafted Ice															
4.1. How do you prepare a rafted ice field?	Composition of two sheets	X	X	X	X		X					X		X	7
	Grow sheet ice to double thickness		X									X			2
	Other											X			1
4.2. Do You Measure?	Ice Properties	X	X	X	X		X					X		X	7
4.3. Tests in Rafted Ice	Towing Tests	X	X	X						X		X			5
	Towed Propulsion	X	X	X								X			4
	Self propulsion	X	X	X								X		X	5
	Other	X	X		X							X			4
5. Ice Under Pressure	Level Ice			X			X			X		X			4
	Pack Ice	X					X					X			3
	Channels											X			1
	Rafted ice											X			1
	Ridges	X					X					X			3
		-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	COUN

- The simulation of a self-propelled vessel is relatively rare. Perhaps this is due to increased scatter and interpretation of the results.

4. MODEL TEST PROCEDURES FOR STRUCTURES

In February 1998, a questionnaire was sent out to all ice tanks requesting information regarding the model testing of structures, as opposed to ships, in ice. Responses were received from 13 tanks:-

- Arctic and Antarctic Research Institute (I. Stepanov)
- Helsinki University of Technology (K. Riska)
- HSVA (K-U. Evers)
- IHI (K. Kato)
- Iowa Institute for Hydraulic Research (W. Nixon)
- Krylov Shipbuilding Research Institute (K. Sazanov)
- Masa Arctic Research Centre (G. Wilkman)
- Mitsubishi Heavy Industries (S. Ishikawa)
- NKK (S. Kishi)
- NRC/Canadian Hydraulics Centre (G. Timco)
- NRC/Institute for Marine Dynamics (S.J. Jones)
- SRI (K. Izumiyama)
- VTT Building Technology (E. Lehmus)

This report is an attempt to summarize the responses and if possible draw some conclusions.

Question 1: What type of structures have you tested?

Nearly all tanks have tested all types of structures mentioned, namely vertical, sloping, floating and fixed structures.

Question 2(a): What is a typical size or scale factor of your model?

Typical scales are in two groups depending on the size of the facility. Smaller tanks use scales of approximately 1:50 to 1:100. Larger tanks uses scales of approximately 1:15 to 1:50.

Question 2(b): What is typical ice thickness? (cm)

Typical ice thicknesses lie in the range 2-10 cm for all tanks.

Question 2(c): What is typical speed of testing? (cm/sec)

Responses covered a fairly wide range of 0.1 to 50 cm/sec reflecting the different scales used in the different tanks.

Question 3: In what ice conditions have you tested structures?

All tanks have tested in level ice, of course. Only 5 of the 12 have attempted multi-year ridges but 10 have attempted first year ridges. Rubble has been attempted by 8 tanks and one reported trying non-uniform thickness ice.

Question 4: Do you usually move your structure on a carriage through fixed ice, or push your ice against a fixed structure?

Most tanks (10 of 12) usually move a structure on a carriage through fixed ice. Four had used both methods.

Question 5: Have you ever tested a compliant structure? A segmented structure?

The first part of this question, compliant structures, may have been misunderstood in that tanks may have included any floating structure as compliant, which is not what was intended in the question. However, 8 of 12 tanks reported testing a compliant structure.

A segmented structure has been tested by 8 tanks.

Question 6: What ice properties would you *normally* measure in a structure test? (level ice only)

As expected, almost all talks (10/12) normally measure flexural strength, compressive strength, and ice thickness. Elastic modulus is normally measured by 8 tanks. Other properties, ice density, friction coefficient, crystal structure are normally measured by only a few labs (4).

Question 7: What do you typically observe?

Failure pattern, model speed, friction coefficient, and ice loads are measured by all tanks. Model acceleration is typically measured by 6, and model stiffness by 7. Other items mentioned by individual tanks were moments, and load transmitted to seafloor, local pressures and ice/ice friction.

Question 8: What are the major problems you see with this work?

One item was mentioned by 5 tanks in different words, namely, the lack of reliable full-scale data. Two tanks expressed concern about ridge properties, both controlling and measuring them. One felt that getting the right failure mode was a problem.

Question 9: Can you give a reference to your recent work that is freely available in the published literature? Or a publicly available report?

Eleven of the twelve tanks provided reference lists of varying lengths.

Question 10: Any further comments would be welcome

One tank stated that the committee should not prepare a static guideline, but give rational recommendations according to the up-to-date understanding of the problems. They felt that the techniques are not fully developed and stating guidelines might hinder further development.

Conclusions. There were no big surprises in the survey. Institutes have tested fixed and floating structures of a size suitable to their facility. Most had attempted to model non-uniform ice conditions. The major problem seen by most tanks was the lack of reliable full-scale data against which to calibrate the model test results. The survey will be useful for drawing up recommended procedures for structures testing in ice.

5. UP-DATED LIST OF ICE TANK FACILITIES

The Ice Committee asked all existing ice tanks in the world (including a non-ITTC member organization) to inform the Committee a contact person of each ice tank. Table 4 summarizes all the information received.

Table 3 Summary of responses to structure model tests questionnair

Tank Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Qu. 1 What type of structures have you tested?													
Vertical	X	X	X	X	X	X	X	X	X	X	X	X	X
Sloping	X	X	X	X	X	X	X	X	X	X	X	X	X
Fixed	X	X	X	X	X	X	X	X	X	X	X	X	X
Floating	X	X	X		X				X		X	X	X
Qu. 2(a) What is typical size, or scale factor, of your model?													
	1:15-1:40	2.0m w.	0.5m w.	1:26 - 1:40	1:20 - 1:60	1:50-1:100	1:50-1:100	see (1)	1:20-1:40	see (2)	see (3)	1:12-1:30	1:25-1:50
Qu. 2(b) What is typical ice thickness? (cm)													
	2 - 6	max 12	2 - 3	2 - 6	2 - 4	1.5 - 3.5	4 - 10	1 - 2	2 - 6	2 - 5	see (4)	2 - 8	2 - 4
Qu. 2(c) What is typical speed of testing? (cm/s)													
	0.1 - 10	max 100	0.7 - 7	2.0 - 25	0.5 - 2.5	1.0 - 10	0.6 - 10	0.1-50	0.1-30	0.05-40	see (5)	5 - 40	0.1 - 20
Qu. 3 In what ice conditions have you tested structures?													
Level Ice	X	X	X	X	X	X	X	X	X	X	X	X	X
Ridges, MY		X	X				X		X			X	
Ridges, FY	X	X	X	X	X	X	X		X		X	X	
Rubble	X		X	X see (6)	X				X		X	X	X
Qu. 4 Do you usually move your structure on a carriage through fixed ice, or push your ice against a fixed structure?													
Move struc.	X	X	X	X	X	X	X	X	X	X	X, usual	X	X
Move ice	X	X, usual			X						X		X
Qu. 5 Have you ever tested?:-													
compliant st.	X, offsh. pl.			X, several	X		X		X, float.st.	X		X, float.st.	X
segment st.	X, ship hull	X	X,cyl./cone	X, several	X		X		X			X	
Qu. 6 What ice properties would you *normally* measure in a structure test? (level ice only)													
flex. str.	X, up/dn	X	X, slope st.	X	X	X	X, slope st.	X	X	X	X	X	X
comp. str.	X		X, vert.st.		X, indentor	X	X, vert. st.	X	X	X	X	X	
elastic mod.	X	X			X			X		X	X	X	X
ice thick.	X	X	X	X	X			X	X	X	X	X	X
density		X			X, sometime			X	X			X	X
friction coef.						X			X			X	X
crystal st.						X		X					

Table 3 Summary of responses to structure model tests questionnair (continued)

Qu. 7 What do you *typically* observe?

failure patt.	X	X	X	X	X	X	X	X	X	X	X	X	X
ice loads	X	X	X	X	X	X	X	X	X	X	X, 6 comp	X	X
model accel.		X		X			X	X	request	X	somtime	usually	
model speed	X	X	X	X	X, ice speed	X	X	X	X	X	X	X	X
model stiff.			X	X	X		X	X	not usual	X		X	
friction coef.	X	X	std.coating	X	X	X	X, slope str.		not usual	X	X	X	
other				X, moments	X,seaflr.load						loc.pres.	moment	

Qu. 8 What are the major problems you see in this work?

Ratio of compressive to bending strength
Deficient theoretical basis
Ridge test - how to control or measure its properties (2 tanks similar)
Vertical structure: continuous crushing at low speeds difficult
Sloping structure: do not think Froude number is suitable for velocity effects on ice loads
Validation against reliable full-scale data (5 tanks said similar)
Observation of local ice failure in real time
No standard definition of ice load: mean? peak? mean + standard deviation? etc.
Investigation of ice loads accounting for a flexible bottom
Getting right failure mode

Qu. 9 Can you give a reference to your recent work that is freely available in the published literature? Or a publicly available report?

X	X	X	X		X	X		X	X	X	X	separate list

Qu. 10 Any further comments would be welcome

VTT	Our basin is not used for small scale testing. We've done research only for simulating the ice-structure interaction in reduced scale with real ice. Besides we've done also other tests like oil-spill in icy conditions and friction between ice and some other materials.
HSVA	The committee should not prepare a static guideline but give rational recommendations according to the up-to-date understanding of the problems. The technique is not fully developed and stating guidelines might hinder further development.

NOTES:-

1. Only physical modelling
2. For sloping structure: 50 - 80 cm diam. at the waterline. For vertical structure: 10-20 cm in diameter or width
3. The main factor
4. Is taken into account
5. Is taken into account
6. Non-uniform thickness of ice

Table 4 List of Ice Tank Facilities (1998.12)

Organization	Mailing address	Contact person	Tel/Fax/E-mail
AARI, State Research center of the Russian Federation Arctic and Antarctic Research Institute	38 Bering street, St. Petersburg, 199397 Russian Federation	I.V. Stepanov	+7-812-3521003 +7-812-3522688 aaricoop@aari.nw.ru
CHC, Canadian Hydraulic Center National research Council Canada	Montreal Road, Building M-32, Ottawa, Canada K1A OR6	G.W. Timco	+1-613-993-6673 +1-613-952-7679 garry.timco@nrc.ca
HSVA, Hamburg Ship Model Basin	Bramfelder Strasse 164, D - 22305, Hamburg, Germany	K.-U. Evers	+49-40-69203-426 +49-40-69203-345 evers@hsva.de
HUT, Helsinki University of Technology, Ship Laboratory	P.O. BOX 5300 FIN - 02015 HUT FINLAND	K. Riska	+358-9-4513498 +358-9-4513493 kaj.riska@hut.fi
IHI, Ship Model Basin, Research Institute, Ishikawajima-Harima Heavy Industries Co., Ltd.	1 Shin-nakaharacho, Isogoku, Yokohama, PC 235-8501, Japan	K. Kato	+81-45-759-2086 +81-45-759-2185 kazuyuki_katou@ihi.co.jp
IIHR, Iowa Institute of Hydraulic Research,	The University of Iowa, 404 Hydraulic Laboratory, Iowa City, Iowa 52242-1585, USA	W. Nixon	+1-319-335-5166 +1-319-335-5238 wanixon@icaen.uiowa.edu
IMD Institute for Marine Dynamics National Research Council	Kerwin Place, Memorial University Campus, P.O.Box 12093, Station A, St. John's,	S.J. Jones	+1-709-772-5403 +1-709-772-2462 sjones@minnie.imd.nrc.ca
KSRI Krilov Shipbuilding Research Institute	Moskovskoe Shosse 44, 196158, St. Petersburg, Russia	V. A. Beljashov	+7-812-127-93-48 +7-812-127-93-49
MARC Kvaener-Masa Yards Arctic Research Centre	Kaanaantie 3 A, FIN-00560, Helsinki, Finland	G. Wilkman	+358-9-1942540 +358-9-1942527 goran.wilkman@kmy.mass-yard.fi
MHI Nagasaki Research & Development Center	5-717-1 Fukahoricho, Nagasaki, Nagasaki Pr. PC 851-0392, Japan	S. Ishikawa	+81-958-34-2600 +81-958-34-2605 ishikawa@ngsrdc.mhi.co.jp
NKK Tsu Research Laboratory NKK Corporation	1 Kumozukokancho, Tsu, Mie Pr. , PC 514-0393, Japan	S. Kishi	+81-59-246-3031 +81-59-246-2790 skishi@lab.tsu.nkk.co.jp
SRI Ship Research Institute Ministry of Transportation	6-38-1 Shinkawa, Mitaka Tokyo, PC 181-0009, Japan	K. Izumiyama	+81-422-41-3154 +81-422-41-3152 koh@srimot.go.jp
TU Faculty of Ocean Engineering, Tianjin University	P.O. Box 9, Ba Li Tai Post Office 300072, Tianjin, China	X. Chen	+86-22-83710035 +86-22-83710082 xingchen@public.tpt.tj.cn
USACRREL US Army Cold Regions Research and Engineering Laboratory	72 Lyme Road, Hanover, NH, 03755-1290, USA	J.-C. Tatinclaux	+1-603-646-4361 +1-603-646-4477 jctatin@crrel.usace.army.mil
VTT VTT Building Technology Technical Research Centre of Finland	P.O.box 1807, Fin-02044 VTT, Finland	T. Hyvonen	+358-9-456-6910 +358-9-456-7003 Tauno.Hyvonen@vtt.fi

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7. COMMENTS FOR THE ITTC RECOMMENDED PROCEDURES

The Ice Committee of the 22nd ITTC has reviewed the pertinent sections of the draft of ITTC Recommended Procedures (hereafter, the Draft), and the Ice Committee has the following comments for the Draft.

The Draft represents a significant amount of work, that is most impressive, especially given the short period of time in which it has been undertaken. In reviewing the various sections of the Draft, the committee found three levels of response to the sections. These three levels are:

Category1: Some sections are acceptable with minor editorial changes.

Category2: Some sections are not acceptable. They should not be published at the present time, but need to be completely rewritten by the next committee.

Category3: Some sections are clearly on the right lines, but are incomplete and in need of substantial revision (beyond the scope of the current committee’s work) prior to publication.

The committee placed each section into categories as indicated below:

Category 1:
  Ship trials in Ice (4.9-03 03-04.3)
Category 2:
  Test Methods for Model Ice Properties (4.9-03 03-04.1)
  General Guidelines (4.9-03 03-04.2)
  Tests in Deformed Ice (4.9-03 03-04.2.4)
Category3:
  Ice Resistance Tests in Level Ice (4.9-03 03-04.2.1)
  Propulsion Tests in Ice (4.9-03 03-04.2.2)
  Manoeuvring Tests in Ice (4.9-03 03-04.2.3)

Specific comments on each section are as follows:

Test Methods for Model Ice Properties (4.9-03 03-04.1)

This whole section should be deleted and replaced with the new recommended procedures given in the report to the 22nd ITTC.

General Guidelines (4.9-03 03-04.2)

This section is not acceptable in its current form. It should be extensively rewritten, omitting all mention of ship models and concentrating on description of facilities and the type of ice used in those facilities. It should serve as a general introduction to the ice testing section of the Quality Manual, and should be numbered as 4.9.-03 03-04.1 The previous section (on Ice Properties) should take the number 4.9.-03 03-04.2.

Ice Resistance Tests in Level Ice (4.9-03 03-04.2.1)

The committee feels that this section is in general focused correctly but needs significant revisions before being acceptable. In particular, the section on friction should be removed, and a new section dealing with friction measurements alone (which apply to almost all tests) should be written.

Propulsion Tests in Ice (4.9-03 03-04.2.2)

Again the committee feels that this section is heading in the correct direction, but needs substantial revision before being acceptable. It is in general not very accessible to the reader, and the main message does not get through well.

Manoeuvring Tests in Ice (4.9-03 03-04.2.3)

The committee has a major concern that this section does not consider the use of PMM (Planar Motion Mechanisms) for these tests, and is thus inherently incomplete. There was also concern expressed that this was very much a developing field and that a substantial change may be needed to the section.

Tests in Deformed Ice (4.9-03 03-04.2.4)

In the opinion of the committee, it is too premature to give any recommended procedures for the testing of deformed ice under current levels of knowledge. therefore this section should not be published at this time, but should be reviewed by the next committee and completely rewritten, with a more informational focus.

Ship Trials in Ice (4.9-03 03-04.3)

The committee felt that this section was acceptable with minor editorial changes. Nonetheless, this section should be reviewed by the next committee.

Additional Sections

The committee also feels that four additional sections should be developed by the next committee. These new sections are:

Scaling and Correction Methods
Friction
Operational Tests
Areas under Development

In addition, the committee felt that it would be useful to have all these sections identified in the Draft, even if certain sections simply have a title and an indication that they are under development. As noted above, other sections may need a clear indication that they are subject to review by the next ITTC Ice Committee, and should thus be considered as preliminary only at this time.

GENERAL THECNICAL CONCLUSIONS

The floating uni-axial compressive test is promising as a new method of compression testing at ice tanks. It is felt, however, that improvements are required in the test method to obtain more reliable and consistent results. At this stage the committee does not feel that the floating uni-axial compressive test should be recommended as a standard method for testing the compressive strength of model ice.

The measurement of properties of the ridges themselves has the most potential for development. There still seems to be some lack of understanding of the importance of the properties of the consolidated layer, and even more so for the properties of the inner part of the ridge.

Deformed ice conditions are more complicated than level ice and ridges are not simulated very often. The building and controlling of the model ice for such conditions is difficult. Tests in these uncommonly simulated conditions are mostly simply towing tests. The simulation of a self-propelled vessel is relatively rare. It is difficult to recommend any standard procedures for deformed ice at this stage.

Institutes have tested fixed and floating structures of a size suitable to their facility. Most had attempted to model non-uniform ice conditions. The major problem seen by most tanks was the lack of reliable full-scale data against which to calibrate the model test results. The survey of test procedures carried out by the committee will be useful for drawing up recommended procedures for offshore structures testing in ice.

RECOMMENDATIONS TO THE CONFERENCE

Adopt the Procedure for Model Ice Properties(ITTC Procedure 4.9-03-03-04.2) including testing procedures for elastic modulus , flexural strength, and specific weight.

RECOMMENDATIONS FOR FUTURE WORK

Studies on test procedures for compressive strength and future toughness of model ice should be continued to obtain recommended procedure.

Clear definitions and classifications of deformed ice should be documented in order to discuss the procedures for ice properties and model tests.

More detailed studies on offshore structure model tests should be carried out to understand common problems involved in the regard.

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