SESSION ON TOWING TANK SYSTEMS AND TECHNIQUE TESTING IN ICE

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Discussion of the Report and draft Recommendations of the ICE PANEL

I. DISCUSSION

F.N. BIEWER - Offshore Technology Corporation, Escondido, U.S.A.

As a general comment I feel the report restricts itself in that it addresses only ships and ice breaking despite the fact that the objective speaks also of floating platforms. I suggest that the work of the panel should also include fixed structures in an ice environment. Thus the laboratory tests of paragraph 1.4.1.C should include: "d. moored platforms", and "e. fixed platforms".

The implication of the first paragraph is that only real ice is used in model testing. In view of the rather significant contribution of testing in synthetic ice, I recommend that equal emphasis be given to testing in synthetic ice.

If the panel is to develop a standard measurement system then I suggest that they must specify tests which are to be conducted, test specimen configurations, and test conditions so that meaningful results can be obtained which have a common basis for comparison. In testing I believe compressive strength must also be determined. In general, strain rates are important in ice testing and the test specification should include strain rates for the particular tests. This is not to say that the other measurements mentioned are not also important.

While I appreciate the problems associated with implementing the above suggestions, unless we start with a knowledge of the fundamentals we will not make significant progress in understanding the difficult and complex problems of testing in model ice. Just as in the other technical fields it has been necessary for the various classification societies to set forth detailed standards, so in this field some group or organization must correlate and document the techniques in use with a view towards putting together a set of meaningful standards for testing.

Th. BRATANOW - University of Wisconsin, Dept. of Engineering Mechanics, Wisconsin, Milwaukee, U.S.A.

On the Standard System for Measurements on Ships in Field Conditions

First of all, I would like to express my appreciation of the very good work of the Ice Panel in preparing the report. The Ice Panel has established a very valuable foundation for further developments in the Icebreaking Technology. All material assembled in the report has been carefully selected, digested, and arranged. A congratulation is due to the Ice Panel and the able chairman Mr. Guenther Frankenstein.

On this occasion, due to the urgency of the matter, I would like to ask the Executive Committee of the ITTC to consider elevating the Ice Panel to a regular Technical Committee. Ice Technology is growing in importance particularly because it is related to the energy crisis. Another reason is, that the difficulties with the resistance to motion in ice are mainly due the three-dimensional aspect of the problem and the non-linearities, i.e., the strong interactions between the individual resistance components, requiring thus much and comprehensive preparations.

On the overall, I fully agree with and support the Ice Panel that much investigation and research must be carried out before a standardization is attempted. I appreciate the statement of the Ice Panel that the standardization should be justified. The Ice Panel should aim to expand the co-operation between all five major tank facilities. I feel that the Ice Panel should make an effort to have Arctec join the Panel. They are a very productive and useful organization. The proposed testing of a model standard series for ice transiting vessel is very appropriated. Then, the Ice Panel should make efforts for co-ordination with the Technical Committee on Open Water Resistance, because this committee also realizes the urgency and importance of treating the three-dimensional aspects of the problem and the interactions between the individual resistance components. Very soon the ice tank facility of the U.S. Army in Hanover, N.H. will be completed. Its work will be a strong contribution to the Ice Technology. Results from this facility will greatly benefit all aspects of the technology. Finally, a hope is expressed that the ice tank facility in Leningrad will increase its interest in the operation of the Ice Panel of ITTC.

The following comments are related to the basic objective of the Ice Panel to develop a format for the analysis and a standard system for measurements on ships in ice in field conditions. I believe that the following recommendations by the Ice Panel are particularly approriate:

- the specific procedures and techniques in the report of the panel be adapted for international use,
- continued investigations be made by testing ships in all ice conditions and, in particular, that ship owners and/or ship builders allow for model and full scale testing of all ice transiting vessels,
- ship owners and/or operators of all transiting vessels be encouraged to record and collect reliable ship performance and ice condition data during operational voyages,
- that thrust meters and torque and r.m.s. monitors be installed in all new icebreaking models.

Hopefully, the ship builders, owners, and operators themselves will realize that such information will benefit them in the first place.

Considering now the icebreaking problem in its entirety, it is desirable to establish a firm basis for the standardization. I appreciate it, that the Ice Panel agrees that more work should be carried out before uniform recommendations can be made. Then, truly, full scale tests are the only valid comparison for theoretical calculations of resistance to ship motion. Thinking for instance of the three basic modes of icebreaking operations (ramming, continuous motion in ice fields, and motion in channels clogged with ice), the last mode can only be resolved by full scale tests and hydrodynamics theory similar to the open water resistance. Model testing for this particular mode of operation would be less realistic. In passing, it must be mentioned that very good full scale work has already be carried out by Arctec in the U.S.A. and Wärtsila in Finland, and recently by the H.S.V.A. in Hamburg, West-Germany.

R.A. MAJOR - Arctec Incorporated, Columbia, U.S.A.

The ice panel is to be congratulated on their efforts to develop a standard measurement system for ships and floating platforms in ice. Although the goals of the panel are universally desired, the panel correctly notes that the current state-of-the-art precludes accomplishment of all goals at the present time. The report highlights some of the differences in testing techniques which have arisen during the short history of model testing in ice. These differences have developed because no model ice material meets all of the requirements for correct scaling. This is true even if the viscous forces governed by Reynolds scaling are small enough to be neglected completely. At ARTCTEC, Incorporated; ARCTEC, CANADA; Wärtsila; and AANII; tests in unbroken level ice are conducted when the flexural strength of the ice is correctly scaled, accepting mis-scaling of elastic modulus. HSVA conducts such tests when the elastic modulus is correctly scaled, accepting mis-scaling of flexural strength. It would seem to be useful for each model tank to try the other's techniques in order to learn the change in results which might occur. Although some parameters might be miscaled with some techniques, only data which shows the effect of mis-scaling compared to accurate full-scale test results should be used to calculate the importance of correction for mis-scaled parameters. The panel's conclusion regarding elastic modulus has not been proven experimentally. Lack of accurate hull-ice friction data in most existing full-scale test data makes standard corrections impossible at this time.

I believe that the basic measurements listed in Table II and Table III should be refined and separated for model and full-scale data. The list of data as it now stands is too long to be economically accomplished for each test data point. Nevertheless, it has been our experience that some properties do not have identical values, although ice sheet preparation may seem similar. Thus, only ice properties which have been measured at the time of testing should be reported as part of test data. Multiple measurements of each property should be made, perhaps using a minimum of three measurements for each reported value. I have prepared a revision to Tables II and III which rank priorities from 1 to 10. We believe priority 1 measurements should be made for each data point separately, and reported in the test data. Particularly, elastic modulus and hull-ice friction must be repeatedly re-measured.

In the section on tank size, the information on required wall-to-model separation to avoid wall effects is less restrictive than our data would show to be necessary. It is logical to assume that models with higher beam would require more distance from the tank walls than narrow ones. Thus, we believe that the critical distance should be measured from the widest point on the model to the basin wall, rather than to the model centerline. Our data shows this minimum distance to be 3 characteristic lengths /1/*. We know of no tests in which tank depth was varied upon which to base the criteria for minimum depth required. However, tank bottom interference in open water is usually considered to be a function of towing speed as well as tank depth ($\frac{v}{\sqrt{gD}}$).

Since icebreaking speeds are low, a shallow tank may exhibit no bottom effects even when depth is less than the panel's recommended minimum. The choice of model scale should be left to the discretion of the customer, based on the cost per data point at different scales as well as the minimization of scale effects.

* References at end of comments.

Similarly, it is the customer who decides how extensive an instrumentation suite should be used (reaching which priority level).

In broken channel tests, for a channel 100% filled with broken ice, it is essential that the thickness of broken ice be accurately measured at multiple sampling points.

Due to the discontinuous nature of icebreaking against a hull, planar motion mechanisms will have limited use in ice tanks. ARCTEC has measured manoeuvring coefficients using a rotating arm and constant skew towing /2/. Nevertheless, free self-propelled models still are used most frequently to assess manoeuvring ability.

In the measurement of ice properties, we would recommend that actual cantilever beam tests be accomplished both in the laboratory and field. Care must be taken that buoyancy effects are removed from the results. One way of insuring that buoyancy effects are small is to keep beam length small. Figure 1 shows the ratio of flexural strength ignoring buoyancy to corrected flexural strength as a function of beam length /3/. As the figure shows, beam length must be kept less than 0.5 ℓ_c where ℓ_c is the characteristic length of an infinite ice sheet. Longer length beams would have to be corrected by entering the figure.

Tests must be conducted rapidly to avoid creep. If SI Units are to be used for reporting, then σ_0 and E_0 should be in Pascals (N/m^2). The values of 7.0 kg/cm^2 and 10 x 10^{10} $dynes/cm^2$, then become 690 kPa and 10 GPa, assuming standard gravity. Similarly, grams and centimeters should be avoided.

Elastic modulus measurements will be more accurate if the deflection is measured

TABLE II

ENVIRONMENTAL PARAMETERS

Parameter	Lab Test Priority	Full-Scale Priority
Ice Thickness	1	1
Ice Temperature Profile		3
Ice Salinity Profile		3
Snow Cover Thickness		1
Ice Pressure		2
Pressure Ridge Profile (Depth and Length)	1	1
Broken Channel Size and Percent Coverage with Broken or Mush Ice	2	4
Elastic Modulus	1	5
Qualitative Description of Environment		6
Ice Floe Size and Percent Coverage	1	1
Qualitative Description of Ice Profile and Type		6
Ice Density	5	7
Snow Density		8
Ice Flexure Strength	1	1
Ice Cristal Size	10	10
Ice Tensile Strength	9	9
Ice Compressive Strength	7	7
Ice Shear Strength	8	8
Wind Speed and Direction		3
Air Temperature		3
Current Speed and Direction		3
Water Depth		3
Cusps Length and Width	6	6
Pressure Ridge Porosity	3	2
Photographic Documentation of Ice Patterns	4	4
Seawater Temperature and Salinity	5	5

TABLE III

VESSEL PARAMETERS

Parameter	Lab Test Priority	Full-Scale Priority
Vessel Particulars (Complete Definition of the Vessel, i.e. Lines Drawings)	1	1
Ship Speed	1	1
Shaft Thrust	1	1
Shaft Torque	1	2
Shaft RPM	1	2
Ice-Hull Coefficient of Friction Dynamic (with and without snow; Wet and Dry)	1	1
Ice-Hull Coefficient of Friction Static (with and without snow; Wet and Dry)	1	1
Propeller Pitch	1	2
Vessel Draft Fore and Aft	1	1
Penetration Distance on Ram	1	1
Heeling System Cycle Time	1	1
Bubbler System Flow	1	1
Trim System Cycle Time	1	1
Photographic Documentation of Ice/Ship Interaction	1	2
Total Resistance Towed Model (Dynamometer Reading)	1	
Total Thrust Self Propeller Model	1	
Turning Circle Radius	1	1
Time History of Above Events During Testing	1	1
Hull Roughness	2	2
Vertical Acceleration (Fore and Aft)	3	3
Horizontal Acceleration (Fore and Aft)	3	3
Pitch Angle	3	3
Roll Angle	3	3
Rudder Angle	3	3
Rudder Torque	3	3
Propeller Blade Bending Moments		4
Propeller Pitch Torque		4
Hull Strain Gages (Full Scale Only)		4
Propulsion System Monitoring Sensors		5
Wake survey in Ice vs Open Water		6

away from the load rather than at the load. For a small area load, remote deflection is related to characteristic length by:

$$\omega(r) = \frac{P}{2\pi\gamma_\omega \ell^2} \text{kei}\left(\frac{r}{\ell}\right) \qquad (4)$$

where $\omega(r)$ = remote deflection
P = center load
γ_ω = specific weight of water
r = distance from load to point deflection is measured
ℓ = Characteristic length of an infinite ice sheet

Friction measurements should be made using the test material on the actual model in model tests. These tests must adequately cover the underwater body to know any variation by area. Particular attention must be paid to the ice belt.

In all properties measurements, it is essential that the human element be minimized. Thus, motorized drives with load cells should be used in preference to spring scales operated by hand. Nevertheless, the motorized drive is no substitute for the collection of sufficient data to be statistically meaningful.

No mention was made in the panel's report of the towing apparatus for the model. Perhaps this is because open water tests using such apparatus are so common. Nevertheless, it should be emphasized that the model towing constraints must be included in any test report. ARCTEC's standard arrangement is to restrain the model in surge, sway, and yaw while allowing no restriction on roll, pitch, or heave.

ARCTEC, Incorporated, wholeheartedly

supports the work of the Ice Panel, and will be happy to continue its support of answering questionnaires or specific inquiries.

REFERENCES

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3. Hentenyi, M., Beams on Elastic Foundation; Theory with Application in the Fields of Civil and Mechanical Engineering, The University of Michigan Press, Ann Arbor, 1971.
4. Wyman, Max, "Deflections of an Infinite Plate," Canadian Journal of Research, Vol. 28, Sec.A, 1950.

H. TAKAHASHI - Ship Research Institute, Tokyo, Japan

The Ice Panel is to be congratulated for its valuable contribution to the advancement of knowledge in the engineering of ships for operation in ice.
However, I would like to add some comments on the Panel Report. This report seems to be all-inclusive. Consequently I venture to hope, the Panel will provide us definite and illustrative material for each item in the report. I am sure difficulty in obtaining reasonable results with in situ testing of ice and low productivity of experimental study in ice model basins will force us into energetic international co-operation in attaining the object.

Secondly, the Panel should exert considerable effort to standardize the terminology of ice technology, and it will give us more rational understanding of the phenomena relating to behaviour of ships in ice. Finally, ice engineering of ships should be based on recent developments on fracture mechanics and theory of mechanical properties of ice.

V.R. MILANO - Davidson Laboratory, Stevens Institute of Technology, Hoboken, U.S.A.

I have reviewed the report of the Ice Panel to the 15th ITTC. In general, I think it is well done. It is quite comprehensive and a good first step in arriving at standard procedures and methodology for testing in ice.

I have several specific comments on various sections of the report as follows:

Section 1.3 (page 157) ... I would expand the objective slightly to include "floating and free standing structures on platforms in ice". I am sure much of your testing for the offshore industry will be on moored, free standing an embedded structure subject to ice pressures. Hence, your objective should be as broad as possible.

Section 1.4.1 B (page 157) ... add "much ice", "snow cover" and "confined harbours" as environmental conditions whose modeling require standardization and treatment.

Section 1.4.1 C (page 157) ... ad "ramming" and "Hydrodynamic Flow" as testing procedures that also require standardization and treatment.

The tests listed tend to be associated with surface displacement ships. I can see the need for more emphasic for high performance craft line air cushion vehicles and also offshore structure. These types of test procedures should somehow be included.

Section 1.4.1 D and 1.4.2 D (page 158 ...

I would delate any reference to standardized resistance equations as inappropriate and very premature. There are two forms to the currently used equations and we know too little about the synthesis of total ice resistance to say that any one, if any at all, are correct. That is a detail that may evolve in time, (if at all) and really can not the purpose of ice testing.

Section 2.2.5.1 (page 166) ... The last paragraph allows up to 15% variation in ice thickness thoughout a model ice sheet. In section 2.2.6.2 you allow a variation of only 10% in full scale ice. This seems in appropriate since ice thickness can be controlled more closely in an ice tank than it can in nature. I would suggest that these be reversed or kept at 10-15% in both test environments.
Section 2.2.6.2 (page 170), Paragraph eight states that hull roughness is significant, yet in Table II you show at as a priority 2 parameters whereas fuction coefficient is listed as priority 1. This is inconsistent and should be corrected.

The thrust deduction factor at normal speeds of advance in ice is negligable and should not be considered. There is no way to measure it, and to use that which may be determined in a model tank is totally wrong. In addition, I do not believe that anyone has shown that it can be determined with any accuracy in model ice. This is over as far as I am concerned implying a level of accuracy and sophistication of testing which is not really achievable.

Section 2.3.7 (page 173) at the present time a universal resistance equation, is subjective, unsupported by sufficient analytical or data and gives the impression of scientific fact which is premature. The statement that total resistance may be grouped in the form of three terms, or that the terms are linearly independent gross conjecture at this point ... We think it is so, it appears to be so ... but that does not make it so, especially to incorporation ITTC Standard.

Section 2.2.8.1 (page 174) in photograph five, the treatment of function should perhaps be more general. The methods discussed are apply if we accept a column type function. There is still a lot of question about that, and for the ship-ice case we may find the effects better represented by a viscous drag or shear mechanism. We need to do more work in this area and ITTC standards should remain more open ended until we know better.

In paragraph six, the treatment of propeller thrust is a problem. I agree that estimating thrust developed from open water propeller characteristics is not ideal, but it does provide the most consistent, repeatable set of data for test analyses. To determine the propulsive coefficient as you suggest is near impossible in an ice environment.

Section 2.3 (page 175). It should be clearly stated that use of the beam tests, small or large, simple or cantilever, is applicable only if the ice behaves elastically, in fact. Experience to date tends to indicate that this is a function of rate of loading, but also of ice temperature or strength. If the ice is anywhere near the visco elastic or plastic regime, these tests will not be adequate.

O. BJÖRHEDEN - KMW Marine Laboratory,
AB Karlstads Mekaniska Werkstad,
Kristinhamm, Sweden

The panel has presented an excellent report and I think we are all impressed by their achievements after only 3 years of co-operation. However, I cannot agree with the panel as regards the priority given to some of the parameters proposed for measurements during ice-breaking tests as listed in table III on page 166. I refer to such parameters which are related to the interaction between propeller and ice and in particular those which are relevant to the strength of the propeller. Very little information is available on this subject in the literature and since safe propulsion of the ship is a matter of the utmost concern to both ship operators and propeller designers, this is a very serious lack indeed. In table III of the report only one parameter provides detailed information on the propeller-ice interaction, namely the propeller blade-bending moment which has been given a 3rd order priority and is to be measured in full scale tests only. I suppose, what the panel has in mind is stress measurements by strain gauges fitted to one blade of a full scale propeller, but to my knowledge, no successful measurements have yet been reported. In a model test on the other hand, measurements of blade forces and moments during self propulsion in ice would in principle be possible by means of so-called blade dynamometers installed in the model propeller hub. My question to the panel is whether or not they consider such measurements feasable with regard also to the scaling difficulties described in the report. If meaningful such tests can be carried out, preferably in combination with ice-flow observations, I would strongly recommend the panel to give this kind of investigations a 1st order of priority.

V. KOSTILAINEN - Helsinki University of Technology, Ship Hydrodynamics Laboratory, Finland

The panel has made valuable work in collecting data and developing standards for testing in ice. There is, however, one point mentioned in the report which deserves further consideration. Testing in ice, even in level ice and in laboratory conditions, is characterized by the random nature of the properties of the ice or two-phase water - broken ice - medium. This involves great difficulties both in tankery and in analysis. Therefore, as long as uniform laboratory testing and correlating methods are not established, emphasis should be laid on sample survey in measurement of ice thickness and properties of ice.

D.C. MURDEY - National Research Council, Marine Dynamics and Ship Laboratory, Ottawa, Canada

The report gives tacit approval to test techniques in which test runs are but one model length in duration. This may be too short, bearing in mind the stochastic nature of the ice breaking process.
The National Research Council is carrying out in association with Arctec Canada Limited a project to investigate explicitly several of the ad-hoc assumptions which have been made in the development of ice tanks and ice testing.
One series of tests will study the effect of tank breadth by carrying out runs with the tank width successively reduced to 2/3, 1/2 and 1/3 of its full value.
A second series will include running the model the full length of the tank and then successively 1, 2 and 3 model lengths into the ice. This should show if the one model length mentioned in the report is sufficient.

K. SZPONAR - Ship Design and Research Centre, Gdansk, Poland

In last few years the Ship Hydromechanics Laboratory of the Ship Design and Research Centre in Poland has began to perform tests of ship models in arti-

ficial ice.
The model tests were arranged in an auxiliary towing tank 60 m length in which the water surface was covered with wax-paraffin pieces simulating the brooken ice field. The forms of these pieces were different most of them were triangles.

The ship resistance measurements for comparison of different hull forms and visual observation of ice pieces motion by stern and bow parts of ship were performed. For this purpose a special underwater mounted cabin equipped with windows sufficient lighting and cameras was used.
These tests allow to performance study necessary for development of possible best hull forms for ships using in ice conditions.

II REPLY OF THE ICE PANEL

The panel agrees with *Mr.Biewer* that fixed and moored platforms should be included in any future panel work. The first paragraph does refer only to real ice but synthetic materials are referred to in the remainder of the report.
The testing techniques included in the report should be used, where applicable, for all materials, and the material properties should meet the proper scaling laws. Member ice tanks are urged to describe the composition of their material as well as the preparation techniques.
The panel endorses the recommendations on testing techniques of the IAHR which will soon be published in the Journal of Hydraulic Research. Strain rate is included in this report. The last comment by Mr. Biewer is the subject for future panel work.

The panel gratefully accepts the comments of *Prof.Bratanow*. The panel agrees that full scale testing is very important, in fact, the final recommendations (3.3) include full scale testing. The panel would welcome the participation of the Arctic and Antarctic Institute in the future work of the panel. The panel does not see the evidence that the modeling of clogged channel (mush ice) conditions is less realistic than other conditions.

The panel feels that referring to the discussions of *Mr.Mayor* it is impossible for ice model tanks to duplicate each other's techniques due to existing physical constraints, i.e. freezing systems, size, etc. We would recommend that the same model be tested under similar conditions at each tank for comparison of results. The importance of the elastic modulus, in fact, has been proven experimentally in several laboratories. The panel agrees that hull friction measurements are important in both full and model scale tests. The panel considers it very important that the measurements of ice properties be carried out at the time of the experiment. The panel has reviewed the priorities that Mr. Mayor has given to items in Tables 2 and 3 and feels that the original values are more appropriate at this time. The report requirement of measuring the channel length from the center of the load is acceptable in level ice. The work of the type referred to by Mr.Murdey will help in refining this requirement. The panel does not see the evidence for relaxing the requirement for tank depth. Choosing the scale ratio to give meningful results is the important consideration. Lower cost, high scale ratios, may lead to meaningless results. To this end, the panel maintains its recommendation regarding choice of scale. The panel recognizes the work that Arctec has done in manoeuvring tests. It is interesting to note that self-propelled tests are most generally used. The panel, as stated in the report, feels that more manoeuvring studies should be carried out. Regarding Mr.Mayor's comments on the measurements of mechanical properties, the panel, as stated in the reply to Mr.Biewer, has recommended the adoption of the IAHR standards. Further details on testing techniques will be referred to the next panel.

Regarding ice terminology the IAHR has recently published a report in 12 different languages. It can be received by writing to the IAHR, Delft, Holland.
WMO has a classification of ice conditions that is available. It is recommended that the next ice panel review these reports along with the ITTC standard list of symbols and give comprehensive recommendations on these items. The panel agrees

with *Dr.Takahashi's* comments on ice engineering of ships and its relation to fracture mechanics and ice properties.

The panel agrees with *Dr.Milano* that the objective should be expanded to include structures. We disagree, however, Dr. Milano's comments regarding preparation of the model ice. The panel feels that it is very important to report on how the model ice was prepared because it may explain differences during analysis of the test data. We agree that repeatability is important and should be addressed. We did not include scale and side effects in the outline but did discuss them in the report. In fact, an upper limit was put on scale factors. Slush ice will be included as another ice condition. The others are already included. We have no objection to having the ice thickness variation be 15% or better in both model and full scale. The panel, after much discussion, feels that it is very important to address the problem of a standard resistance equation. It is recommended that future committees continue to address the subject. The panel agrees that hull roughness should have a priority of 1. Where possible hull roughness should be measured. The panel feels that thrust deduction is very important and should be considered. Self-propulsion tests are now being conducted in model ice and thrust deduction measurements are being made. We agree with Dr. Milano's comments on friction but consider it important, in the meantime, to adopt the recommended method. Model self-propulsion tests carried out in an ice environment have given good correlation with full scale results. Open water self-propulsion test data do not give correct correlation when operating a vessel in ice.

The panel recognize the importance of propeller/ice interaction as mentioned by *Mr.O.Bjorheden*, but the details will need to be left to future committees.

In answer to *Prof.Kostilainen* we like to comment that by adopting the IAHR recommendations on testing ice properties the ice panel is attempting to emphasize the importance of using uniform testing methods. Multiple tests are encouraged where possible.

The panel appreciates being informed by *Mr.Murdey* of the NRC's proposed towed test series and looks forward to receiving the results. In the meantime the panel recommends that one ship length be a minimum for a test.

The ice panel appreciates the model studies of *Mr.K.Szponar* and would be interested in receiving any available detail reports. The panel questions the use of triangular ice pieces in place of random piece size and shape.

The ice panel would like to thank all those that commented on the final report and recommendations.