SESSION ON PERFORMANCE IN ICE-COVERED WATERS

Chairman: Prof. O. Krappinger

Performance in Ice-Covered Waters Committee Memberships: E. Enkvist (Chairman) - T. Heideman (Act. Secretary) - J. Alekseyev - G. Frankenstein - H. Kitagawa - D. Maksutov - R. Milano - J. Schwarz - M. Williams.

Discussion of the Report and the Draft Recommendations of the Performance in Ice-Covered Waters Committee. (Cf Proceedings, Volume 1, p. 589-625.)

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ON THE REPORT OF THE PERFORMANCE IN ICE COVERED WATERS COMMITTEE

Representing an oil company operating in the arctic environment, an end-user of the results of model testing of ships and structures in ice, I do appreciate being given the opportunity to comment on the work of the Committee.

First of all, it should be recognized that a considerable amount of development work related to ice model testing techniques, and especially to the validation of the results of such testing, has been done outside the ITTC Group, mainly by arctic operators. The industry, mainly the oil sector in North America, has spent millions of dollars every year on collecting full scale data of a confidential nature on icebreakers, drilling structures operating in ice and also in field research programs around other natural and experimental structures in ice. Here we are entering an area where the user of model testing, i.e. industry, has learned more about real problems to be modeled than the model facilities. Consequently, I would hope that in order to close this knowledge and communication gap, ITTC would reconsider conditions for memberships in its committees, and allow for end-user representation where the technical goals of ITTC would clearly benefit.

Technical Comments

1. As the Committee reports , friction is definitely a key parameter in ice model testing. It is a difficult task to determine what a representative friction value in actual field conditions is. It is clear though that the interaction conditions do consist of qualitatively different kinds of contacts, each of which have its own friction value.

1.1 High pressure area: Immediate contact in an area where breaking takes place. This contact may be between a ship (or structure) and ice or snow depending on environment and other contact conditions.

1.2 Lower pressure areas where ice is being submerged and where ice is simply gliding over a surface. This contact again can be between a ship (or structure) and ice or snow.

In both cases the friction value may be different for different smoothnesses of hull or materials of hull coatings or degrees of water lubrication which may be effected by many contact parameters, and especially by using an active lubrication system. Also the temperature plays an important role in contact friction. It is quite difficult not to consider friction as one correlation factor in scaling methodologies as long as a clear reference value can not be pointed from full scale tests. The important thing for model testing itself from the end-users angle, is to be able to repeatedly reproduce the same friction values and friction measurements in order to accommodate a range of field friction coefficients. Then a user will have reasonable confidence in the consistency of the test results from ice model tests. The scatter of friction factors between facilities is considerable as shown in the Committee's report and can hopefully be explained and reduced.

2. The Committee has rightly pointed out that the scatter in ice model test results with the same model in different ice model basins is of concern. It indeed raises a serious concern as far as the applicability of ice model tests themselves, as a predictive tool, is concerned.

It is recognized that ice model testing is a young science but at the same time the inconsistency in results is one reason why some end-users (i.e. industry) are using more direct ways of getting field data, interpretating and calibrating ice model tests within industry, and thus get involved in development of model testing.

3. Concerning propulsion tests in ice, the Committee is talking about the right important parameters when listing in their report:

- simulation of propulsion system characteristics
- simulation of piece size of broken ice and ice kinematics around ship hull
- correlation between model and full scale test results

Yet this can be analysed a bit further.

There are three main purposes why propulsion tests are done and consequently three categories of tests:

(category 1): To help design the hull and propulsion arrangement in a way which minimizes (or optimizes) the amount of propulsion ice interaction.

(category 2): To predict (or quantitate) for a design, the effects of ice on the efficiency of propulsion in given ice conditions.

(category 3): Ice load measurements on the propulsion system for strength determination purposes.

It is now possible to see which are important parameters for any particular type of use of the model test. For a designer in category (1), the key is to quantify the amount of propulsion ice interaction so that he can get an assessment between various design alternatives of the quality of the design from the point of view of its tendency to steer or to suck ice into the propulsion. This means scaling:

- ice piece size
- flow of ice around the stern
- suction of propulsion

For a designer for quantitative disturbance prediction (2), additionally important are scaling:

- engineering properties of ice
- energy output of propulsion system and gross response of it
- water flow around the propulsion

For ice load determination category (3), category (2) tests can be used with more extensive instrumentation and with an additional requirement on simulation of the dynamics of the propulsion system.

The reason to differentiate between category (1) and (2) is the big difference in the level of complexity in achieving these levels. It would be nice for us end-users to be able to say with confidence that category (1) quality is achievable and we are prepared to move to category (2), but the state of the art of know how is not at that level yet.

My final comment is related to model ice properties. I recommend that fracturing properties of model ice should be added to the list of important parameters of ice model testing (i.e. fracture, toughness, flaw density and size indications) Continuum behaviour of ice is fairly well known to the point where ice starts to fail. As soon as cracks do start to propagate in this extremely brittle material, we lose the solid working knowledge about what is happening. What we know though, is that modelling this brittle material has always been done by much less brittle substitutes. Even the frozen model ice materials so far have not even visually shown the same brittle behaviour as the natural ice and the majority of cracks have tended to propagate only partially through the ice sheet leaving some remnant strength to the model material. Crack propagation does note consume much energy but having cracks propagated through an ice sheet will reduce the energy consumed by local failure mechanisms and even actually changes the failure mechanisms to less energy consuming ones.

I would like to close by agreeing with Committee recommendations and by congratulating the Committee on its good contribution to knowledge in its field and on its first organized effort to get international agreement on ice model testing and its key parameters. Good luck in future efforts.

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ON THE REPORT OF THE PERFORMANCE IN ICE-COVERED WATERS COMMITTEE

Standard Model Tests

I have participated in some of the Committee meetings, as substitute to G. Frankenstein, and therefore had an input to the Committee Report. However, it was my understanding that contrary to the statement at the bottom of the

caption of Figures 2-5, p. 596, the lines drawn in these figures as well as in Figure 6, p. 597, were obtained from regression analyses performed by V. R. Milano on the data provided by each participating tank, and presented in a special report to the Committee ("CCGS Franklin - Prediction of full-scale performance in level ice based on model tests at various ice laboratories," Special Report for the ITTC Ice Committee, 2 February 1984) not listed in the references on p. 602. Because I have some misgivings as to the form of the regression equation used by Milano, I would like to present here an alternate method of comparing the test results from those tanks which tested the 1:20 scale model, namely CRREL, HSVA, JSRI and WADAM. The analysis of the tests performed at CRREL (Ref. 2, p. 602 should be updated to:
J. C. Tatinclaux; "Model tests in ice of a Canadian Coast Guard R-Class icebreaker", CRREL Special Report 84-6, April 1984) yielded the following regression equation for the total resistance in level ice of the model

$$\left.\begin{aligned} R_{IT} &= 18.73\,V^{1.93} \quad \text{(Open Water Resistance)} \; + \\ &+ 1.796\,h_i^2 + 6.328\,V^{1.27}\,h_i^{1.37} \; + \\ &+ 0.04\,h_i^{0.3}\,\sigma^{1.7} \quad \text{(Ice Resistance)} \end{aligned}\right\} \text{(I)}$$

where R_{IT} is expressed in Newtons, h_i in cm, V in m/s and σ in kPa.

For the test conditions (h_i, V and σ) listed in Tables 1, 5 and 6 of the Committee Report, the total resistance in ice was calculated by Eq.(I) These calculated values are compared against the reported measured resistance in Figure A. As can be seen the experimental data obtained by WADAM are very well predicted by Eq.(I) Those reported by HSVA fall

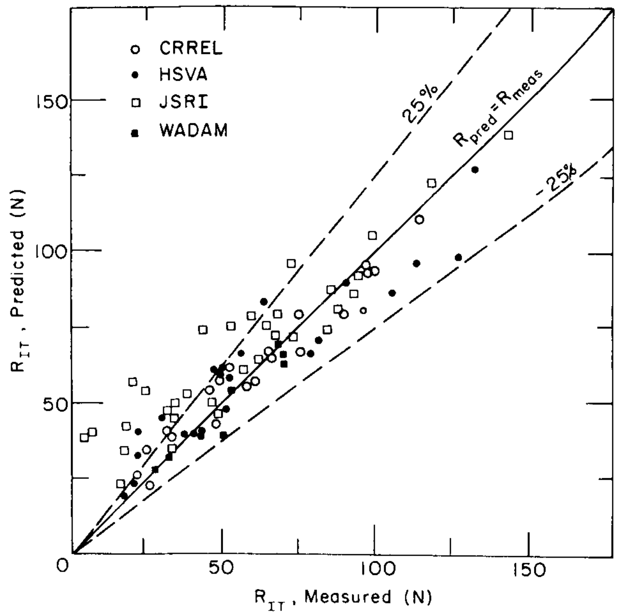

Fig. A Comparisons between resistance in level ice measured at various tanks and that predicted by Equation I

Table A: Relative Error Between Measured and Predicted (Eq. I) Resistance in Ice

$\Delta = (R_p - R_m)/R_m$		HSVA	WADAM	JSRI	CRREL
Level Ice	Mean	0.121	-0.036	0.725	0.053
	Standard Dev.	0.306	0.098	1.691	0.159
Presawn Ice	Mean		0.186		0.015
	Standard Dev.		0.381		0.091

within ± 25% of the predicted values and the fit between measured and predicted resistance is almost as good as for the CRREL data from which Eq. (I) was derived. On the other hand the predicted resistance for JSRI test conditions are consistently and significantly higher than the measured values, especially at low resistance corresponding to thin and/or weak ice. Quantitative evaluation of the fit between measured and predicted ice resistance can be obtained by the mean and standard deviation of the relative error, $\Delta = R_{pred}/R_{meas} - 1$ as given in Table A below.

The form of Eq. (I) for $\sigma = 0$ was obtained from tests in presawn ice. WADAM also ran similar tests, and comparison between measured and predicted resistance in presawn ice is presented in Figure B and Table A. Here again the fit is quite satisfactory.

The above remarks are not meant to imply that Eq. (I) is the correct form of the resistance equation for the 1:20 R-class model in ice (this would be far too presumptuous), but to show that it is reassuring to find that similar tests conducted in various facilities yield in the whole similar results, especially when it is realized that two tests run at the same facility for nearly identical conditions often yield significantly different results (for example compare HSVA tests # 11.1 and 23.1, WADAM tests in level ice # 810310 and 810311 or # 810317 and 810224, JSRI Tests # 5 and 21).

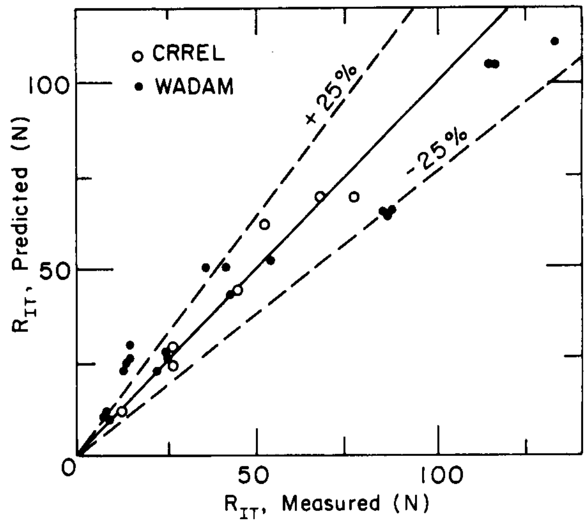

Fig. B Comparisons between resistance in presawn ice measured at WADAM and CRREL and that predicted by Equation I with $\sigma = 0$

Friction Coefficient

In a recent series of experiments on a simple wedge in level ice, the kinetic friction coefficient, μ_k, between the ice and the surface was measured by the customary method of dragging loaded ice samples over the surface and measuring the drag force. The corresponding values of μ_k was found to be

$$\mu_k = 0.046 \pm 0.015$$

The friction coefficient could also be calculated from the measured horizontal and vertical components of the force acting on the wedge which was allowed to roll but not to pitch, heave or surge. The calculated value of μ_k was found to be

$$\mu_k = 0.094 \pm 0.045$$

It is my understanding that similar results were recently observed by G. Timco of the National Research Council of Canada in tests on an inclined plate.

In the opinion of the writer, the large discrepancies between the values of μ_k obtained by two totally different methods not only indicate how little is known on the phenomenon of ice friction but also show that, as with all ice properties, it is necessary to describe in detail the method used for determining μ_k if meaningful comparison between results from different facilities is to be attempted.

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ON THE REPORT OF THE PERFORMANCE-IN-ICE COMMITTEE

The Committee is to be congratulated on the fine work it has accomplished since the last meeting of the ITTC. They have followed the Recommendations of the 16th ITTC as well as they could. Their work must be continued and encouraged.

Their immediate tasks as outlined in Section 2.2 are worthy ones, but must be carried out with caution. The difficulty in carrying out task 2.2.1 lies in the fact that full scale test data is normally obtained in terms of thrust and torque of the propellers - the difficulty is converting these values to resistance through some assessment of the propulsion efficiency.

Task 2.2.3 is very important and as in resistance testing, the methods used should be standardized, not varied as described in Section I-1.2 of the Report.

Task 2.2.4 is another task difficult to achieve. Full scale impact tests are very expensive to conduct. Some proprietary work conducted by the oil industry has indicated that the impact phenomena are complicated and not yet very well understood. It appears that the local hydrodynamic interactions have a significant effect on the impact loads and have to be modeled very carefully.

The results of the testing presented in Section II-1 appear reasonable. I would suggest that in addition to the information presented, that the length, width and depth of each tank be added to the table listing ice types on page 3. Table 1 appears to have a mistake in the units of flexural strength. I believe the units should be KPa. Figure 6 in Section II-1 is not as pessimistic as the Report states. The results of the CRREL, WADAM and HSVA tests for 20 KPa ice are very close. It is only when the ice strength is increased that the results seem to vary. The Committee should try to determine why this occurs.

Even though the propulsion tests were carried out using different methods, the results shown in Figure 7 show reasonable agreement for the relatively short development of this technology.

Full scale testing is complicated and the varying results related in Section I-13 will remain until a standard technique with standard equipment is established by the Committee, particulary with regards to measuring the friction coefficient and the hull roughness. Section II-2 is a beginning in this standardization process, however, the Committee has introduced a relatively new term "ice hardness"; they should clarify the definition of this term and specify how it is measured. I believe research should be conducted on determining a relationship between roughness and friction under various conditions. If such a relationship could be derived then one would only have to measure hull roughness to estimate the friction coefficient.

Analytical predicting techniques may have limited value because of the stochastic nature of the ice resistance phenomena. It is difficult to predict a stochastic event with a deterministic equation. However, some of the techniques are in fair agreement and the Committee should compare these techniques with tank and full scale results and provide a listing of those techniques that are most accurate. In addition, if Dr. Milano's latest techniques are reasonably accurate, the Committee should publish the results referred to on page 21 of Volume 1.

I believe that before more work is done in "modeling" ridges in the tank, more work must be undertaken to understand the *morphology* of a ridge in the field. Again the oil industry and the U.S. government have measured and described many ridges in the Bering Sea. This information is in the public domain, and should be used to describe the details of a ridge so it can be modeled properly.

I would suggest that basic research on propeller ice interaction be conducted in a propeller tunnel or flume so that a better understanding of what is occurring to the propeller behind the ship can be formulated.

I heartily endorse the Recommendation put forth in Section III of the Report. I would strengthen Recommendation 2.2 by stating that a standard method should be adopted to conduct propulsion tests on the standard model.

In closing, I would like to compliment the Committee for the work they have accomplished todate, and encourage them to continue their efforts.

II. REPLY BY THE PERFORMANCE IN ICE-COVERED WATERS COMMITTEE

The Ice Committee is grateful to *Dr. Keinonen* for his comments, especially since he represents a group of "end users" who closely follow the work of this and other ITTC committees.

The Committee agrees with the discusser that the friction is different for the high and low pressure areas and must be handled separately. It is true that it is difficult to measure and control the friction in model tests, and there is still no reliable method to measure the hull friction or roughness at full scale. One important recommendation of this Committee is to initiate work on establishing standard methods to measure both friction and roughness at model and full scales.

The discusser indicates that the scatter in the results from tests using the same model in different facilities casts doubts on the reliability of such tests for full scale predictions. The Committee agrees that scatter exists but it has been greatly reduced through their efforts with the testing of the ITTC standard model. The Committee strongly feels that model tests can reliably predict full scale operational capabilities for both ships and structures in ice and that these laboratory efforts should be continued.

The Committee would welcome the opportunity to obtain the confidential data from end-users which the discusser refers to. It is very difficult for model basins to receive full scale results. Therefore, cooperation from end-users would advance the state of the art in ice modeling testing.

The Committee shares the views of the discusser on propulsion tests and this is reflected in their Recommendations.

The fracture properties of model ice are a concern to all ice facilities. The measurement of these properties has not been included as a Recommendation but a number of facilities have initiated such tests and it is hoped that by the 18th ITTC methods and results can be reported. However, measurement of the fracture properties of ice at full scale is extremely difficult.

The Committee agrees with Dr. Keinonen that the ITTC could benefit from having end-user representation on and contributions to ITTC committees. However, selection of committee membership is a function of the Executive Committee of the ITTC and not of the individual committees.

Replying to *Dr. Tatinclaux* the Ice Committee is sorry for having not listed the reference of Dr. Milano's special report. However the Ice Committee is very grateful to Dr. Milano for his valuable contribution to the Committee's work.

The Ice Committee wants to point out, that the lines shown in Figures 2-6 are indeed drawn by eye and not the result of a regression analysis as Dr. Tatinclaux has assumed.

The Ice Committee appreciates the effort of Dr. Tatinclaux to compare the results of the various Ice Tanks. The comparison, however, is carried out by establishing a regression formula on the basis of the test results of one establishment (CRREL).

It is suggested to calculate the coefficients of the regression equation by using the model test data of all participating Ice Tanks. It should be noted, that the given regression equation should not be used for predicting the icebreaking resistance, because this formula is based on too small amount of data and would anyway only be valid for the icebreaker being investigated.

In summary, the Ice Committee is satisfied that the discrepancy between the results of the various Ice Tanks are more or less within ± 25%.

The difference in the friction coefficient obtained by two methods, as mentioned by Dr. Tatinclaux, reemphasizes the fact that friction coefficient results are affected by the measuring technique. This is one of the key problems in dealing with friction in ice engineering, which needs further intensive studies as already is mentioned in the Recommendations of these 17th ITTC Proceedings.

The Ice Committee appreciates *Dr. Vance's* knowledgeable comments. Dr Vance is a former member of this Committee and understands its objectives. Some of the points mentioned by Dr. Vance, specifically concerning the importance of friction and the level of correspondence among model test results at various facilities, were also raised by other discussers and the previous responses need not be repeated.

The interest in impact tests is strong. Studies of a fundamental nature on ice impact are underway at CRREL, and some full scale tests of ship ice impact have been carried out by other groups, e.g. CCG and HSVA. None of this information is available to the Committee yet, but the Committee looks forward to the opportunity to review the problem.

In Table 1 of the Committee Report in Volume 1 there is a misprint; the units should be kPa.

Dr. Vance's comments on propulsion test results underline the improvement which has been achieved in propulsion model testing in recent years. Development is continuing at the different Tanks. Rather than specifying a standard technique for propulsion tests, the Committee prefers to define the test conditions so as to ensure comparable results, but to leave the individual Tanks free to further develop testing techniques.

The Committee's work on friction coefficient and hull roughness is continued in the Recommendations to the 17th ITTC. The current Committee Report uses the concept of ice hardness to illustrate some of the complexities of the problem. It was not the Committee's intention to define ice hardness precisely, nor to recommend a standard method of measurement, as research is continuing.

Information on analytical predicting techniques requested by Dr. Vance is contained in a special report to the Ice Committee by Dr. V. R. Milano. This report is available from the Secretary of the Committee.

The discussion refers to full scale measurements which have been carried out on ridges. It is clear that there is large variation in prototype ridges. The usual practice is for a Tank to select a representative ridge shape for model tests, and such tests can provide useful information about the general performance characteristics of the ship in ridges.

The Committee was pleased to receive Dr. Vance's thoughtful comments.