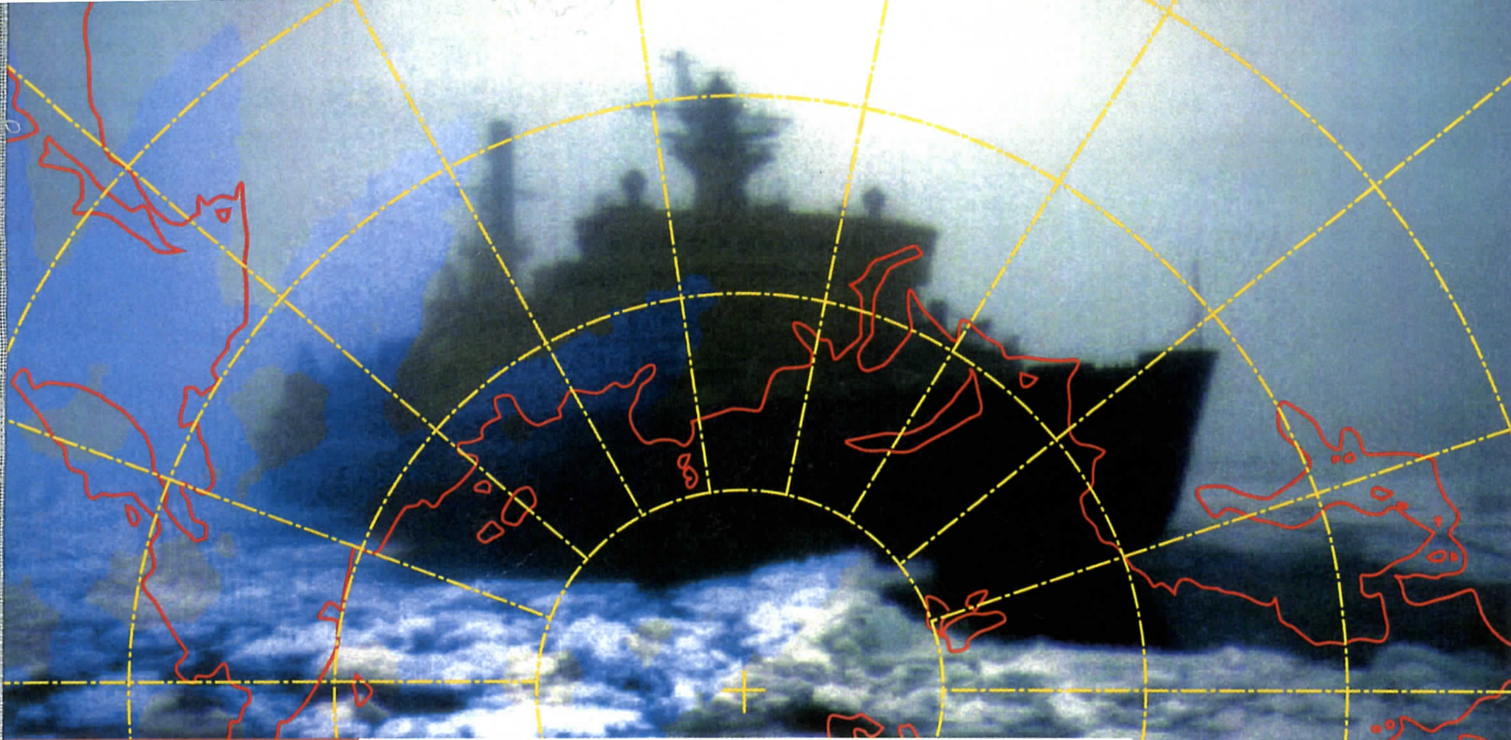
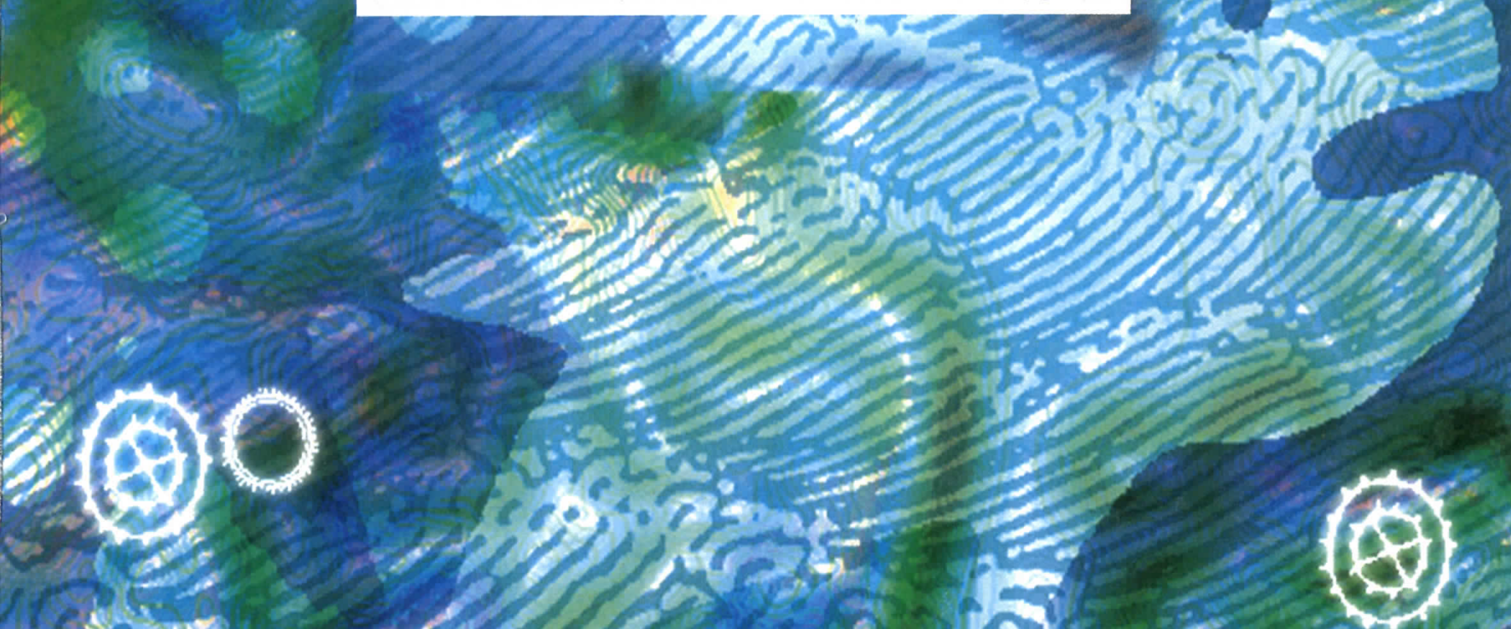


INSROP WORKING PAPER
NO. 151 - 1999, IV.3.4

Arctic Environmental Law. Harmonization of Polar Ship Rules. International and National Provisions.

By L.G. Tsoy, M.A. Grechin, S.B. Karavanov, Yu.V. Glebko and V.V. Mikhailichenko



INSROP International Northern Sea Route Programme

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship and Ocean Foundation, Japan

International Northern Sea Route Programme (INSROP)

Central Marine Research & Design Institute, Russia

The Fridtjof Nansen Institute, Norway

Ship & Ocean Foundation, Japan

INSROP WORKING PAPER NO. 151-1999

Sub-Programme IV: Political, Legal and Strategic Factors

Project IV.3.4: Arctic Environmental Law. Harmonization of Polar Ship Rules. International and National Provisions.

Supervisor: Loly G. Tsoy, CNIIMF

Title: **Arctic Environmental Law. Harmonization of Polar Ship Rules. International and National Provisions.**

Authors: **L.G. Tsoy (1), M.A. Grechin (1), S.B. Karavanov (1), Yu.V. Glebko (1) and V.V. Mikhailichenko (2)**

Addresses: (1): Central Marine Research and Design Institute (CNIIMF), Kavalergardskaya Street 6, 193015 St.Petersburg, RUSSIA.
(2): Northern Sea Route Administration (NSRA), Ministry of Transport, 1/4 Rozhdestvenka, 103759 Moscow, RUSSIA.

Date: 23 March 1999

Reviewed by: Dr. James W. St. John, Project Manager, Arctic Technology Group, Science and Technology Corporation, Columbia, Maryland, USA.

What is an INSROP Working Paper and how to handle it:

This publication forms part of a Working Paper series from the **International Northern Sea Route Programme - INSROP**. This Working Paper has been evaluated by a reviewer and can be circulated for comments both within and outside the INSROP team, as well as be published in parallel by the researching institution. A Working Paper will in some cases be the final documentation of a technical part of a project, and it can also sometimes be published as part of a more comprehensive INSROP Report. For any comments, please contact the authors of this Working Paper.

FOREWORD - INSROP WORKING PAPER

INSROP is a five-year multidisciplinary and multilateral research programme, the main phase of which commenced in June 1993. The three principal cooperating partners are **Central Marine Research & Design Institute (CNIIMF)**, St. Petersburg, Russia; **Ship and Ocean Foundation (SOF)**, Tokyo, Japan; and **Fridtjof Nansen Institute (FNI)**, Lysaker, Norway. The INSROP Secretariat is shared between CNIIMF and FNI and is located at FNI.

INSROP is split into four main projects: 1) Natural Conditions and Ice Navigation; 2) Environmental Factors; 3) Trade and Commercial Shipping Aspects of the NSR; and 4) Political, Legal and Strategic Factors. The aim of INSROP is to build up a knowledge base adequate to provide a foundation for long-term planning and decision-making by state agencies as well as private companies etc., for purposes of promoting rational decisionmaking concerning the use of the Northern Sea Route for transit and regional development.

INSROP is a direct result of the normalization of the international situation and the Murmansk initiatives of the former Soviet Union in 1987, when the readiness of the USSR to open the NSR for international shipping was officially declared. The Murmansk Initiatives enabled the continuation, expansion and intensification of traditional collaboration between the states in the Arctic, including safety and efficiency of shipping. Russia, being the successor state to the USSR, supports the Murmansk Initiatives. The initiatives stimulated contact and cooperation between CNIIMF and FNI in 1988 and resulted in a pilot study of the NSR in 1991. In 1992 SOF entered INSROP as a third partner on an equal basis with CNIIMF and FNI.

The complete series of publications may be obtained from the Fridtjof Nansen Institute.

SPONSORS OF INSROP

- Nippon Foundation/Ship & Ocean Foundation, Japan
- The government of the Russian Federation
- The Norwegian Research Council
- The Norwegian Ministry of Foreign Affairs
- The Norwegian Ministry of Industry and Energy
- The Norwegian Ministry of the Environment
- The Central and Eastern Europe programme
- State Industry and Regional Development Fund, Norway
- Phillips Petroleum Company, Norway
- Kværner a.s.
- Norwegian Federation of Shipowners
- Norsk Hydro
- Fridtjof Nansen Institute

PROFESSIONAL ORGANISATIONS PERMANENTLY ATTACHED TO INSROP

- Ship & Ocean Foundation, Japan
- Central Marine Research & Design Institute, Russia
- Fridtjof Nansen Institute, Norway
- National Institute of Polar Research, Japan
- Ship Research Institute, Japan
- Murmansk Shipping Company, Russia
- Northern Sea Route Administration, Russia
- Arctic & Antarctic Research Institute, Russia
- Norwegian Polar Research Institute
- SINTEF (Foundation for Scientific and Industrial Research - Civil and Environmental Engineering), Norway.

PROGRAMME COORDINATORS

- **Yuri Ivanov, CNIIMF**
Kavalergardskaya Str.6
St. Petersburg 193015, Russia
Tel: 7 812 271 5633
Fax: 7 812 274 3864
E-mail: cniimf@neva.spb.ru

- **Willy Østreng, FNI**
P.O. Box 326
N-1326 Lysaker, Norway
Tel: 47 67 11 19 00
Fax: 47 67 11 19 10
E-mail: sentralbord@fni.no

- **Hiroyasu Kawai, SOF**
Nippon Zaidan Building
15-16 Toranomon 1-chome
Minato-ku, Tokyo 105-0001, Japan
Tel: 81 3 3502 2371
Fax: 81 3 3502 2033
E-mail: sofkawa@blue.ocn.ne.jp

GENERAL

The objective of Project IV.3.4 was to study the present day practice and experience of the arctic shipping in Russia, Canada, Scandinavia and in the USA. Also encompassed are developments of the External Working Group on Harmonization of Polar Ship Rules in relation to its work on the IMO Code and the unified IACS requirements, SOLAS and other Rules in connection with the Arctic Environmental Protection Strategy/Protection of the Arctic Marine Environment (AEPS/PAME). Within the framework of the present Project the Russian Party has made collection and analysis of existing Russian legislative acts regarding the arctic shipping. On the basis of the long-standing experience of the operation of ships in the Arctic and of their damageability, proposals on the common international ice classification of arctic ships taking into account differences in the ice performance between icebreakers and icebreaking cargo ships have been developed.

Authors are deeply thankful to the reviewer, James W. St. John, Project Manager of the Arctic Technology Group from Science and Technology Corp. USA, for the detailed review of the report on Project IV.3.4 (review and authors' comments are attached to the report). One should agree that process of the harmonization of Rules on the safety of polar ships is going on and requirements for these ships will be refined and improved in the future.

Table of contents

INTRODUCTION

Works on the present Project IV.3.4 were carried out jointly by the Norwegian (supervisor – Mr D. Brubaker, FNI) and Russian (supervisor – Dr L. Tsoy, CNIIMF) Parties. According to the program agreed upon by partners and recommendations of the Assessment Committee, the Russian Party was asked to gather and translate into English the Russian legislative documents regarding the safety of navigation along the Northern Sea Route (NSR) and to summarize its studies within the framework of the external (international) working group on the harmonization of rules of polar ships as applied to the preparation of the IMO Code on the safety of ships navigating in polar waters and of the International Association of Classification Societies (IACS) specifications to these ships. Besides, CNIIMF, in an effort to improve the Draft Polar Code and IACS Rules, on the basis of the long-standing experience of construction, operation and damageability of ships in the Arctic, has elaborated proposals on the further development of a common international ice classification of polar ships.

Consequently the Russian Party has published in English the *"Guide for the through navigation of ships along the Northern Sea Route"* developed by the Northern Sea Route Administration (NSRA) and the State Hydrographic Enterprise under the Ministry of Transport of the Russian Federation. The Guide comprises "*Regulations for navigation on the seaways of the Northern Sea Route*" and the "*Requirements for the design, equipment and supplies of vessels navigating the Northern Sea Route*" the latter document having been developed by CNIIMF.

Within the framework of the harmonization of polar ships rules the Russian Party has drawn up comments and proposals on the IMO Code pertaining to the safety of polar ships submitted by Canada and also has given recommendations as to requirements to the unsinkability and stability of ships in the case of ice damages. In addition to the above, proposals on the selection of cold-resistant steels and taking account of allowances for the corrosive and abrasive wear of the shell plating of ice ships were inserted into the unified IACS requirements.

As to the consideration of the ice performance of ships the necessity of the introduction into the Code and unified requirements of ice propulsion characteristics and in particular of the icebreaking capability have been substantiated.

Division of polar ships into classes is to be made in accordance with both the ice strength and ice propulsion criteria. Besides, the proposal was introduced on the mandatory consideration in the classification of polar ships of differences between specialized icebreakers and icebreaking cargo ships.

1. COMMENTS AND PROPOSALS OF THE CNIIMF AND OF THE NSRA ON DRAFT 4 OF THE "INTERNATIONAL CODE OF SAFETY FOR SHIPS NAVIGATING IN POLAR WATERS"

After having considered the Polar Code Draft, CNIIMF and NSRA note that the draft presented considerably differs from the previous wording. It is more of a general declarative character, without specific supplementary requirements for the structure and equipment of polar ships. In the opinion of CNIIMF and NSRA, the Code should include concrete specifications taking into account peculiarities of the ice navigation and improving safety of polar class ships. These special requirements should supplement requirements of the valid International Conventions and Codes for conventional ships. Unfortunately the draft in question, especially as far as part A is concerned, mainly contains general declarations and wishes.

As to the substance of this draft of the Code, the Institute and the Administration have the following comments and proposals.

Preamble

1. Item i) 2.6 should be adopted in the following wording: "This Code is not intended to infringe on the shipping rules existing in individual countries. The Circumpolar Administration has the right to apply or not this Code to domestic ships engaged in coastal voyages on routes and waterways being under the jurisdiction of these countries taking into account local conditions, infrastructure and procedures".
2. Item ii) 2.3. Instead of the word "pollutants" write down "polluting, noxious and toxic cargo".

Chapter 1. General

1. Item 1.1.1. Add at the end the words: "and being engaged on international voyages".
2. Item 1.1.5. As appears from the acquaintance with draft 4 of the Polar Code, all its requirements and regulations on safety basically apply to three main groups of ice ships. The first group embraces icebreakers and icebreaking cargo ships intended for the year round operation in high latitudes of the Arctic, that is under the multi-year ice conditions (polar classes 1-3). The second group - ships designed for the year round navigation along traditional coastal routes of the polar seas, that is under conditions of the first-year ice (polar classes 4 and 5). The third group includes ships intended for the episodic navigation in polar waters, that is during the summer-autumn navigational period through the decayed ice (polar classes 6 and 7). Apparently bearing in mind the above (three groups) one should regulate in the Code all the matters associated with the safety of navigation of ships in polar waters.

As to the classification of polar ships presented in the Code Draft in question, while recognizing the advisability of the subdivision of all polar ships into 7 classes (and this complies with the Russian experience) depending on operational conditions in ice one cannot agree with the statement of item ii) 3.16 that the classification suggested "defines the ship's operating capabilities" of a particular class. This classification specifies only restrictions as to ice conditions and requirements to the outdoor air temperature for the equipment and materials. Experience of the design, construction and operation of ships for the Arctic shows that as a principal parameter of the operational capabilities of ice ships the icebreaking capability has to be taken the latter being a maximum thickness of the level compact ice of a certain standard strength broken by the continuously moving ship at a minimum steady speed of about 2 knots (1 m/s). This characteristic defining the ice propulsion of ship and on which to a considerable extent the safety of navigation under ice conditions depends lacks in the classification. It would be also necessary to indicate for ships of each polar class the maximum ice thickness for which ship's hull structures should be designed proceeding from the most hazardous scenario of the hull/ice interaction – for instance, direct impact against an unbroken ice floe (for icebreaking cargo ships) or repulsed impact (for icebreakers) with a really achievable speed of about 7 m/s.

It is necessary to thoroughly examine the possibility of combining in one class icebreakers and icebreaking cargo ships. These ships having even the same icebreaking capability differ considerably in the maneuverability and capability to independently navigate in drifting ice, in particular under conditions of the ice compression.

And finally, there is no explanation concerning conditions under which the escorting of cargo ships by icebreakers is to be used. Obviously the use of icebreakers along with ensuring higher safety and more efficient work of cargo ships in ice allows to extend possibilities to operate a ship of each class maintaining the same safety level.

The above stated shows the necessity of a more detailed study of the classification of polar ships and of its special consideration. For the purpose of normalization within the Polar Code, as it was mentioned before, it seems to be sufficient to break down all ships navigating in polar waters into three principal groups according to operational conditions.

Chapter 3. Subdivision and stability

1. Item 3.2.1. Add the following: "Spaces in double boards may be used as tanks of the segregated ballast or should be empty".
2. Change the numbering of item 3.2.4 by 3.2.2 and complement it with the following: "It is allowed to use double bottom-tanks within the length of the aft machinery space for the storage of fuel and lubricants the capacity of each tank not exceeding 20 cubic m".

   Grounds

   2.1. Probability of the bottom damage within the double bottom for the aft machinery space is low and does not exceed, according to maximum estimations, 0.0010 - 0.0015 for 20 years of the operation of ship.

   2.2. Arrangement of cofferdams in the double bottom of the machinery space separating tanks from the outer shell plating does not provide for acceptable structural solutions and would result in the complication of the operation of ship because of difficulties in the maintenance of cofferdams.
3. Change the numbering of item 3.2.5 by 3.2.3.
4. Instead of items 3.2.2 and 3.2.3 insert the following common item 3.2.4: "In addition to requirements of the International Conventions, Codes and other IMO documents, all ships navigating in ice regardless of their length should meet requirements of item 3.2.7 in the case of the ice damages specified in item 3.2.8".
5. Insert the following new items:

   3.2.5. Presumed ice damages for all ships including dry cargo vessels of the polar class PC5 and higher may be located at any place within the zone of ice damages; for dry cargo vessels of polar classes PC6 and PC7 – between watertight bulkheads, platforms and decks[1].

   3.2.6. Requirements of 3.2.7 do not apply to the cases of flooding of the aft machinery space for ships of class PC6 less than 90 m in length and of class PC7 less than 125 m in length.

   3.2.7. Requirements for the damaged trim and stability of a damaged ship are considered to be met if the following conditions are complied with:

   .1 emergency waterline after equalization of the ship, and in cases when the equalization is not provided after flooding, runs below the bulkhead deck and lower edge of any opening through which progressive flooding may take place;

---

[1] If the distance between two adjacent watertight constructions is less than the extent of damage the corresponding adjacent compartment should be considered as one flooded compartment.

.2 initial metacentric height of ship at the final stage of symmetrical flooding calculated by the constant displacement method before taking measures for its increase should be not less than 0.05 m;

.3 angle of heel in the case of unsymmetrical flooding should not exceed 20° (15° for passenger ships) and after equalization where provided it should not exceed 12°;

.4 the righting lever curve of a damaged ship at the final stage of flooding should have the area under the righting lever curve of not less than 0.0175 m×rad, the range of positive righting levers not less than 20° beyond the angle of equilibrium and maximum righting lever not less than 0.1 m within this range.

3.2.8. In the calculation of the damage stability one should assume the following sizes of ice damages in the zone of their location from the base line up to the level 1.2 $\mathbf{d}_i$ within the length $\mathbf{L}_i$ (here $\mathbf{L}_i$ is the length of ship along the waterline corresponding to the draught $\mathbf{d}_i$ up to the upper limit of the ice belt):

.1 longitudinal extent is 0.045 $\mathbf{L}_i$ if the center of hole is located at a distance of 0.4 $\mathbf{L}_i$ from the forward perpendicular and 0.015 $\mathbf{L}_i$ in any other part of the ship;

.2 depth of the damage measured at right angles to the ship's shell plating at any point of the calculated damage area is 0.76 m;

.3 vertical extent is 0.2 $\mathbf{d}_i$.

Chapter 6. Anchoring and towing

Item 6.3.6 should be complemented with specific requirements to the construction and form of the forebody above waterline of the cargo ships navigating in ice under support of icebreakers. The above-water part of the forebody of cargo ships should be unified to provide for the compliance with the shape of the afterbody cut-out of the icebreakers carrying out close towing of ships. Such unification for Russian ships and icebreakers has been accomplished and relevant requirements to the unified shape of bow and towing cut-out of the stern may be formulated for the inclusion into the Polar Code. Besides, the Russian experience of operations in the Arctic has shown that close towing of ships through ice can be efficient only if mass of the towed ship is smaller than that of the tug-icebreaker. Therefore, bearing in mind the construction in future of large ships for the Arctic (tankers, gas-carriers, bulkers, containerships), another tactics of the escorting of large ships should be used. When such ships get stuck in heavy ice, icebreakers should have the possibility of pushing these ships by tandem. The latter procedure requires the availability on all large icebreaking ships of a stern towing cut-out and of a corresponding unification of the form and dimensions of this cut-out as well as of the above-water part of the forebody of icebreakers.

Chapter 7. Main machinery

1. Item 7.2.4. To be complemented with the following:
   "Necessary power of the main machinery should be determined depending on the ship's icebreaking capability required for each polar class".
2. Bearing in mind the necessity of ensuring reliable operation of a propulsion plant it is advisable to add the following item 7.2.5:
   "Propellers should have at least 4 blades and be manufactured out of stainless steel or high-strength bronze. It is recommended to use propellers with removable blades".

Chapter 11. Life-saving appliances and survival arrangements

1. In the titles of tables 11.2 and 11.3 instead of "Contents..." to insert "Recommended contents...".

Chapter 12. Navigational equipment

1. Item 12.4.1. Instead of S (10 cm) there should apparently be X (3 cm).
2. Item 12.4.2. Instead of X (3 cm) there should be S (10 cm).
3. Item 12.5.2. To state in the following wording:
   "All ships should be equipped with receivers of the satellite navigation systems".
4. Item 12.6 apparently can be deleted taking into account the new wording draft of Chapter V of SOLAS.
5. It is suggested to delete item 12.10. As the Russian experience shows, general hull bending stresses are not limiting factors for the safety of sailing in ice. At the same time, registration of local ice loads over all sections of hull seems to be unreal. One should also bear in mind that at direct impacts of ice floes against the places, where strain-gauging stress sensors are fixed, the latters, as a rule, get out of order.

Chapter 15. Emergency equipment

1. Item 15.2.1. To be complemented with the following:
   "All the ships bound for polar waters should be provided with at least double stock of fuel and lubricating materials taking into account the planned route of navigation. When calculating fuel stocks the full speed in the open water should be taken as a designed speed. Stocks of fresh water (taking account of their replenishment from a distilling plant), provision and all other types of ship's supplies should be provided for not less than 60 days".
2. Item 15.2.2. The existing text to be replaced by the following:
   "On each ship of polar classes 1 - 5 there should be a spare propeller or two spare blades if propellers with removable blades are used".
3. Item 15.3.1. Instead of the polar class "1 - 3" to write down "PC1 - PC4".

Chapter 16. Environmental protection and damage control

1. Item 16.1.2. It is suggested to change the wording as follows:

- "The sea disposal of polluting substances is to be carried out in accordance with requirements for special areas stated in annexes I, II, IV and V of the MARPOL Convention, 73/78, with amendments, or of the Administration of the relevant Coastal State whichever are the most stringent"

2. Item 16.1.3. To delete words "both" and "and accident conditions" adding at the end of the item words: "and those under accident conditions into the shipboard oil pollution emergency plan according to requirements of the MARPOL Convention, 73/78".

Annex II. Permit to operate in polar waters

1. Information on ship should contain "deadweight" and "nominal power of the main engine".

Appendix III. Draft IMO Resolution

. In Table 1 (Annex) the indication of equivalencies between Finnish ice classes (1ASuper, 1A) and CASPPR'72 (type A, type B) of existing classes of the MRS Rules is incorrect. Actually the above foreign classes are equivalent to UL and L1 classes of the MRS Rules in force.

2. COMMENTS AND PROPOSALS OF CNIIMF ON THE UNIFIED IACS REQUIREMENTS TO THE SELECTION OF STEEL GRADE AND THE TAKING INTO ACCOUNT OF CORRECTIONS FOR THE WEAR OF HULL PLATING OF ICE SHIPS

2.1. Selection of steel grade

In compliance with the experience of the construction of arctic ships in Russia, recommendations on the selection of steel grade of hull structures of these ships are given not only in dependence on the class of structure (I, II, III) as it is proposed, but also on the calculated values of negative temperatures for a ship being designed.

At the same time, the operation of ships in the Arctic shows that cases of the occurrence of cracks in structures under the effect of negative temperatures is rather rare. Nevertheless they were detected and materials with their description analysed. In doing this it was found out that at low negative temperatures cracks emerged, as a rule, in areas of the concentration of stresses or higher vibration. For instance, it occurred in constructions of helicopter decks of icebreakers of the *Moskva* and *Admiral Makarov* type (Figure 2.1). Brittle fracture cracks under the impact of negative temperatutes occur mainly in constructions of superstructures and houses made out of steels of grades "A" and "B".

During the period from 1973 to 1979 the Murmansk Shipping Company registered 7 events of emergency structural damages caused by the effect of low temperatures. These damages happened to occur in January and December when ships were in the Yenisei Gulf and in the Yenisei river at an ambient air temperature from -30 to -46°C (Table 2.1).

The approach to the selection of steel for hull structures of polar ships put forward by the American Bureau of Shipping (ABS) takes no account in an explicit form of values of the ambient air negative temperature in areas of operation of the designed ships. In an indirect way, however, it is reflected in polar classes of ships of the international ice classification and accordingly in the recommended steel grades. Therefore such approach may be recognized as rightful.

Taking into account the above stated and the Russian experience on ordering and building of icebreakers and icebreaking cargo ships for the Arctic one may agree with the proposed ABS requirements (Tables SG2a and SG2b) on the use for ice strengthenings of ships covered by the group of polar classes PC1 - PC5 of steels of only the highest D and E categories because these ships are intended for all the year round operation in polar waters. For ships of polar classes PC6 and PC7 designed for the summer-autumn navigation in ice it is admissible to use for structures of ice strengthenings steels of lower categories B and AH.

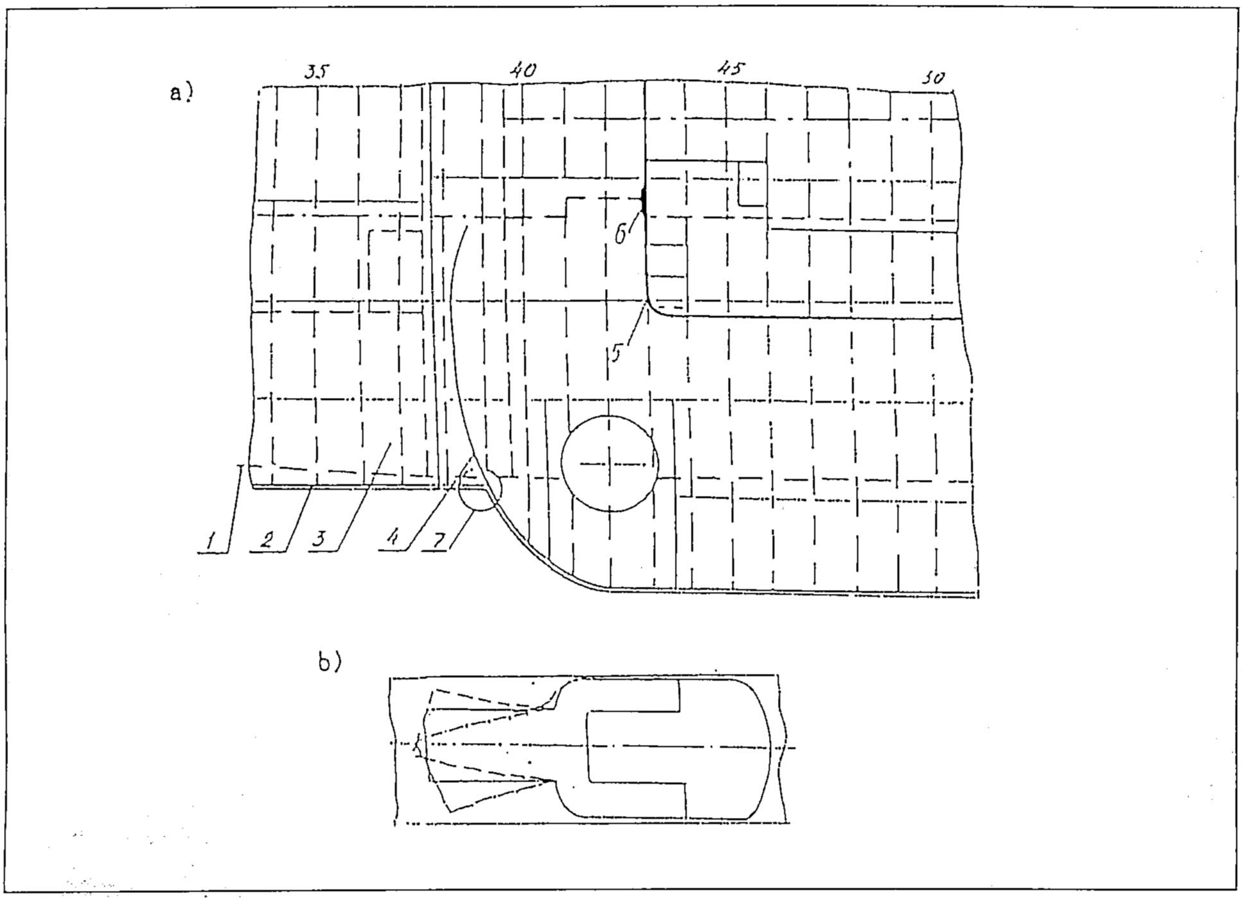


Fig.2.1. Location of cracks on the boat deck of icebreaker *Admiral Makarov* produced during the winter sailing in the Sea of Okhotsk in December 1979 (a); deck swinging pattern (b)

1 - lateral wall of the superstructure below the boat deck;
2 - finishing strap of the deck edge;
3 - boat deck; 4 - crack (5300 mm);
5 - walls of the upper tier of superstructure;
6 - crack in the area of the "rigid point";
7 - zone of the occurrence of crack.

Table 2.1

Structural damages on cargo ships and icebreakers, caused by low temperatures

Name of ship	Place of accident	Date	Ambient air temperature, deg.	Wind speed, m/s	Type of the emergency damage
Icebreaker *Murmansk*	Yenisei Gulf	11.01.73	- 37...- 40	4-8	Crack in the helicopter deck and in the superstructure wall over the whole length starboard in the area of frame 42. Crack length along the superstructure - 7 m.
Icebreaker *Kiev*	Yenisei Gulf	16.01.76	- 30...- 39	4-12	Crack in the forecastle deck starboard in the area of frame 50, 3.75 m long, 10-15 mm wide. Crack in the vertical forecastle bulkhead in the area of frame 50, 0.65 m long, 10-15 mm wide.
Electrically-driven m/s *Pavel Ponomarev*	Yenisei, Turushinsky Rapid	16.01.76	-39	14	Crack in the shell plating in the area of frames 57-59, 3 m long, 12-13 mm wide. Crack in the deck of the first bridge, 1.1 m long, 5-7 mm wide.
Electrically-driven m/s *Ghizhiga*	port of Dudinka	16.01.76	-46	4-12	Deck cracks in the area of frames 70-71, 3 , 4.3 and 4. 86 m long and 10 mm wide each.
Nuclear icebreaker *Àrktika*	Krestovsky Strait	14.12.76	-39	23-25	Area of frame 82. Crack in the deck of the 3-rd tier, 1.6 m long, 5-6 mm wide.
Electrically-driven m/s *Ob*	Yenisei river	02.12.79	-33		Area of frame 86. Crack in the enclosure, 0.32 m long, 1 mm wide. Port - 2 cracks in the upper deck, 1.8 and 1.57 m long; cracks in bollard stands, 2-3 mm wide, 0.36 and 0.31 m long.
Electrically-driven m/s *Ob*	port of Dudinka	03.12.79	-37		In the area of cracks 7 ribs of rigidity are broken, the width of breakage is 2-5 mm. Starboard - 2 cracks of the upper deck 1.9 and 0.57 m long, 5-10 mm wide. Cracks in the ventilation column. In the area of cracks 5 ribs of rigidity are broken, the width of breakage is 2-5 mm.

2.2. Corrections for the wear of plating

The proposed tabulated form of wear allowances as final values is more convenient than the use of methods of calculation of these corrections contained in the MRS Rules (section 1.1.5 of the Rules).

As a whole, absolute values of wear allowances determined from table $$$AC-1 are fairly close to the values calculated by the MRS methodology for cargo ice ships as of the middle of the rated service life. However for ships of the highest ULA category and linear icebreakers the Russian Register Rules specify the allowances which are 1.5 - 2 times as large as those for corresponding classes of the ABS table mentioned above. At the same time, it should be noted that the way of assigning wear rates set forth in chapters 3.10 and 3.11 of the MRS 1995 Rules is not free of disadvantages. Recommendations on the wear rates for cargo ships (L1 - ULA) poorly comply with the recommendations for icebreakers (classes LL4 - LL1). The influence of steel grades on the corrosion resistance of structure is not taken into account.

Analysis of data on the wear of hulls of ice ships shows that intensity of the wear of plating substantially depends on the type of ship (cargo ship, icebreaker) and the character of its operation in ice (all the year round independently, all the year round under the icebreaker support or sailing only during the summer navigation). So, if for MRS L1, UL ships and port tugs the wear of the bow shell plating is 0.2 - 0.3 mm/year, for linear icebreakers it may reach 0.4 - 0.5 mm/year and more.

Besides, as to the results of the analysis of wear of the bottom plating of the Far East Shipping Company one may come to the following conclusions:

- wear of the bilge and flat bottom plating increases in the direction from stem to bow the bilge wear being greater than that of the flat portion;
- rate of wear of the bottom plating is not less than that of the ice strake its average values for the bilge changing within 0.4-0.8 mm/year and for the flat bottom – within 0.3-0.6 mm/year;
- distribution of the wear intensity over the surface of the flat bottom is irregular and the wear substantially increases in the areas of welding of bottom framing webs due to the abrasive effect of ice (Figure 2.2);
- wear rate considerably depends on the steel grade and the value of pressure the wear becoming higher with the increase of the latter.

The conclusions drawn are indicative of the advisability while rating the wear to additionally take into account such factors as:

- purpose of ship (icebreaker or cargo ship);
- influence of the steel grade on the wear rate;
- shallow water effect characteristic of ships operating in the Russian *Arctic*.

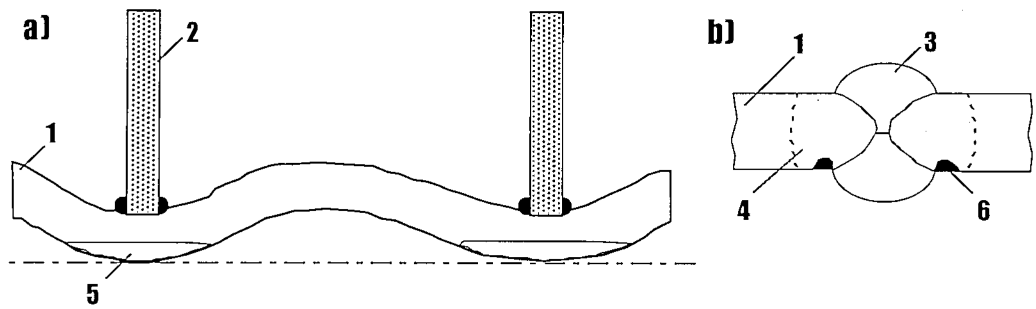


Fig.2.2. Wear of plates of the shell plating of icebreakers
a) - wear of plating below the framing web;
b) - failure of the near-seam zone of plates;
1 - plating; 2 - framing; 3 - welding seam;
4 - zone of the thermal effect;
5 - area of the plate wear by friction;
6 - corrosion failure of the zone of the thermal effect.

While realizing the necessity to further study the problem, at this stage and taking into consideration the above stated the following version of table as a basic table of wear allowances ($$$AC-1) is suggested:

Table 2.2

Abrasion and corrosion wear allowances Δt (mm) of the shell plating depending on the hull area

Hull area	PC1, PC2 and PC3	PC4 and PC5	PC6 and PC7
Bow and intermediate areas of the ice belt	4.0	3.0	2.0
Side areas below the ice belt	3.0	2.0	1.5
Bottom and other hull areas including bilge	2.0	1.5	1.0

In the absence of a protective cover of the ship's surface, tabulated Δt values should be doubled.

As to protective hull coatings (subsection $$$AC-2) it should be stressed that these should be ice resistant coatings of the *Inerta-160* type. At the same time, as the experience shows, even such coating should be reapplied on cargo ships at least once in 2 - 3 years and on powerful icebreakers – annually. Besides, to protect plating against the corrosion wear the electrochemical protection of the ship's hull may be used as well.

3. DEVELOPMENT OF REQUIREMENTS TO THE UNSINKABILITY AT ICE DAMAGES OF SHIPS

3.1. Statistics of ice damages

Statistical data on the parameters of ice damages are based on the information covering 200 cases of side ice damages of cargo ships in their navigation under ice conditions along the NSR. In all the cases of ice damages the water penetrated into the ship and compartments were flooded.

There is no information on the bottom ice damages. Therefore the statistical data given below refer only to side damages while navigating through ice.

3.1.1. Distribution of damage locations over the length of ship

Histogram of the dimensionless location of the middle of holes and the corresponding probability density function **f(x/L)** are given in Figure 3.1 (**L** - ship's length over the waterline at a draft $\mathbf{d_s}$ up to the summer load line). The cumulative distribution function **F(x/L)** is shown in Figure 3.2. As one can see from figures, ice damages principally occur in the forebody of ship at a distance of 0.4 **L** from the forward perpendicular (about 90 % of damages).

3.1.2. Distribution of damage length

Distribution function $\mathbf{F(\ell/L)}$ of the dimensionless length of damages presented in Figure 3.3 shows that 90 % of ice damages have a length ℓ less than 0.04 **L** with 57 % of damages of a small length ($\ell/\mathbf{L} \leq 0.005$) being located between frames and 43 % of damages affecting frames. Bearing in mind the fact that number of frames is considerably larger than that of transverse bulkheads one may assume that events of the ice damage of transverse bulkheads are highly rare and this is confirmed by the practice of operation of ships.

Analysis of the statistical data has also shown that average length of damages in the forebody located within 0.4 **L** from the forward perpendicular is three times as large as in the afterbody.

3.1.3. Distribution of damage penetration

Distribution function of the depth of damages $\mathbf{F(b_i)}$ presented in Figure 3.4 shows that 99 % of ice damages have a depth not exceeding 0.5 m. Proceeding from this it would be possible to assume standard depth of ice holes as being equal to 0.5 m. Due to technological considerations, however, taking into account the necessity of the maintenance of protecting cofferdams it is advisable to assume depth of damages equal to 0.76 m.

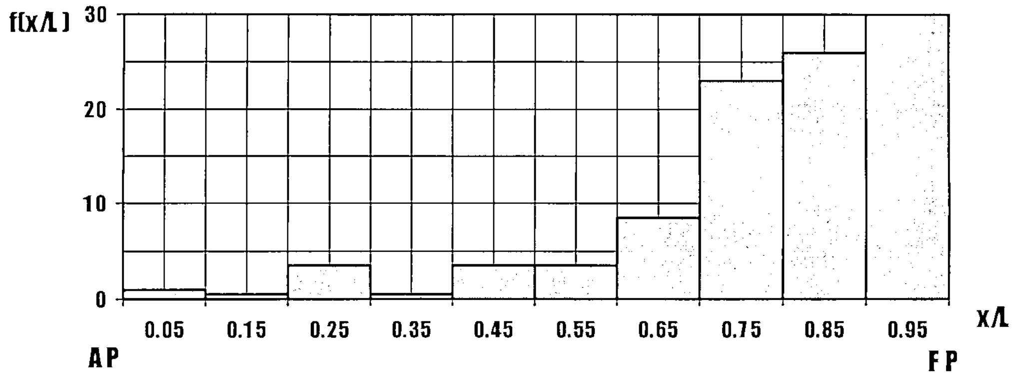


Fig.3.1. Distribution density of nondimensional longitudinal damage location

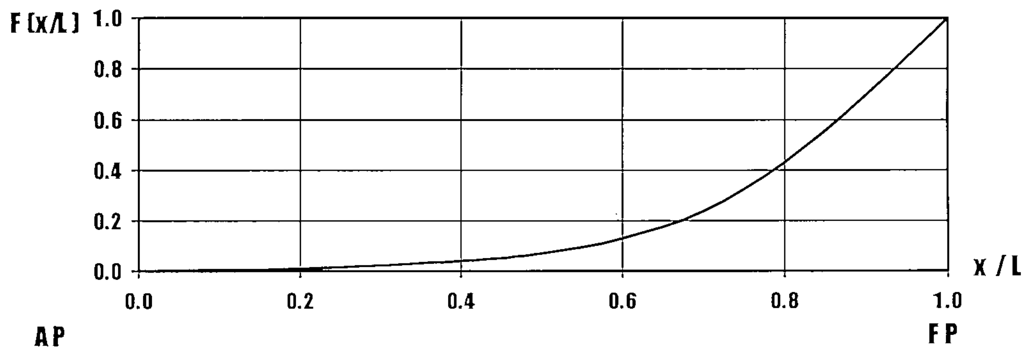


Fig.3.2. Distribution functions of nondimensional longitudinal damage location

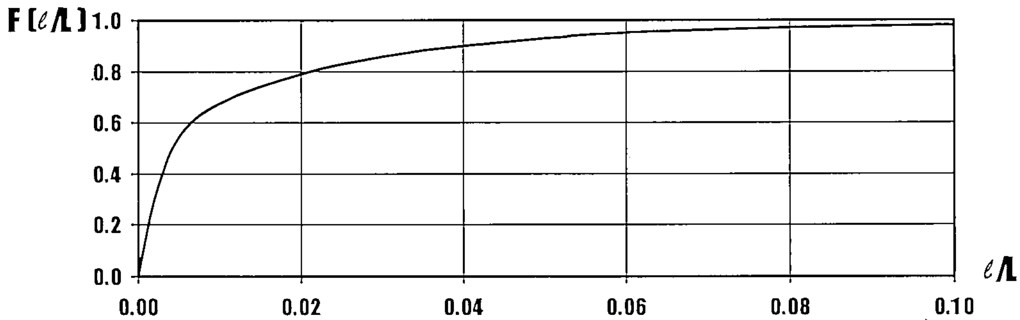


Fig.3.3. Distribution function of nondimensional longitudinal damage extent

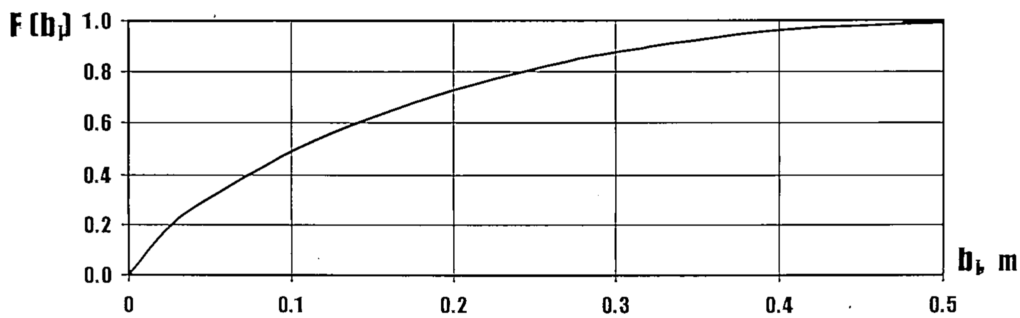


Fig.3.4. Distribution function of transverse damage penetration

3.1.4. Distribution of vertical location and the extent of damages

Distribution functions of the location of the lower edge of damage $\mathbf{F(z_\ell)}$ and of its upper edge $\mathbf{F(z_u)}$ (Figure 3.5) are given in Figure 3.6. They show that about 60 % of damages are located within the change of the lower boundary $\mathbf{z_\ell/d_s}$ from 0.1 to 0.4 the upper damage boundary $\mathbf{z_u/d_s}$ being located within the range from 0.13 to 0.55. Such concentration of ice damages in the area between the upper edge of the bilge strake and the ballast draft (below the ice strake) may be attributed to a lesser damageability of sides within the ice strake which has a higher thickness of plating. Maximum vertical extent of damages in this area at $\mathbf{z_i/d_s} = 0.5$ is about 0.15 $\mathbf{d_s}$.

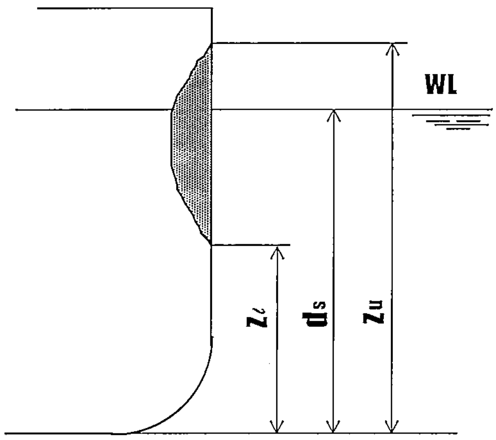


Fig.3.5. Vertical location of damage

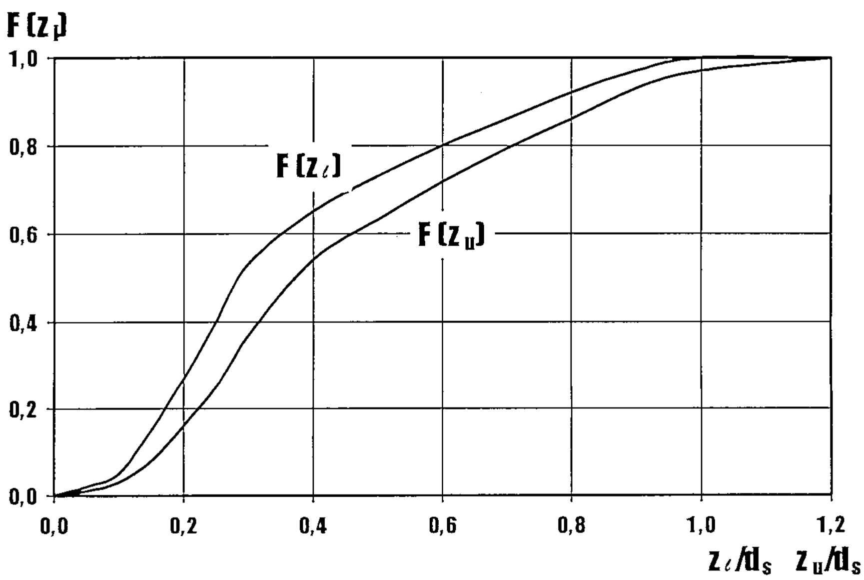


Fig.3.6. Distribution functions of nondimensional vertical damage location

Figure 3.7 shows the distribution function of an absolute vertical extent of damages. The function shows that 97 % of damages have a vertical extent up to 2 m and only 1 % – more than 3 m.

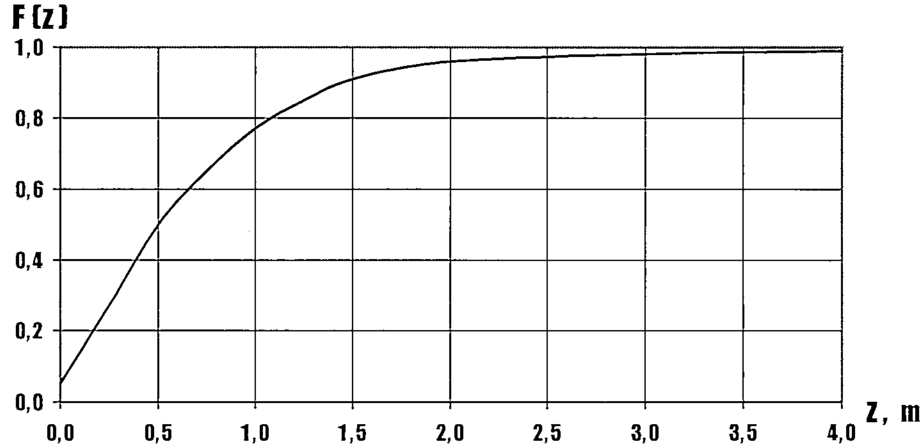


Fig.3.7. Distribution function of vertical damage extent

3.2. Recommendations on design sizes of ice damages, damage trim and stability

Ships operating under ice conditions run into an extra risk of probable hull ice damages. Probability of getting side damages in the zone exposed to the impact of ice loads is higher than at the collision of ships sailing in open water. Therefore for the purpose of reducing the probability of the loss of ships as well as diminishing the risk of the environmental pollution, more strict requirements for the subdivision and damage stability should be imposed upon polar ships in the case of ice damages. At the same time, one should bear in mind that sizes of ice damages are considerably smaller than those of the damages caused as a result of the collision of ships moving in open water at a higher speed the location of damages over the ship's length and hull height being different. Therefore, polar class ships, along with meeting the subdivision requirements established by the International Conventions and Codes in force for conventional ships should meet supplementary requirements for the damage trim and stability of ships taking into account location and sizes of damages to be determined on the basis of statistical data. Supplementary requirements may be based both on the probabilistic and deterministic approach. At the moment, probabilistic requirements exist only for passenger and dry cargo ships. Therefore at the fist stage for all types of ships it is expedient to adopt supplementary requirements based on the deterministic approach.

Statistical data given in the above permit to recommend[1] assuming in the calculation of the damage trim and stability the following sizes of ice damages in the zone of their location from the base line up to the level 1.2 $\mathbf{d}_s$ within the length **L** (here **L** is the length of ship along the waterline corresponding to draft $\mathbf{d}_s$ up to the summer load line):

1. longitudinal extent is 0.045 **L** if the centre of damage is located at a distance of 0.4 **L** from the forward perpendicular and 0.015 **L** in any other part of the ship;
2. transverse extent of the damage measured at right angles to the ship's shell plating at any point of the calculated damage area is 0.76 m;
3. vertical extent is 0.2 $\mathbf{d}_s$ in the zone of the location of damage from the base line up to the 1.2 $\mathbf{d}_s$ within the length **L**.

The above ice damages for all types of ships including dry cargo ships of the polar class PC5 and higher may be located at any place within the zone of ice damages (two compartment standard of subdivision). In our opinion, for dry cargo ships of polar classes PC6 and PC7 not carrying hazardous cargo, damages may be located between watertight bulkheads (one compartment standard) having regard to the operation of such ships only during the summer-autumn period in the decayed ice.

Besides, one should remember that on comparatively small ships, requirements for the subdivision when the after machinery space is flooded cannot be met without substantial deterioration of their performance qualities. The probability of the side ice damage location close to the after machinery space situated within up to 0.25 **L** from the after perpendicular does not exceed $\mathbf{P}_1 = 0.03$. Ships of PC 6 and PC7 polar classes may be operated only during the summer-autumn period of navigation. For such ships the average relative number of side ice damages with 3 - 4 voyages a year would not exceed 0.10 and the mathematical expectation of a number of such accidents, if the Poisson distribution law is applied, for 20 years of the service life would be $\mathbf{a} = 2$ the probability of each accident being:

$$\mathbf{P}_2 = 1 - e^{-\mathbf{a}} = 0.865. \qquad (3.1)$$

Overall probability of a side ice damage within the machinery space is as follows:

$$\mathbf{P} = \mathbf{P}_1\, \mathbf{P}_2 = 0.0255. \qquad (3.2)$$

[1] Note of the delegation of the Russian Federation to the SLF 42 Subcommittee of IMO with comments and proposals is given in the ANNEX.

Taking into account relatively low probability of the occurrence of a side ice damage near the after machinery space it seems possible to allow not to apply subdivision requirements to cases of the flooding of the after machinery space on dry cargo PC6 and PC7 class ships less than 90 m and 125 m long accordingly not carrying hazardous cargo.

With the above sizes of ice damages all polar class ships should meet the damage trim and stability requirements specified by the IMO instruments in force for conventional ships of different types. Moreover the following additional requirements should be met:

1. emergency waterline after equalization of the ship, and in cases when the equalization is not provided after flooding, runs below the bulkhead deck and lower edge of any opening through which progressive flooding may take place;
2. initial metacentric height at the final stage of symmetrical flooding calculated by the constant displacement method before taking measures for its increase should be not less than 0.05 m;
3. angle of heel in the case of unsymmetrical flooding should not exceed 20° (15° for passenger ships) and after taking measures on the equalization – 12°.

These requirements, supplementary for all ships except passenger ones, are directed towards the prevention of the entry of ice during its shearing onto the bulkhead deck and of the damage of watertight deck structures as well as towards making possible for people to move over decks in the presence of icing.

4. DEVELOPMENT OF PROPOSALS ON THE TAKING INTO ACCOUNT OF ICE PROPULSION CHARACTERISTICS OF SHIPS IN THE IACS REQUIREMENTS AND IN THE POLAR CODE OF IMO

4.1. Analysis of existing requirements to the power of ice ships

4.1.1. Requirements of the MRS to the power of icebreakers

According to Rules of the Russian Marine Register of Shipping (MRS) now in force all the icebreakers are divided into 4 categories or classes [1]. Requirements to each of the above categories depend on thickness of the level ice through which an icebreaker can move and on the total shaft power. Specified values of the ice thickness and icebreaker power are shown in Table 4.1.

Table 4.1

Requirements to the power and thickness of ice broken through by icebreakers of different classes according to the MRS Rules

Category of icebreaker	Thickness of compact ice field, m	Total shaft power, kW
LL1	> 2	≥ 47807
LL2	< 2	22065 - 47808
LL3	≤ 1.5	11032 - 22065
LL4	≤ 1	< 11032

The acquaintance with these requirements shows that the Rules strictly (unambiguously) relate thickness of the broken ice with the icebreaker power. At the same time, there is no accurate definition of the icebreaking capability, no indication is given of the speed of movement of icebreaker through ice and it is not clear whether this ice is the level one, covered with snow and what is its strength. In practice of the icebreaker building there exists a ship ice propulsion criterion – icebreaking capability under which we understand thickness of the compact level ice broken up by ship moving at a speed of about 2 knots.

Simultaneous assignment of the icebreaking capability and power of icebreaker adopted in the MRS Rules does not seem successful. Experience of the construction of icebreakers testifies to the continuous improvement of their lines. Advanced achievements in the field of the development of a traditional forebody shape of icebreakers show that at the same set icebreaking capability the power of icebreaker with the improved traditional bow shape (not to mention non-traditional hull lines which should become the subject of special consideration of the Register) may be reduced by up to 50 % . Accordingly, without changing the power it is possible to raise the icebreaking capability of LL2 icebreakers from 2.0 up to 2.6 m, of LL3 –

from 1.5 up to 1.9 m and of LL4 – from 1.0 up to 1.3 m. Figure 4.1 shows anticipated dependencies of the shaft power upon the icebreaking capability of icebreakers with improved hull lines.

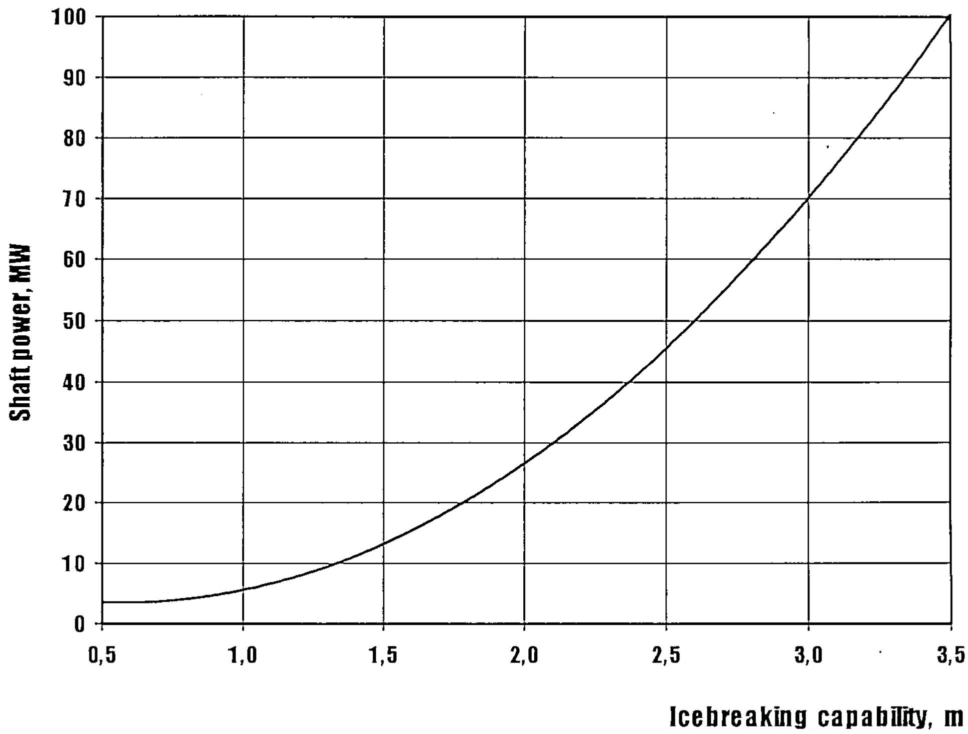


Fig.4.1. Dependency of the shaft power on the icebreaking capability of modern icebreakers with the improved conventional hull shape

As to the inexpediency of regulating simultaneously icebreaking capability and power of icebreakers one should also bear in mind that at a set icebreaking capability the icebreaker with the same hull shape but different draft may have different power owing to the change of the propeller diameter and accordingly of the thrust. Various technical means to improve the icebreaking capability may be used as well.

For the tentative assessment in a first approximation of the needed shaft power of icebreakers with a triple-shaft propulsion plant the following empirical formula may be used:

$$\mathbf{N_p = 51 \frac{h_i^3}{T^{1.2}}}, \text{ kW} \quad (4.1)$$

where

h_i - icebreaking capability, m

T - design waterline draft, m.

The above stated shows that it is more correct to impose requirements for the icebreaking capability and not for the power of icebreakers. Classification of icebreakers should be based on the criterion of icebreaking capability depending on the purpose and anticipated operational conditions of icebreaker during different periods of navigation and in different areas of the Arctic.

4.1.2. MRS requirements to the minimum power of cargo ships of the arctic navigation

In accordance with the requirements the minimum shaft power[1] is determined by the formula:

$$P_{min} = f_1 \ f_2 \ f_3 \ (f_4 D + P_0), \ kW \qquad (4.2)$$

Besides four coefficients it contains in an obvious way only one parameter – displacement **D**. Coefficients, in their turn, depend on the stem angle φ, breadth of ship **B**, its ice category and type of the propulsion device. Parameter P_0 being a function of displacement and ice category is given in a tabulated form. Of some interest is the qualitative and quantitative influence of these parameters upon the minimum acceptable power.

Coefficients f_1 and f_2

These coefficients should be considered jointly because the MRS imposes restrictions on their product

$$f_1 \cdot f_2 \geq 0.85. \qquad (4.3)$$

Values of coefficients f_1 and f_2:

$f_1 = 1.0$ – for fixed pitch propeller (FPP)

$f_1 = 0.9$ – for controllable pitch propeller (CPP)

$$f_2 = 0.005\,\varphi + 0.675. \qquad (4.4)$$

Additional requirement to coefficient f_2:

$$f_2 \leq 1.1. \qquad (4.5)$$

MRS requirements to the stem angle φ :

- category ULA – 25 - 30°,
- category UL – 45°,
- category L1 – 60°.

Taking into account all the requirements and restrictions as applied to coefficients f_1 and f_2 the dependency of their product on the stem angle was obtained which is shown in Figure 4.2.

[1] Though not specified in the Rules, minimum admissible values of the maximum continuous power which a propulsion plant can develop is apparently meant here.

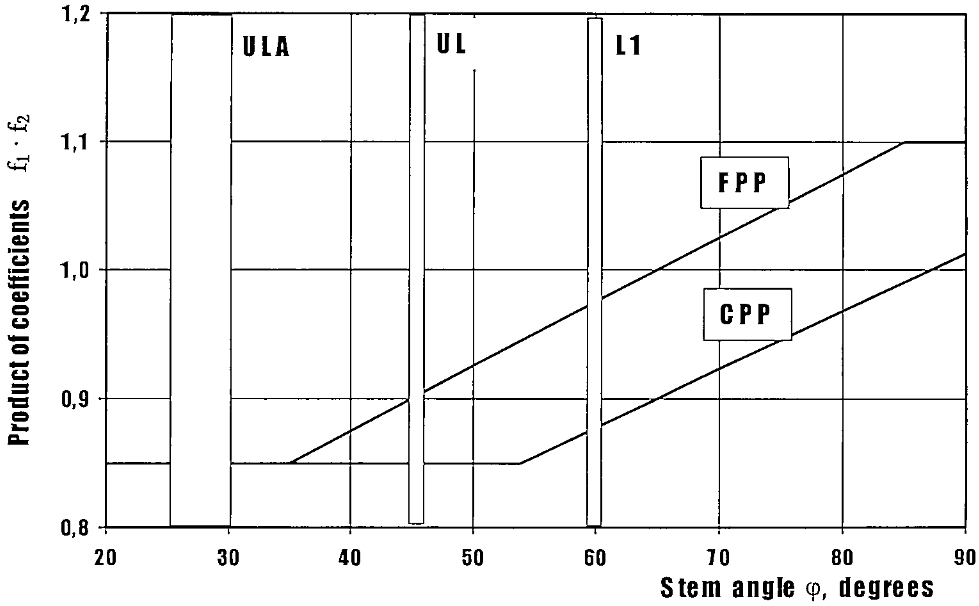


Fig.4.2. Influence of the stem angle on the product of coefficients $f_1 \cdot f_2$ with due account of the type of propulsion plant

The analysis made for two ice categories has shown the following:

- category ULA
  - there is no dependency between $\mathbf{f}_1 \bullet \mathbf{f}_2$, stem angle and type of the propulsion plant,
  - stem angle φ starts having an effect at values exceeding 35° (for FPP) and 54° (for CPP) which are outside the zone of values recommended by MRS,
- category UL
  - there is no effect of the stem angle upon $\mathbf{f}_1 \bullet \mathbf{f}_2$ for ships equipped with CPP,
  - reduction of stem the angle by each degree (for FPP) results in decrease of the minimum power only by 0.5 %; for example, the reduction of angle φ from 45 down to 35° according to the recommendations of CNIIMF will result in the decrease of the minimum power by 5 %.

The result obtained is inconsistent with experimental data and the experience of designing ice ships. Reduction of the stem angle from 45 to 35° under other similar conditions will lead to the increase of the icebreaking capability at least by 20 % [2]. This corresponds to the win of power approximately by 50 % and not by 5 % as it was obtained by the MRS formula.

Besides, from the point of view of the improvement of the ice performance of ships the advantage of CPP against FPP does not seem apparent. It is not clear, why in the presence of CPP the reduction of the minimum admissible power by 10 % is allowed.

In the case of a direct power transfer to CPP, as against FPP, while operating in ice conditions the constancy of revolutions of the main engine can be provided. However this will be achieved at the expense of the automatic decrease of pitch of CPP during the interaction with ice though protecting the reduction gear and engine against overloading, but inevitably leading to a decrease of the propeller thrust and thus to the stoppage of ship under heavy ice conditions. As a result, CPP, like FPP by which the thrust during the interaction with ice is also reduced, but through the reduction of revolutions, will not be able in the deficiency of the necessary power margin[1] to provide for normal operation of ship under heavy ice conditions. Besides, one should take into account the fact that the efficiency of CPP is lower than that of FPP. Considerably smaller is also the thrust of CPP in going astern – it does not exceed 54 - 55 % of the ahead motion, while the same ratio for FPP is 70 - 75 %. These disadvantages will deteriorate the maneuverability and operating capacity of ship in ice

---

[1] On subarctic icebreakers of *Mudyug* type where for the first time in the domestic practice the CPP was used, in addition to an ice flywheel, 30 % power margin of main engines is provided.

as a whole. Therefore it seems unjustified to reduce power of ice ships with CPP in comparison with FPP.

It should be noted that in accordance with the analysis made of the MRS Rules only ships with UL and L1 category of ice strengthenings (Figure 4.2) may have advantages from the use of CPP as to the reduction of power. The advisability to use CPP on ships of these categories seems to be questionable in general both from the economical and operational points of view.

<u>Coefficient f_3</u>

The coefficient is determined by formula:

$$f_3 = 1.2 \frac{B}{D^{1/3}}. \tag{4.6}$$

Additional restriction: $f_3 \geq 1.0.$ (4.7)

Additional restriction: $f_3 \geq 1.0.$ (4.7)

After a simple substitution the value in question becomes more convenient for the analysis:

$$B \geq 0.833\ D^{1/3}. \tag{4.8}$$

This inequality is presented graphically in Figure 4.3. The same figure shows values of breadth plotted for 40 ice ships built in different years according to the Register Rules.

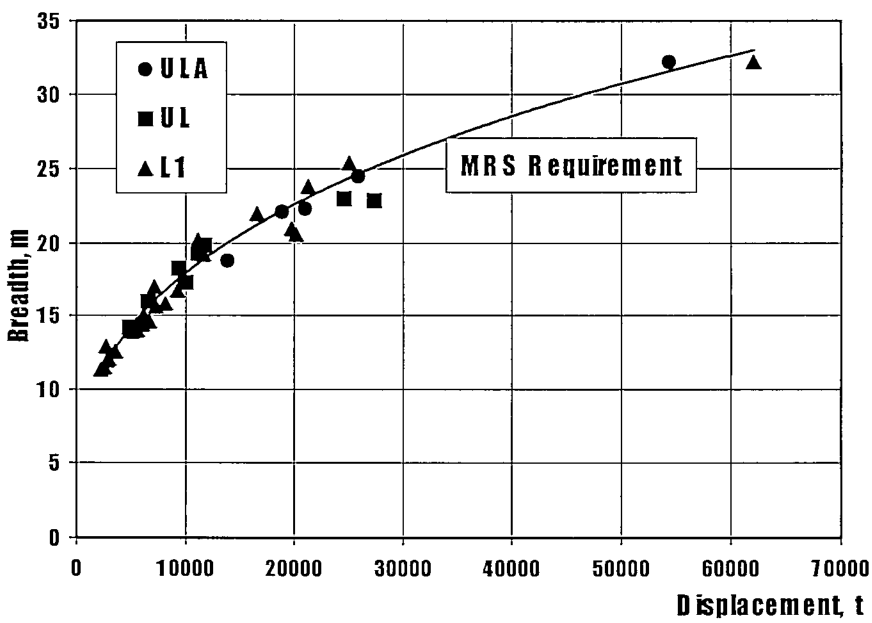


Fig.4.3. Ship's breadth / displacement and ice category relationship

In the figure it is not difficult to see practically full coincidence between the character of relationship of the MRS and actual values with the existing ships. This indicates that coefficient f_3 for ships of traditional types is always close to unity and its dependence on breadth and displacement practically does not exist or is negligible.

Coefficient f_4

It is more convenient to consider this coefficient not separately, but as a multiplier $(f_4 D + P_0)$ being a part of the principal formula. This multiplier is a basic power which after correction by coefficients f_1, f_2 and f_3 becomes the investigated value P_{min}. The basic power depends on the displacement, ice category, coefficients f_4 and P_0. One can see the character of this relationship in Figure 4.4. The analysis shows that increase of the displacement is accompanied by the smooth rise of the basic power. As a whole, the increase of displacement by 1 % results in rise of the basic power level approximately by 0.5 %.

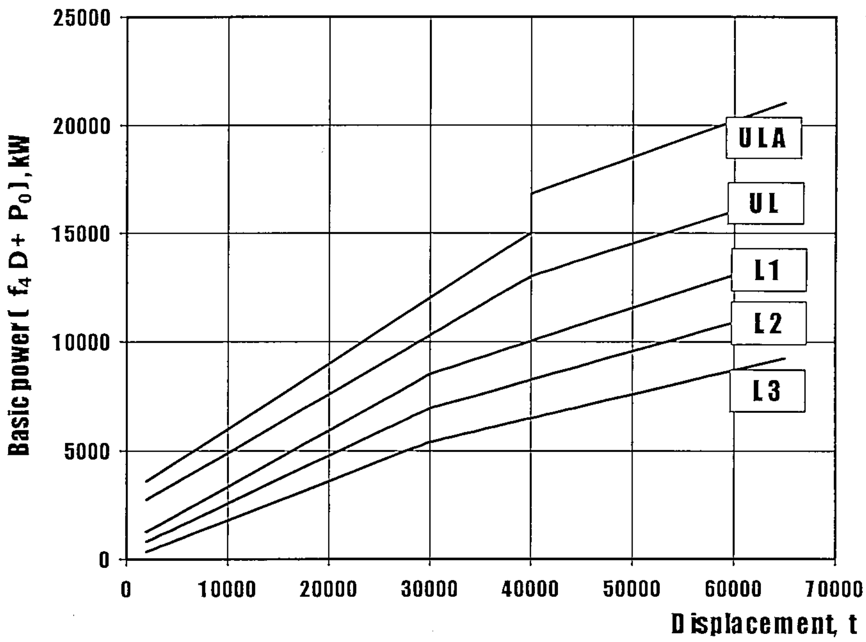


Fig.4.4. Dependence of the basic power of ships of different ice categories upon the displacement

Exception is the stepwise change of the basic power for ULA category ships with a displacement of 40000 t. At this point there is a break in power equal to 1800 kW. The nature of the break is not clear and it is scarcely possible to physically explain this event. Most probably, there is a misprint in Table 1.4.1 of the MRS Rules.

After the analysis of all components entering in the formula (4.2) values of $\mathbf{P}_{min}$ for ULA (Figure 4.5) and UL (Figure 4.6) category ships were calculated by this formula, not only displacement, but also breadth of ship being varied. Relationships presented in the last figure have been obtained for ships equipped with FPP and having a stem angle of 45°. If ship is fitted with CPP the level of minimum power is reduced approximately by 6 % due to the reduction of the product of coefficients $\mathbf{f}_1 \bullet \mathbf{f}_2$ from 0.9 to 0.85.

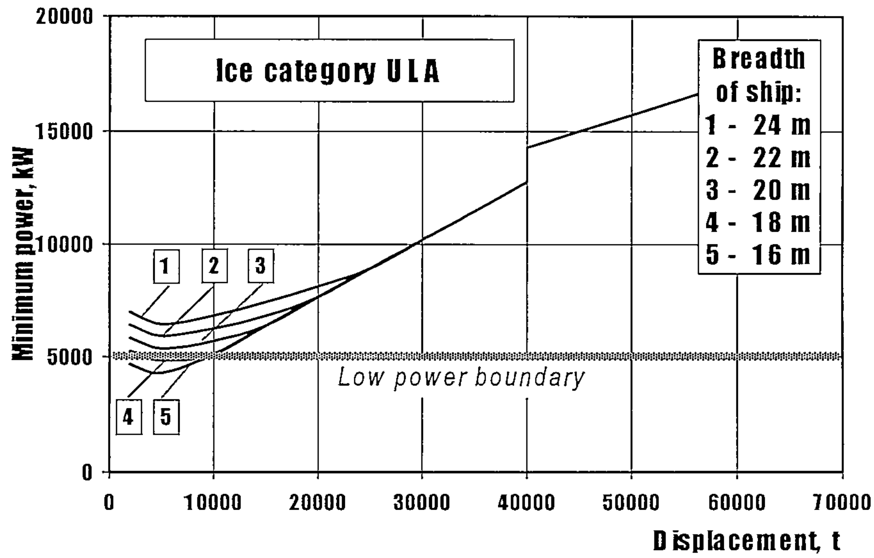


Fig.4.5. Minimum shaft power according to the MRS requirements for ships of ULA category (with CPP or FPP) depending on the displacement and breadth

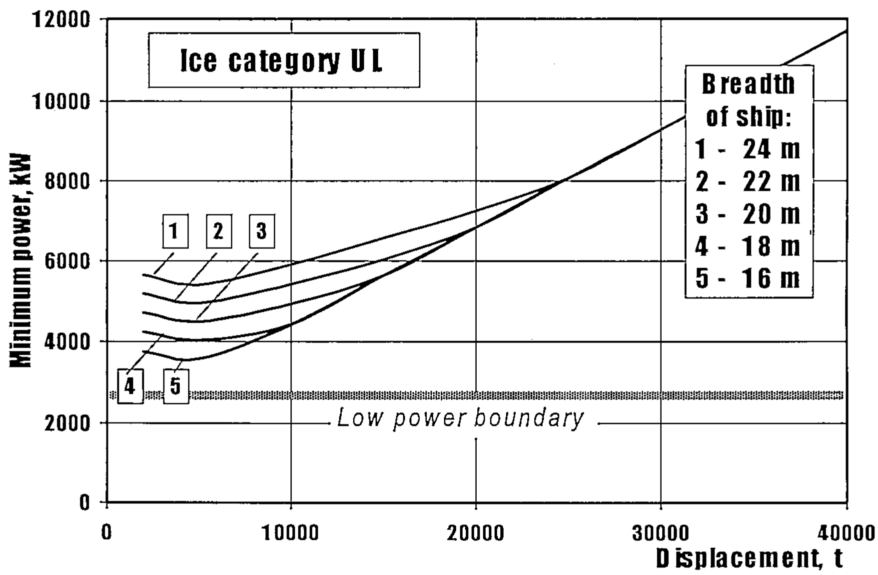


Fig.4.6. Minimum shaft power according to the MRS requirements for ships of UL category (with FPP) depending on the displacement and breadth

Analysis of the above relationships has shown the following:

- category ULA
    - shaft power restriction of 5000 kW extends practically only to ships with a displacement of up to 10000 t,
    - low power boundary of ships with a displacement exceeding 10000 t practically fully repeats the character of change of the basic power within the range of stem angles recommended by the MRS,
    - effect of breadth is manifested only on ships with non-standard ratios of principal dimensions.
- category UL
    - low power boundary of 2600 kW for ships with FPP is known to be underrated because the design formula within the whole range of change of ships' displacement and breadth gives higher values,
    - deviation of principal dimensions ratios associated with the increase of ship's breadth from standard ones is accompanied by the increase of minimum power and as in the case of ULA category ships, a hardly explicable optimum of power near a displacement of 4000 - 5000 t was detected.

During last 10 years there were certain changes in the Register Rules including those concerning requirements to the minimum power. With the same structure of the design formula two new parameters have been added into the latest wording of the Rules – stem angle φ and breadth of ship **B**, general minimum power level being reduced. Comparison of the design values obtained in accordance with the USSR Register requirements, 1985, and those of the MRS, 1995, is shown in Figures 4.7 and 4.8.

In both figures the data are plotted for built domestic ships of ULA and UL classes. One can see that the power of UL class ships rather satisfactorily complies with that required by the Register Rules. At the same time, existing and efficiently operated in the Arctic modern ULA class ships have a power appreciably exceeding that required by the Rules.

It should be noted that in the domestic practice while ordering ULA class ships the request for proposal should specify the required icebreaking capability of ship. This permits for a customer to have clear ideas as to the capability of ship navigating in ice. Therefore the power of icebreaking cargo ships of active ice navigation is a derivative value of the required ice propulsion depending on the assumed operational conditions in the Arctic.

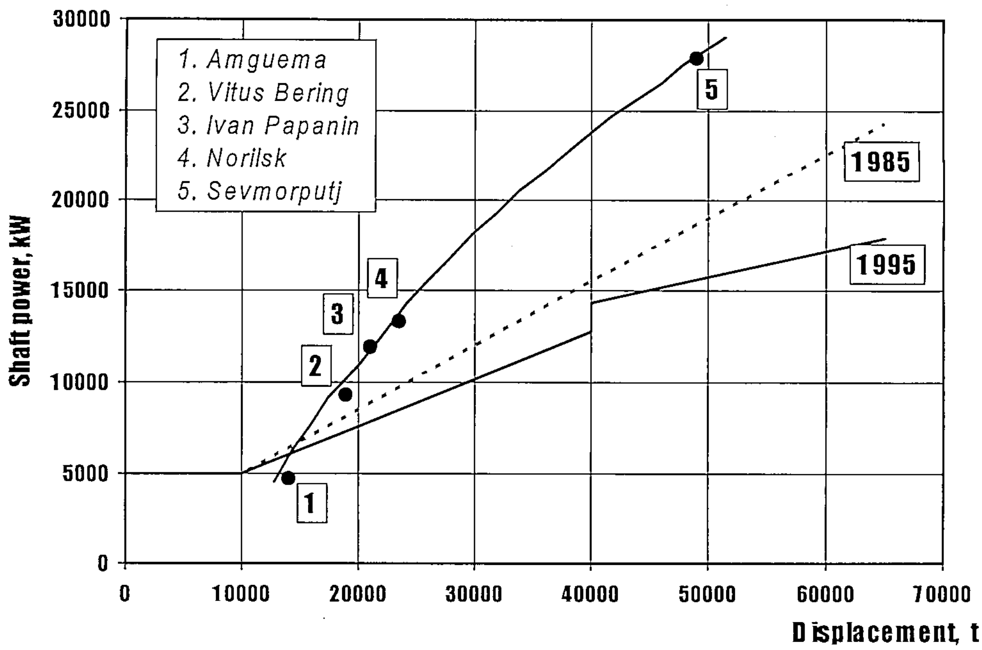


Fig.4.7. Minimum shaft power of ULA category ships according to 1985 and 1995 requirements

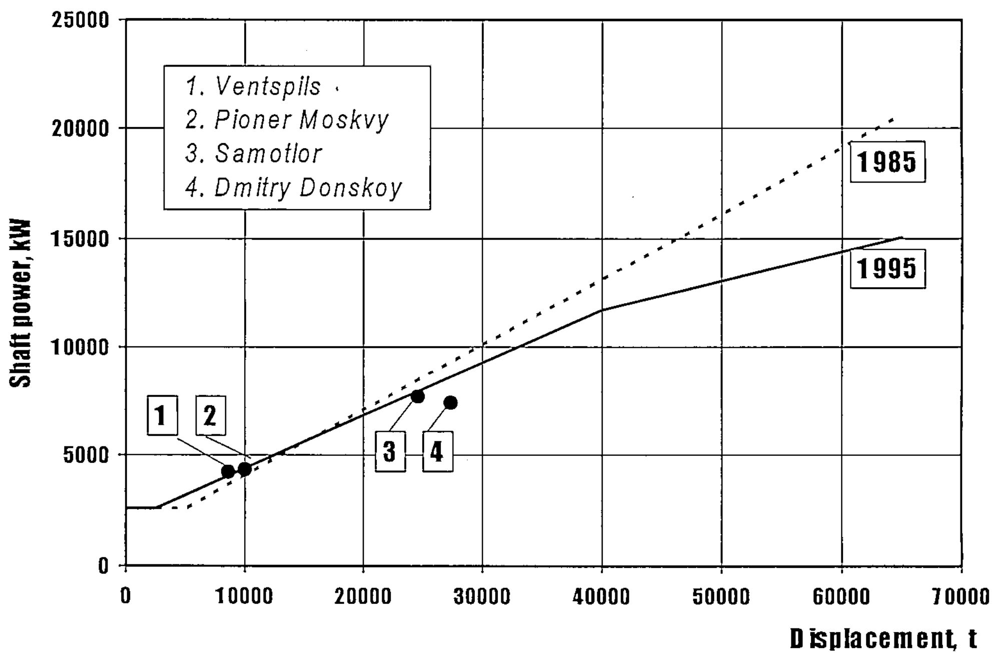


Fig.4.8. Minimum shaft power of UL category ships according to 1985 and 1995 requirements

As the experience of designing UL class ships has shown, the power of these ships is mainly stipulated by the condition of ensuring a given speed of motion in open water. Therefore in ice of the Arctic they work exclusively escorted by icebreakers and often (under relatively heavy ice conditions) icebreakers have to tow these ships. Bearing in mind the above stated, it is advisable while giving out a request for proposal of a UL class ship to specify also the required ice performance and in particular minimum value of the icebreaking capability assuring a satisfactory propulsion in a channel behind the icebreaker. Proceeding from the experience this icebreaking capability for UL class ships should be at least 0.5 - 0.6 m.

Taking into account the fact that in the Arctic during the summer period it is allowed to use L1 class ships these ships should possess minimum (necessary) ice performance and in particular, along with ice strengthenings, have the hull shape facilitating motion through ice. Experience of the construction and operation of L1 class ships shows that at the forebody characteristics recommended by the MRS Rules the icebreaking capability of these ships is usually 0.3 - 0.4 m. It permits them to operate fairly successfully under the escort of icebreakers in freezing non-arctic seas and in easy summer ice conditions in the Arctic.

Thus the study of the MRS Rules requirements for the power of ships with ice strengthenings of ULA, UL (1A Super of the Finnish-Swedish Rules) and L1 (1A of the Finnish-Swedish Rules) categories designed and admitted to the operation in the Arctic makes it possible to draw the following principal conclusions.

1. The formula of the current MRS Rules for the determination of a minimum shaft power practically does not permit to take into account particular features of the ship's hull shape and does not encourage using advanced icebreaking lines which would ensure the reduction of the required power at a given icebreaking capability.
2. As to ULA class ships the requirements for power seem to be underrated. The experience of the construction of modern ships of this class shows that to ensure reliable operation under conditions of all-the-year-round arctic navigation as well as for their compliance with advanced powerful icebreakers these ships should have the icebreaking capability of at least 1 m. The power of such ships is approximately 1.5 times higher than the regulated one and accordingly approved by the Register Rules.
3. For cargo ships of the arctic navigation, just as for icebreakers, it would be more correct to impose requirements not on the power, but on the icebreaking capability giving idea of the operability of ship in ice. Thus ample scope is offered to develop a joint ice classification of ships and icebreakers navigating in the Arctic proceeding from the criterion of the ice propulsion specified in an apparent way. Taking into consideration the experience of the construction and operation of icebreakers and ships of the domestic arctic fleet as well as the experience of the world icebreaker building it is advisable to assume a numerical value of the icebreaking capability,

that is a maximum thickness of the level compact ice broken through by a ship in continuous motion at a minimum steady speed of 1 m/s (2 knots), as a principal operational criterion of the subdivision of ships into ice classes.

4.1.3. Requirements of Det Norske Veritas for maximum continuous power of the propulsion plant of ice ships

Rules of Det Norske Veritas (DNV) specify the power of ice navigation ships proceeding from the given ship's icebreaking capability during the movement through level compact ice. Such requirement based on the evaluation of ship's ice propulsion by the thickness of level compact ice broken through is consistent with the Russian approach. According to the DNV requirements however consideration is given to the movement of ship through a given ice thickness at a speed of 4 knots. These conditions do not characterize limiting capabilities of an icebreaking ship. Therefore in Russia, as mentioned earlier, a maximum (practically limiting) thickness of the level compact ice broken through at a minimum steady speed which is usually 1.5 - 2 knots is taken as a principal criterion of the icebreaking capability.

Maximum continuous power of a propulsion plant[1] of icebreaking ship in accordance with the DNV requirements which corresponds to speed in the level compact ice equal to 4 knots should be not lower than that determined by the formula:

$$\mathbf{P} = 15\,\mathbf{C_x\,C_p\,C_n\,t\,B}\left(1 + 1.6\,\mathbf{T} + 27\sqrt{\frac{\mathbf{t}}{\mathbf{T}^{1/4}}}\right), \quad \text{kW} \tag{4.9}$$

where

$C_x = 1.0$	for ships with ordinary icebreaking stem;
$C_x = 0.9 + \varphi / 200$, but $1.0 \le C_x \le 1.2$;	
$C_p = 1.0$	for CPP;
$C_p = 1.1$	for FPP;
$C_p = 1.0$	for a type of mechanisms capable to sustain 100 % of torque at the zero speed of ship;
C_n	coefficient of the influence of duct upon the thrust, minimum value is 0.8 (efficient thrust / propeller thrust at a low speed ratio is dealt with);
t	thickness of ice in m broken through at a speed of 4 kn;
B	waterline molded breadth in m (local increase towards the stem should not be taken into consideration);
T	ship's draft in m.

[1] One should suppose that in the DNV Rules the propeller shaft power is meant.

Table 4.2 shows comparison of the power calculated by the DNV formula with the actual shaft power of existing Russian icebreakers and of a modern ULA class icebreaking cargo ship of *Norilsk* type moving through the level compact ice at a speed of 4 knots. The table shows also calculations as applied to the designs of two perspective powerful icebreakers for the Arctic where the improved hull shape has been used.

Table 4.2

Verification of Det Norske Veritas requirements to the minimum power needed for the movement of an icebreaking ship through the level compact ice of a given thickness at a speed of 4 knots (2 m/s)

Name of ship	C_x	C_p	C_n	t, m	B, m	T, m	Shaft power **P**, kW calculated	Shaft power **P**, kW actual	Error, %
					Icebreakers				
Lenin	1	1	1	1.3	26.8	10.4	21 220	28 800	-26
Moskva	1	1	1	1.15	23.5	9.5	15 430	16 200	-5
Ermak	1	1	1	1.5	25.6	11.0	24 830	26 500	-6
Arktika	1	1	1	1.9	28.0	11.0	36 850	49 000	-25
Kapitan Sorokin	1	1	1	1.1	25.6	8.5	15 320	16 200	-5
Mudyug	1	1	1	0.7	20.0	6.0	6 020	9 300	-35
LK-60Ya (design)	1	1	1	2.4	33.0	11.0	58 920	62 000	-5
LK-110Ya (design)	1	1	1	3.0	40.0	13.0	100 330	100 000	0
					Ships				
Norilsk	1	1	1	0.8	24.0	9.0	9 720	13300	-27

As one can see from the table, the compliance of calculated data with actual values is not satisfactory. No general rule can be detected in the effect of hull line shape. For instance, if for perspective icebreakers with the improved line shape practically full coincidence of calculated and actual values of power is observed, the same good conformity has been obtained for existing conventional icebreakers *Moskva* and *Ermak* as well as for a shallow-draft icebreaker *Kapitan Sorokin*. Apparently the main reason lays in the fact that the ship's draft was not appropriately taken into account. So, according to calculations by the Norwegian formula, increase of the draft results in the increase of the required power. It is known, at the same time, that increase of the ship's draft allows to proportionally increase diameter of the propeller and accordingly its thrust at the invariable power. Prevailing positive influence of the increased propeller diameter indicates that in the evaluation of ship's icebreaking capability the required power should decrease with the increase of the draft. This was reflected in the empirical formula (4.1).

The above stated does not permit considering advisable to include the DNV formula, as it was provided, into the IACS requirements. Besides, in application to ships navigating in ice it would be preferable to impose requirements not to the power, but to the icebreaking capability. Proceeding from this conclusion the general classification of icebreakers and icebreaking cargo ships should be formulated.

It should be noted that mode of the continuous motion of ship through the level ice of maximum thickness at a minimum speed is not hazardous, i.e. indecisive from the point of view of providing for the ice strength of ship. Therefore the admissible power or more accurately the maximum speed at which ship can move following the most dangerous scenario of the interaction with ice should be taken into consideration indirectly while normalizing design ice loads on the ship's hull depending on its ice class characterizing the purpose and operational conditions. At the same time, apparently, for icebreaking cargo ships of the independent navigation, despite their icebreaking capability being similar to that of the specialized icebreakers, additional requirements for the propulsion plant power within one and the same class will be needed which would provide for the maneuverability in ice, propulsion under conditions of ice compacting, capability of getting released of sticking etc. identical to icebreakers.

4.2. Proposal to include the ice propulsion criterion into the Rules for polar ships

The majority of classification societies regulating the construction of ice ships impose requirements to their power as a criterion of the ice propulsion. Obviously in the same way it would be well to include requirements on the needed propulsion in ice into the unified IACS Rules and the IMO Code on the safety of polar ships. However, as the analysis made shows, none of known recommendations on the admissible level of power of ice ships can be recognized as being satisfactory, because these recommendations do not allow to take adequately into account the most significant factors upon which the power necessary for the assignment of ship to a certain class of the required ice propulsion depends. At the same time, it would be wrong not to consider at all in the Polar Rules the icebreaking properties of ships. It follows from the Russian experience that the most suitable criterion of the ice propulsion is the icebreaking capability characterized by maximum thickness of the level compact ice through which a ship can continuously move at a minimum steady speed of 2 knots (1m/s). It is also assumed that the bending strength of ice is at least 500 kPa the ice having a natural snow cover about 20 cm deep.

Subdivision of ships into polar classes adopted in the now prepared unified IACS requirements to ice ships gives only some idea about the admissible safe (in respect to the ice strength) operational conditions of ship of one or another class. As the Russian experience of the development of requests for proposal while ordering icebreakers and icebreaking cargo ships and also the experience of their design and operation show, along with the determination of rated conditions to ensure the ice strength of ship, the ice class should characterize operational possibilities of ship. Just in accordance with this operational criterion permitting to assess the efficiency of the use of ship and accordingly economical indicators of its work the order to build a ship is given. For ships actively navigating in ice the icebreaking capability is taken as such criterion. It proves the necessity of imposing to polar ships the requirements for the icebreaking capability sufficient to provide for both the satisfactory operation and acceptable safety under conditions of the ice navigation specified for each class. Apparently not only the efficiency, but also the safety of navigation in ice depends on the level of the ship's ice propulsion.

Consequently, the structure of the ice classification of ships should make provision for the icebreaking capability determined for each class and conditions of the safe work in ice regulated for the hull structure.

The Russian experience of the design, construction and operation of arctic ships permits drawing up requirements to the icebreaking capability of ships depending on class of the ice classification included into the draft of the IMO Polar Code. Suggested values of the icebreaking capability are presented in Table 4.3. As one can see from the table, the division of polar ships into classes taken in the IMO Code is in fairly good agreement with the experience gained in Russia.

Table 4.3

Suggested division of ships by the icebreaking capability depending on the polar class of the international ice classification

Ice class	Icebreaking capability, m	Unrestricted independent navigation	Examples of Russian arctic ships	
			name	MRS category
PC1	3.0 - 3.6	Year-round in all polar areas of the world ocean	Design of the *icebreaker-leader* with a power of 110 MW	LL1
PC2	2.4 - 3.0	Year-round in moderate multi-year ice	Nuclear icebreaker *Arktika*	LL1
PC3	1.8 - 2.4	Year-round predominantly in second-year ice	Icebreaker *Ermak*, nuclear icebreaker *Taimyr*	LL2 LL2
PC4	1.2 - 1.8	Year-round predominantly in first-year thick ice	Icebreaker *Moskva,* Icebreaker *Kapitan Sorokin,* Barge carrier *Sevmorputj*	LL3 LL3 ULA
PC5	0.9 - 1.2	Year-round predominantly in first-year medium ice	Icebreaker *Mudyug,* M/s *Norilsk,* Electrically driven m/s *Vitus Bering,* M/s *Ivan Papanin*	LL4 ULA ULA ULA
PC6	0.6 - 0.9	Summer/autumn operation in open floating rotten ice	M/s *Dmitry Donskoy,* Tanker *Samotlor,* Tanker *Ventspils*	UL UL UL
PC7	0.3 - 0.6	Summer operation in open floating rotten ice cake	M/s *Pioner,* M/s *Volgoles,* M/s *Bryanskles*	L1 L1 L1

At early stages of the design, for the determination to a first approximation of the icebreaking capability hi of ships with icebreaking hull lines of the traditional type (with a wedge-like forebody) one may use the following experimental and empirical formula presented itself in a good light:

$$h_i = \frac{0,07 \cos^{\frac{3}{2}}\varphi \, \sin^{\frac{1}{2}}\left(\frac{\alpha_0 + \beta_0 + \beta_2}{3}\right)}{2,\sqrt[6]{f_d}\,\sqrt[5]{L/B}\,\sin^{\frac{3}{2}}\left(90^\circ - \beta_{10}\right)} \sqrt{P_e / B}\,\sqrt[6]{D}\,, \text{ m} \qquad (4.4)$$

where

φ - stem angle, deg

α_0 - entrance angle of design water line, deg

β_0 - flare angle of frame line No.0[1], deg

β_2 - flare angle of frame line No.2, deg

β_{10} - flare angle amidships, deg

L - vessel's length on DWL, m

B - vessel's breadth on DWL, m

$\mathbf{P_e}$ - total propeller bollard thrust , t

D - vessel's designed displacement, t

$\mathbf{f_d}$ - coefficient of the dynamic ice/ship's hull friction.

Recommended values of $\mathbf{f_d}$ parameter:

- for stainless steel - 0.065,
- for *Inerta-160* coating - 0.072,
- for typical shipbuilding steel - 0.080.

Total propeller thrust needed for the calculation of the icebreaking capability under conditions close to the bollard pull mode of operation may be calculated by the formula based on the experience of the design of domestic icebreakers:

$$\mathbf{P_e = k_p (d\, N_p)^{2/3}}, \text{ kN} \tag{4.5}$$

where

$\mathbf{N_p}$ - total shaft power, kW

d - propeller diameter, m

$\mathbf{k_p}$ - coefficient taking into account geometric characteristics of propellers, their number and interaction with the ship's hull; depending on the number of propellers this coefficient takes the following values: for triple-shaft ship -1.12, for twin-shaft ship - 0.98, for single-shaft ship - 0.78.

Table 4.4 shows the comparison of icebreaking capability calculated by formula (4.4) with actual values of built and operating domestic icebreaking ships. Results of calculations testify to the satisfactory convergence of calculated and actual data. One can see from the table that maximum deviation does not exceed 2 - 3 %. Limits of the change of parameters of the ships and icebreakers in question were: 50 - 230 m by length, 15 - 31 m by breadth, 4 - 11 m by draft, 2000 - 50000 t by displacement and 3 - 49 MW by power.

---

[1] In the Russian practice the frame line No.0 is assumed to be at the fore perpendicular and not at the after one as it is the case abroad.

Table 4.4

Comparison of actual values of the icebreaking capability of domestic icebreakers and icebreaking cargo ships with the calculated ones

Ship's name and year of construction	Dimensions, m			Angles, deg			D,	N_p,	h_i, m	
	L	B	T	φ	α_0	β_{10}	t	MW	actual	by formula (4.4)
Icebreakers										
Lenin, 1959	124.0	26.8	10.4	30	28	13	19240	28.8	1.65	1.61
Moskva, 1960	112.4	23.5	9.5	26	24	18	13290	16.2	1.45	1.43
Vasily Pronchishchev, 1961	62.0	17.5	6	25	24	16	3100	3.5	0.6 - 0.7	0.64
Ermak, 1974	130.0	25.6	11	26	26	16	20240	26.5	1.8	1.8
Arktika, 1974	136.0	28.0	11	27	28	20	23460	49.0	2.25	2.24
Kapitan Izmailov, 1976	52.2	15.6	4.2	25	37	12	2050	3.0	0.60	0.61
Kapitan Sorokin, 1977	117.3	25.1	7.5	23	28	15	12500	16.2	1.35	1.37
Mudyug, 1982	78.5	20.0	6	25	31	12	5560	9.3	0.95	0.97
Taimyr, 1989	140.6	28.0	8	23	42	10	19600	25.0	2.0	1.95
Kapitan Nikolaev, 1990	120.4	25.0	7.5	15	90	15	14100	16.2	1.95	1.94
Icebreaking cargo ships										
Amguema, 1962	127.0	18.8	8.5	29	24	7	14000	4.7	0.6 - 0.7	0.66
Norilsk, 1982	164.0	24.0	8.5	30	30	8	23500	13.3	1.05	1.08
Sevmorputj, 1988	229.1	31.3	10	30	21	11	49000	27.9	1.4÷1.5	1.49
Ivan Papanin, 1990	132.5	21.7	6.5	25	30	8	12600	11.9	1.1	1.09

On the basis of experimental investigations of the ice propulsion and seaworthiness of ice ships as well as of the experience of their design, construction and operation, recommendations may be formulated on the rational shape of hull lines of the perspective arctic ships with an icebreaking forebody of traditional type.

Icebreaking cargo ships

Proposed values of entrance angles φ and α_0 and also of flare angles at the first from the forward perpendicular frame line β_1 and at the middle frame β_{10} are presented in Table 4.5.

Table 4.5

Proposed hull shape characteristics of arctic cargo ships depending on the ice class

Ship's ice class		Angles, degrees			
IMO	MRS	φ	α_0	β_1	β_{10}
PC4, PC5	ULA	25	35	45 - 50	0 - 8
PC6	UL	30	30	35 - 45	0
PC7	L1	40	25	20 - 30	0

Combination of angles φ, α_0 and β_0 (flare angle at station section 0) should provide for the rounded (moderately convex) shape of fore frames, straight line stem and buttocks.

As experimental investigations have shown, these recommendations on the hull bow lines shape of prospective icebreaking cargo ships will allow either to improve their icebreaking capability by 5 - 10 % in comparison with the existing ones built for the Arctic, propulsion plant power being the same, or to provide for the saving of power up to 20 - 25 % at a set icebreaking capability.

For cargo ships of PC4 - PC5 (ULA) and lower classes it is admissible to use vertical sides amidships so permitting to increase the block coefficient and accordingly the cargo-carrying capacity practically without noticeable deterioration of the ice propulsion.

In compliance with the propulsion tests made in the hydrodynamic tank in still water and in the head regular seas of models of icebreaking cargo ships with the recommended hull shape parameters there are no grounds to expect substantial worsening of their seaworthiness. It is obvious at the same time that the hull shape recommendations stated will require further more accurate definition by the full-scale experimental verification of their applicability in dependence on purpose and specific operational conditions of new ships being constructed.

As to the experience of the construction and operation of icebreaking cargo ships the **L/B** ratio (length to width on the design waterline) is to be within the economically justified values, that is about 6.5 - 7.0. The implementation in the future on icebreaking ships of turning propeller systems of the *Aquamaster* and *Azipod* types will considerably improve the maneuverability of these ships in ice and accordingly the problem of choosing the **L/B** ratio will become less vital.

Icebreakers

The investigations carried out permit also to formulate recommendations to the hull shape of arctic icebreakers of ice classes PC1 - PC4.

The improved traditional shape of forebody lines ought to be considered as most promising for arctic multi-purpose icebreakers, parameters of the forebody meeting the following requirements:

- stem angle at design waterline $\varphi = 20°$,
- design water line entrance angle $\alpha_0 = 45°$,
- side flare angle at frame line No.0 $\beta_0 = 65°$,
- side flare angle at frame line No.2 $\beta_2 = 48 - 50°$,
- side flare angle at middle frame line $\beta_{10} \geq 10°$.

Combination of angles φ, α_0, β_0 and β_2 should provide for moderately convex form of forebody frames, rectilinear stem and buttocks.

Ratio **L/B** for icebreakers should mainly be chosen such as to provide for the satisfactory maneuverability in ice. Proceeding from this, for arctic linear icebreakers, as the experience of their operation shows, the length/width ratio should not exceed 5.1.

The above recommendations on the hull shape of prospective icebreakers for the NSR permit increasing their icebreaking capability in relation to existing icebreakers with traditional hull lines (*Moskva, Ermak, Arktika*) by at least 15 - 20 %. At a set icebreaking capability this implies the energy saving of up to 50 %.

It should be also noted that the use of the recommended lines with the increased flare of bow frames will favourably affect values of ice loads on hull resulting in their appreciable reduction and accordingly in the decrease of the ice damageability of prospective icebreakers.

The comparative propulsion tests of different icebreaker hull shape versions in still water and in the head regular seas carried out in the hydrodynamic tank have shown that icebreakers with recommended characteristics of the forebody shape do not rank below existing icebreakers with the traditional hull shape in the propulsion in open water. Improved traditional forebody lines provide for the appreciably better seaworthiness if compared with nontraditional lines put forward by foreign shipbuilders (forebody of the *Thyssen-Waas* system and conical lines of the *Wärtsilä Marine*).

5. PROPOSAL ON THE COMMON INTERNATIONAL ICE CLASSIFICATION OF POLAR SHIPS

The common ice classification of these ships prepared within the scope of the harmonization of the Polar Ship Rules does not provide for any difference between icebreaking cargo ships and icebreakers, though this difference is significant. So, even at the same icebreaking capability and the extent of the structural safety of navigation in ice, icebreaking cargo ships as to their performance will be much at a disadvantage in relation to specialized icebreakers. Primarily it concerns the maneuverability in ice, propulsion under conditions of the ice compacting and the ability to get released from sticking.

One may expect that use in the future of reliable (ice strengthened) thrusters and new turning propulsion units of the *Azipod* or *Aquamaster* type will allow improving the maneuverability of cargo ships and alleviating their release from sticking. However the problem of increasing the efficiency of work of cargo ships under conditions of the ice compacting still remains unsolved because this is the inherent shortcoming of ships with a parallel middlebody and accordingly with a larger (in relation to icebreakers) relative length.

For the equalization of differences in propulsion in drifting ice subject to compacting of arctic seas the increase of power of icebreaking cargo ships will be required. This increase will be rather significant as even for the achievement of the same icebreaking capability in compact ice, cargo ships will require higher power consumption due to the worsened, in comparison with icebreakers, hull lines.

The calculated assessment has shown that taking into account the operation under the ice compacting, for the achievement of the efficiency similar to that of icebreaker the icebreaking capability of a cargo ship should be increased by 10 - 15 % equivalent to the additional power increase by 30 - 50 % [3].

Figure 5.1 shows the shaft power/icebreaking capability relation calculated as applied to the design of a large icebreaking containership. This relationship was obtained for optimum (improved) traditional hull lines of prospective NSR icebreaking cargo ships [2].

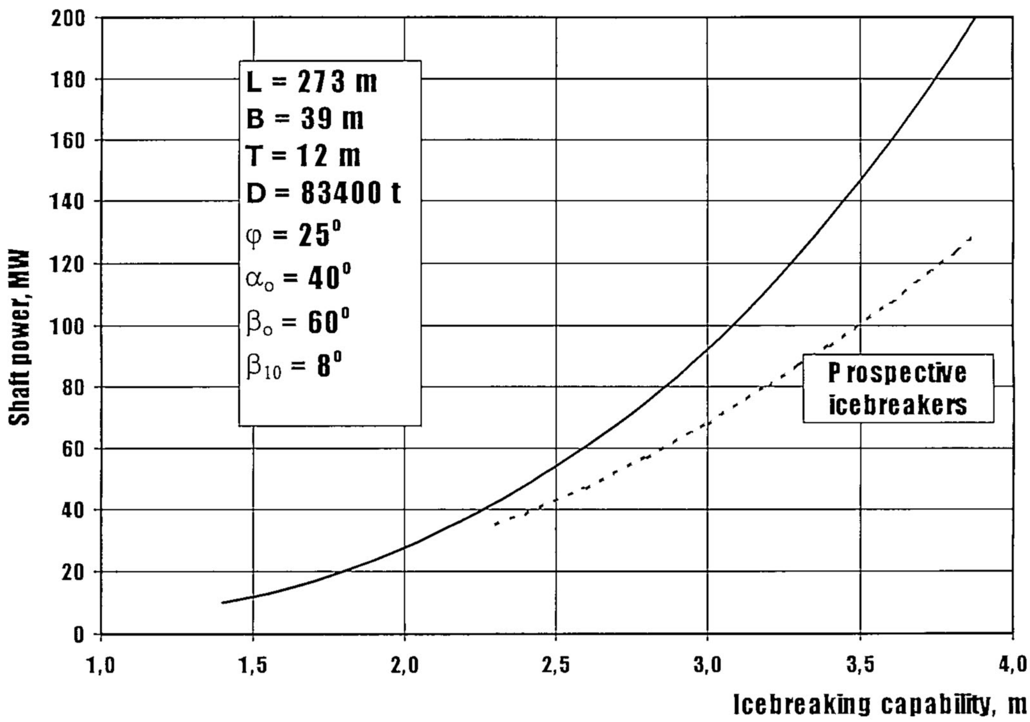


Fig.5.1. Relationship between power and icebreaking capability of a large arctic containership with a capacity of 3000 TEU with the improved traditional hull lines shape and the triple-shaft propelling unit

One can see from the plot, that as the icebreaking capability increases the power will appreciably become higher. For instance, if the power required for the achievement of icebreaking capability of 2 m is 28 MW, this power will increase more than three times and exceed 90 MW to reach an icebreaking capability of 3 m. At an icebreaking capability of 3.7 m needed for safe all the year round transit navigation of a containership along the entire NSR, the shaft power should be about 175 MW (Figure 5.2). The construction of such transport icebreaker is scarcely possible both from the technical and economical points of view. Indeed, at a power of about 175 MW the daily fuel consumption will amount to about 1000 t. Therefore to provide for the cruising capacity of ship equal at least to one month the ship should have 30000 t of fuel aboard in stock. Consequently, such ship will carry not so much useful cargo as its own fuel. Accordingly considerable increase of the ship's dimensions for the accommodation of enormous fuel reserves will be required and hence the cost of construction will substantially rise reducing the competitiveness of ship. In this respect, as the Russian experience shows, it would be expedient to construct powerful icebreaking cargo ships with nuclear propulsion plants. However in contrast to icebreakers escorting ships through ice in the Arctic, cargo ships should have the possibility of regular calling at foreign ports this due to known reasons being very problematic and to-day altogether impracticable.

Bearing in mind the above stated, one can consider as realistic the construction of icebreaking cargo ships with propulsion plants working on the organic fuel their power not exceeding 40 - 50 MW. The icebreaking capability of such ships will be 2.3 - 2.4 m. As calculations and the generalization of the long-standing experience of the operation of the domestic fleet in the Arctic show, the stated icebreaking capability is sufficient for the guaranteed independent transit navigation along the entire NSR during 6 summer and autumn months (Figure 5.2). During the remaining winter and spring period this ship will be able of performing transit transportation in the Arctic only under the assistance of powerful nuclear icebreakers. In the western area of the Arctic, ship with the considered (really achievable) icebreaking capability will operate independently for 9 months.

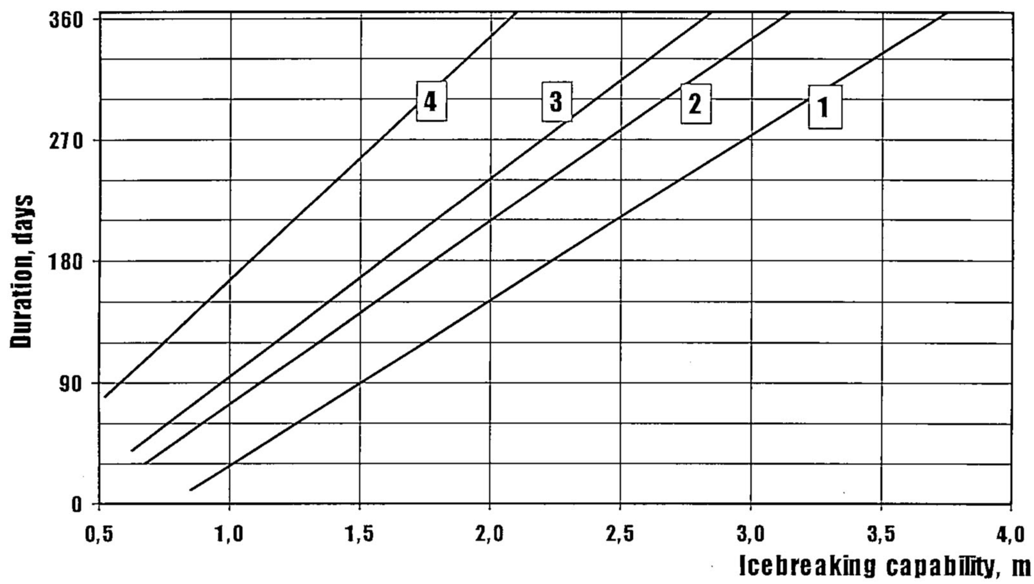


Fig.5.2. Relationship between duration of the safe independent navigation of traditional icebreaking cargo ships in the Arctic and the icebreaking capability (taking into account the long-standing experience of carrying out arctic operations): 1 – eastern area of the Arctic and transit navigation along the NSR, 2 – western area of the Arctic, 3 – western part of the Kara Sea, 4 – Pechora Sea

In that way it seems obvious that it is impossible and inexpedient to build cargo ships of the highest polar classes. At least two first classes PC1 and PC2 should be the prerogative of powerful icebreakers, because only with the help of the latters it would be possible to ensure safe all the year round functioning of the NSR. As far as the experience of the Russian fleet is concerned, such approach is more sound. Arctic marine transportation and technological systems traditionally using icebreakers for the escort of cargo ships under heavy ice conditions are most efficient.

Investigations made and the considerations stated above allow formulating the following main principles of the development of a new ice classification of polar ships:

1. The classification is to be based both on the ice strength criteria and on the criteria of the ice propulsion of ships. Safety of polar ships also to a considerable extent depends on their icebreaking potentials. The icebreaking capability of ship should be considered as a principal ice propulsion criterion.
2. The classification should embrace both specialized icebreakers and cargo ice ships. In this case, real possibilities of the construction of ships of particular ice classes should be taken into account. The Russian practice of the design, construction and operation of ice ships shows that requirements of the highest ice classes are accessible only for icebreakers. The construction of icebreaking cargo ships capable of independently (without the help of icebreakers) sailing in the Arctic in all the year round mode of operation is practically impossible and economically inexpedient.
3. The classification should take into consideration the running traditional practice of icebreaker escorting of ships under the ice conditions more rigid than those admissible for the independent navigation of ship assigned to an appropriate class. This will permit to significantly extend operational possibilities and raise the efficiency of the use of cargo ships of the lowest ice classes.
4. As to requirements to the ice strength of ships the classification should account for the following basic conditions of the hull/ice interaction:
   - for ships of all ice classes - direct impact of the forebody against the ice floe with a design thickness corresponding to the ice class, ships moving at a real speed achievable in open water between separate very open ice floes and ice fields;
   - for icebreakers - additional check up of the hull strength in case of the repelled (secondary) impact while making a channel in ice of a maximum thickness;
   - for ships of all ice classes - nipping of hull (in ice with a thickness corresponding to the ships' icebreaking capability for ships of classes PC1-PC5 and with a design ice thickness in case of the direct impact for ships of classes PC6 and PC7);
   - for cargo ships of the independent navigation of first five ice classes (PC1 - C5) having nontraditionally great length/depth ratio (**L/H** $\geq$ 12-13) - additional check up of the total longitudinal strength the stem striking against the unbreakable ice floe.

Proceeding from these principles of the division of polar ships into classes the following more accurate version of the common international classification may be put forward:

PC1 - leading icebreakers of the highest polar class with an icebreaking capability of 3.0 - 3.6 m designed for all the year round operation in the Arctic including high latitudes and areas near the pole, capable of operating without restrictions in the multi-year thick ice with a design thickness of up to 6 m (design speed –10 m/s).

PC2 - linear icebreakers of the second polar class with an icebreaking capability of 2.4 - 3.0 m designed for all the year round navigation along the NSR, capable of operating without restrictions in the medium multi-year ice with a design thickness of up to 5 m (design speed – 9 m/s).

PC3 - icebreakers and icebreaking cargo ships of the third polar class with an icebreaking capability of 1.8 - 2.4 m designed for all the year round operation without restrictions in the second-year ice, capable of withstanding the direct impact against the multi-year floe up to 4 m thick (design speed – 8 m/s).

PC4 - icebreakers and icebreaking cargo ships of the fourth polar class with an icebreaking capability of 1.2 - 1.8 m designed for all the year round operation without restrictions in the first-year thick ice, capable of withstanding the direct impact against the floe up to 3 m thick (design speed – 7 m/s).

PC5 - icebreaking cargo ships of the fifth polar class with an icebreaking capability of 0.9 - 1.2 m designed for all the year round operation without restrictions in the first-year medium ice, capable of withstanding the direct impact against the floe up to 2 m thick (design speed – 6 m/s).

PC6 - cargo ships of the sixth polar class with an icebreaking capability of 0.6 - 0.9 m designed for the operation in polar seas during the summer-autumn period in open floating residual and young ice, capable of withstanding the direct impact against the floe up to 1.2 m thick (design speed – 5 m/s).

PC7 - cargo ships of the seventh polar class with an icebreaking capability of 0.3-0.6 m designed for the operation in polar seas in summer in open floating rotten ice cake, capable of withstanding the direct impact against the floe up to 0.7 m thick (design speed – 4 m/s).

The adopted approach on the choice of design speeds and ice thickness for each class of polar ships is graphically illustrated in Figure 5.3 where basic modes of the movement of ships in ice according to the considered ice classification are presented. It can be seen that the design speeds proposed are limiting speeds starting with which their further increase does not cause hull damages at a given design ice thickness.

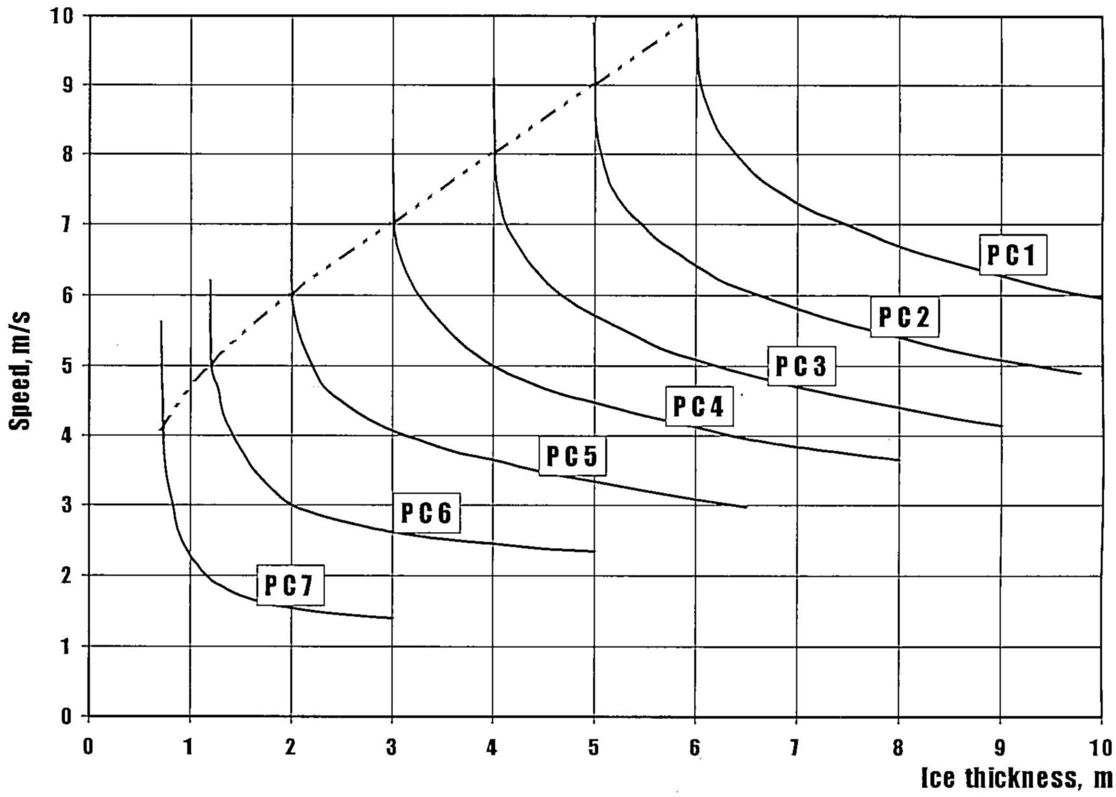


Fig.5.3. Basic dangerous operating conditions of the unified classification

CONCLUSION

Participation of the Russian Party in works of INSROP on Project IV.3.4 was principally to draw up comments and proposals concerning draft of the IMO Code on the safety of ships navigating in polar waters being presently developed as well as on the international unified IACS requirements to the construction of hull and to propulsion plants of polar ships. These works include the following:

- generalization of the long-standing experience of the construction and operation as well as of the ice damageability of Russian arctic ships;
- comparison of the requirements to ice ships of different classification societies and national administrations;
- substantiation of the necessity to take into account differences in the ice performance of icebreakers and icebreaking cargo ships while assessing their safety of navigation and the efficiency of the operation under ice conditions.

As the result of the performed investigations, proposal on the common ice classification of polar ships taking into consideration, along with the ice strength criteria, also characteristics of the ice propulsion of cargo ships and icebreakers was worked out for the insertion into international Rules.

REFERENCES

1. Морской Регистр судоходства. Правила классификации и постройки морских судов. Том 1, СПб, 1995, с.215
Marine Register of Shipping. Rules of the classification and building of sea ships. St. Petersburg, 1995.
2. Цой Л.Г. О совершенствовании традиционной формы обводов корпуса ледоколов и ледокольно-транспортных судов. Труды международной конференции IAHR 94, Том 2. Тронхейм, Норвегия, 1994.
On the Improvement of Traditional Form of the Hull Lines of Icebreakers and Icebreaking Transport Ships. Proceedings of the 12th International Symposium on Ice, IAHR94. Vol.2. Trondheim, August 1994.
3. L.G.Tsoy, S.B.Karavanov, Yu.V.Glebko. Assessment of ship performance and required powering based on ice conditions, Harmonization of Polar Ships Rules, IACS UR, St.Petersburg, 1997.

ANNEX

Note of the delegation of the Russian Federation to the SLF 42 Sub-Committee of IMO

SUB-COMMITTEE ON STABILITY AND LOAD LINES AND ON FISHING VESSELS SAFETY	SLF 42/6 November 1998 Original: ENGLISH

42nd session
Agenda item 12

DEVELOPMENT OF THE POLAR NAVIGATION CODE

Draft International Code of Safety for Ships in Polar Waters (POLAR Code)

Submitted by the Russian Federation

SUMMARY	
Executive summary:	This document contains proposals regarding the requirements for the subdivision and stability of ships in the ice damaged condition.
Action to be taken:	Paragraph 6.
Related documents:	SLF 42/1, DE 41/WP.7.

Having considered the revised version of the Draft Polar Code prepared by the Drafting Group at DE 41 the Russian Federation presents the following comments and proposals.

1 Ships operating under ice conditions run into an extra risk of probable hull ice damages. Probability of getting side damages in the zone exposed to the impact of ice loads is higher than at the collision of ships sailing in open water. Therefore for the purpose of reducing the probability of the loss of ships as well as diminishing the risk of the environmental pollution, more strict requirements for the subdivision and damage stability should be imposed upon polar ships in the case of ice damages. At the same time, one should bear in mind that sizes of ice damages are considerably smaller than those of the damages caused as a result of the collision of ships moving in open water at a higher speed the location of damages over the ship's length and hull height being different. Therefore, polar class ships, along with meeting the subdivision requirements established by the International Conventions and Codes in force for conventional ships should meet supplementary requirements for damage trim and stability of ships taking into account location and sizes of damages to be determined on the basis of statistical data. Supplementary requirements may be based both on

the probabilistic and deterministic approach. At the moment the probabilistic requirements exist only for passenger and dry cargo ships. Therefore at the fist stage for all types of ships it is expedient to adopt supplementary requirements based on the deterministic approach..

2 Statistical data given in the Annex permit to recommend assuming in the calculation of the damage trim and stability the following sizes of ice damages in the zone of their location from the base line up to the level 1.2 $\mathbf{d_s}$ within the length **L** (here **L** is the length of ship along the waterline corresponding to draft $\mathbf{d_s}$ up to the summer load line):

.1 longitudinal extent is 0.045 **L** if the centre of damage is located at a distance of 0.4 **L** from the forward perpendicular and 0.015 **L** in any other part of the ship;

.2 transverse extent of the damage measured at right angles to the ship's shell plating at any point of the calculated damage area is 0.76 m;

.3 vertical extent is 0.2 $\mathbf{d_s}$ in the zone of the location of damage from the base line up to the 1.2 $\mathbf{d_s}$ within the length **L**.

3 The above ice damages for all types of ships including dry cargo ships of polar class PC5 and higher may be located at any place within the zone of ice damages (two compartment standard of subdivision). In our opinion, for dry cargo ships of polar classes PC6 and PC7 not carrying hazardous cargo damages may be located between watertight bulkheads (one compartment standard) having regard to the operation of such ships only during the summer-autumn period in the decayed ice.

4 Besides, one should remember that on comparatively small ships, requirements for the subdivision when the after machinery space is flooded cannot be met without substantial deterioration of their performance qualities. The probability of the side ice damage location close to the after machinery space situated within up to 0.25 L from the after perpendicular does not exceed $\mathbf{P_1} = 0.03$. Ships of PC6 and PC7 polar classes may be operated only during the summer-autumn period of navigation. For such ships the average relative number of side ice damages with 3-4 voyages a year would not exceed 0.10 and the mathematical expectation of a number of such accidents, if the Poisson distribution law is applied, for 20 years of the service life would be $\mathbf{a} = 2.0$ the probability of each accident being:

$$\mathbf{P_2} = 1 - e^{-a} = 0.865.$$

Overall probability of a side ice damage within the machinery space is as follows:

$$\mathbf{P} = \mathbf{P_1}\, \mathbf{P_2} = 0.0255.$$

Taking into account relatively low probability of the occurrence of a side ice damage near the after machinery space it seems possible to allow not to apply subdivision requirements to cases of the flooding of the after machinery space on dry cargo PC6 and PC7 class ships less than 90 m and 125 m long accordingly not carrying hazardous cargo.

5 With the above sizes of ice damages all polar class ships should meet the damage trim and stability requirements specified by the IMO instruments in force for conventional ships of different types. Moreover the following additional requirements should be met:

1. emergency waterline after equalization of the ship, and in cases when the equalization is not provided after flooding, runs below the bulkhead deck and lower edge of any opening through which progressive flooding may take place;
2. initial metacentric height at the final stage of symmetrical flooding calculated by the constant displacement method before taking measures for its increase should be not less than 0.05 m;
3. angle of heel in the case of unsymmetrical flooding should not exceed 20° (15° for passenger ships) and after taking measures on the equalization – 12°.

These requirements, supplementary for all ships except passenger ones, are directed towards the prevention of the entry of ice during its shearing onto the bulkhead deck and of the damage of watertight deck structures as well as towards making possible for people to move over decks in the presence of icing.

Action requested of the Sub-Committee

6 The Sub-Committee is invited to consider the above proposals and decide as appropriate.

ANNEX to the Note

Statistics of ice damages

Statistical data on the parameters of ice damages are based on the information covering 200 cases of side ice damages of cargo ships in their navigation under ice conditions along the NSR. In all the cases of ice damages the water penetrated into the ship and compartments were flooded.

There is no information on the bottom ice damages. Therefore the statistical data given below refer only to side damages while navigating through ice.

1. Distribution of damage locations over the length of ship

Histogram of the dimensionless location of the middle of damages and the corresponding integral distribution function **F(x/L)** are given in Figure 1 (**L** - ship's length over the waterline at a draft $\mathbf{d_s}$ up to the summer load line). As one can see from the figure, ice holes principally occur in the forebody of ship at a distance of 0.4 **L** from the forward perpendicular (about 90 % of damages).

2. Distribution of damage length

Integral function **F(ℓ/L)** of the distribution of the dimensionless length of holes presented in Figure 2 shows that 90 % of ice damages have a length ℓ less than 0.04 **L** with 57 % of damages of a small length (ℓ /L $\leq$ 0.005) being located between frames and 43 % of damages affecting frames. Bearing in mind the fact that the number of frames is considerably larger than that of transverse bulkheads one may assume that events of the ice damage of transverse bulkheads are highly rare and this is confirmed by the practice of operation of ships.

Analysis of the statistical data has also shown that average length of damages in the forebody located within 0.4 **L** from the forward perpendicular is three times as large as in the afterbody.

3. Distribution of damage penetration

Integral function of the distribution of depth of damages $\mathbf{F(b_i)}$ presented in Figure 3 shows that 99 % of ice damages have a depth not exceeding 0.5 m. Proceeding from this it would be possible to assume standard depth of ice holes as being equal to 0.5 m. Due to the technological considerations, however, taking into account the necessity of the maintenance of protecting cofferdams it is advisable to assume depth of damages equal to 0.76 m.

Distribution functions for side ice damages

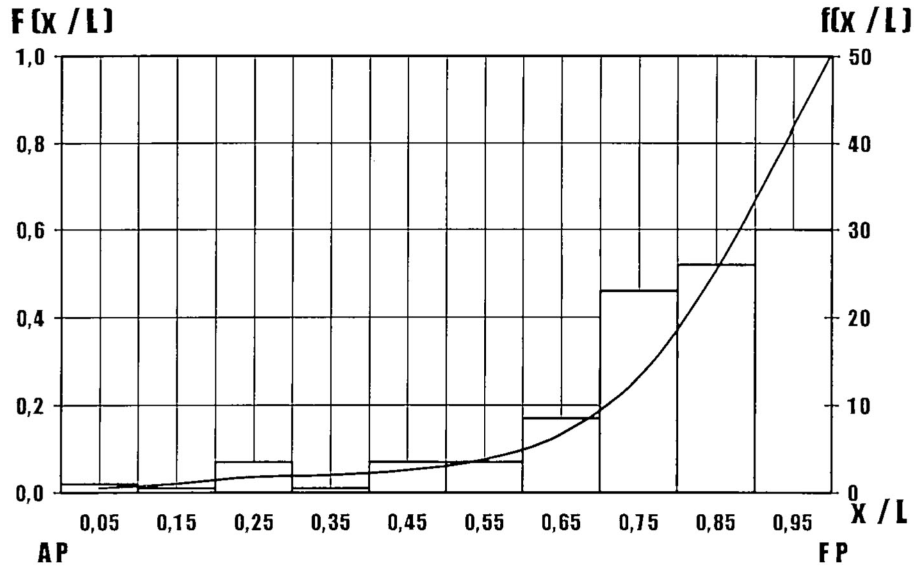


Fig.1. Longitudinal location

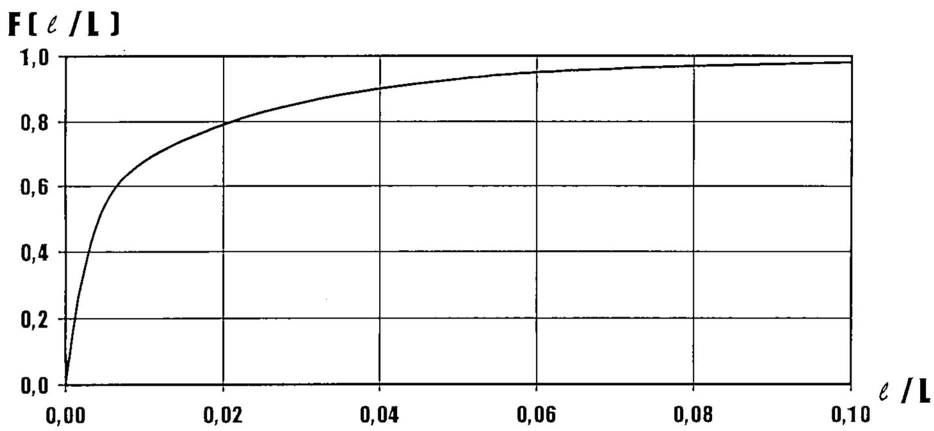


Fig.2. Longitudinal extent

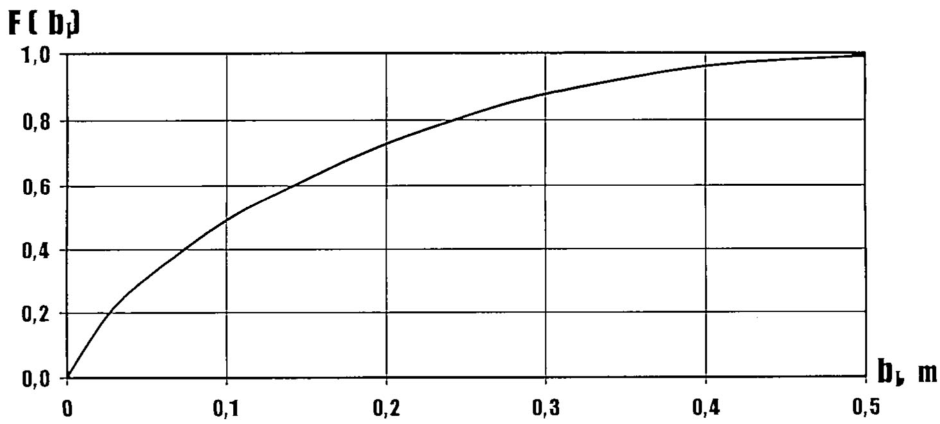


Fig.3. Transverse penetration

4. Distribution of vertical location and the extent of damages

Integral functions of the distribution of the lower edge of damage $\mathbf{F(z_\ell)}$ and of its upper edge $\mathbf{F(z_u)}$ (Figure 4) are given in Figure 5. They show that about 60 % of damages are located within the change of the lower boundary $\mathbf{z_\ell / d_s}$ from 0.1 to 0.4 the upper damage boundary $\mathbf{z_u/d_s}$ being located within the range from 0.13 to 0.55. Such concentration of ice holes in the area between the upper edge of the bilge strake and the ballast draft (below the ice strake) may be attributed to a lesser damageability of sides within the ice strake which has a higher thickness of plating. Maximum vertical extent of damages in this area at $\mathbf{z_i/d_s} = 0.5$ is about 0.15 $\mathbf{d_s}$.

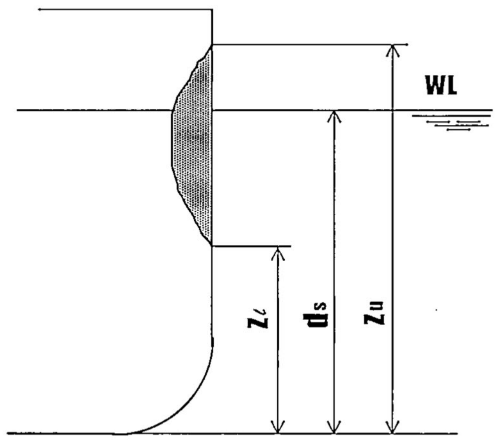


Fig.4. Vertical location of damage

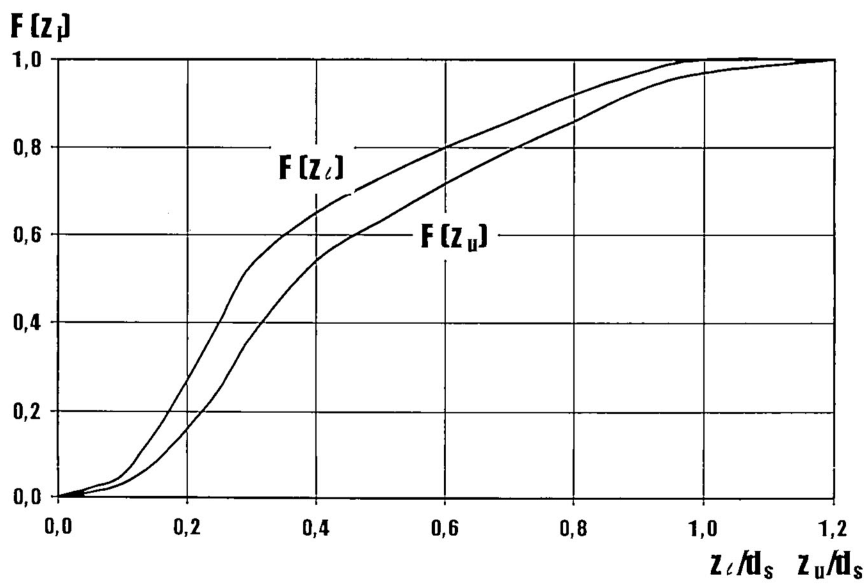


Fig.5. Vertical location

Figure 6 shows the integral distribution function of an absolute vertical extent of damages. The function shows that 97 % of damages have a vertical extent up to 2 m and only 1 % – more than 3 m.

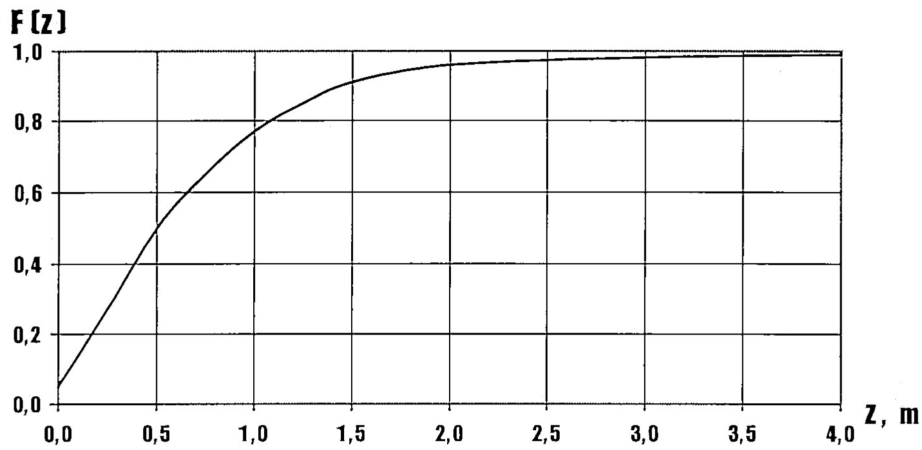


Fig.6. Vertical extent

SCIENCE and TECHNOLOGY CORP.

ARCTIC TECHNOLOGY GROUP
Stevens Forest Professional Center,
9650 Santiago Road, Suite 2,
Columbia, Maryland 21045
Tel: (410) 964-3211 Fax: (410) 964-3213

January 12, 1999

Anne Berteig
INSROP Program Secretary
The Fridtjof Nansen Institute
P.O. Box 326,
N-1324 Lysaker, Norway

Dear Anne Berteig:

I have completed my review of the paper entitled "ARCTIC ENVIRONMENTAL LAW, HARMONIZATION OF POLAR SHIP RULES, INTERNATIONAL AND NATIONAL PROVISIONS", by Dr. L. G. Tsoy, Dr. M. A. Grechin, Dr. S. B. Karavanov, Yu. V. Glebko, Cap. V. V. Mikhailichenko. I am sorry that it took me more time than the desired month you suggested but I hope my comments help to improve the quality of the finished product.

The harmonization of polar ship rules is an on-going process of development and negotiation between countries currently carried out through IMO and IACS. The authors have presented a detailed and well-reasoned description of the position of their organizations in this process. Since these organizations have a great deal of experience studying the operations on the Northern Sea Route and conceptualizing the best means to effect arctic transportation, they have much to contribute to the harmonization process. I found the presentation of damage statistics as function of location on the ship to be very interesting and, to my knowledge, the only statistics of the kind to be published. The analysis presented allows one to draw conclusions on ship strength and shows the weaknesses in existing criteria for ice.

The discussion of power requirements for ships was thorough and appropriate for the discussions of the harmonization process. The authors showed that power is not a valid parameter to regulate but icebreaking capability is much more to the point.

The area that I felt was not so adequately addressed was the issue of using icebreaking capability as a regulatory requirement. In the Chapter 5: "Proposal on the common international ice classification of the polar ships", it is stressed that the classification is to be based both on the ice strength and ice performance criteria. Item 1 of this section states that "Safety of polar ships also to a considerable extent depends on their icebreaking potentials". Generally, this is a reasonable statement but it is not supported by examples of operational experience or by analytical results showing how the safety of polar ship depends on icebreaking capability. Proponents of a strength only set of regulations will need concrete proof of how the lack of icebreaking capability can influence safety.

In the proposed international classification, every ice class definition starts from an icebreaking capability range. This range doesn't seem to have a correlation with the proposed limiting speed versus ice thickness curves shown in figure 5.3. How were the icebreaking capabilities determined for the safety of each ice class. I think that the proposed classification system will benefit from more detailed description of the idea of safety and icebreaking capability.

Additionally, there is the issue of independent operation versus escorted operation. At least for the lower classes, ships could be designed for the strength of a particular class but not be required to have the hull shape and icebreaking capability if they intended to only operate with an escort in those ice conditions. More work in this area is required to fully address all types of ice-going ships.

The suggestions for design speed and thickness and safe speeds were very interesting and will invoke discussion within the arctic design community I am sure. The Russian experience is unique in the uppermost ice classes so it was interesting for me to think about the proposed limits for the higher ice classes. Figure 5.3 shows a dotted line where the hull cannot be damaged regardless of the speed of impact. The line in the figure is plotted from the recommended design speeds given for each ice class. Such a situation can only happen when the load on the critical piece of structure, the weakest under the load, is limited. The load does not increase with increasing impact speed for this critical member. I agree that this is often the case for local structure. The nature of ice impacts is to increase contact area with impact load. As the contact area becomes larger than the area associated with the critical member in the local structure, the load on that member approaches a maximum limiting value, the average pressure reaches a limiting value. For lower ice classes, the total load is small and the local structure is limiting. As we go up in ice class, it seems reasonable that the critical structure could be the intermediate ones, grillage loads, deck or bulkheads loads. It is not clear to the reviewer that maximum limiting loads will be achieved over these larger areas. The authors may wish to comment on the background for their selecting the safe speeds.

A number of minor or editorial comments were noted as I read the text that are included below. Please note that I have not read the text for grammar and typographical errors because I am sure that you will employ a professional editor for this purpose.

Pages 12 and 13. Data on cracking is useful to know. It is not often that these occurrences are documented and it is important to the designers and regulators to know that they occur. Can the authors provide more information about steel type and an assessment of the stress level or material grade category.

Page 15. The text mentions increased wear at the bilges but it is not clear from the table whether the recommendations for the bilge area should be taken from the side below the ice waterline or the bottom category.

Page 17. Distribution of longitudinal extent is also a function of frame spacing. Dividing by frame spacing instead of ship length may provide interesting results.

Figure 3.1 appears to combined a derived cummulative probability density function (CDF) with a histogram of data that should be fit with a probability density function (PDF). I suggest presenting the data in a separate figure first and then the derived CDF can be presented in a separate figure. Intergral distribution function is probably a literal translation but the term used most commonly for this distribution is cummulative probability density function.

A better word for insubmergability would be unsinkability.

Page 18. Figure 3.4 is misleading because the drawing shows the damage at a higher location than it actually occurs. If the damaged area looked more like the distribution, bigger at the bottom near the bilge and tapering to a lower value as the waterline is approached, that would enhance the reader's understanding..

Page 27. Equation 4.8 should define $\hat{A}$ where the equation is presented.

Page 46. It is not clear how the design speed should be used until after the recommendations are presented. It would be better to describe what is meant by design ice thickness and speed before they are presented.

I congratulate the authors on a fine report. I look forward to seeing it published. I am sure it will be of interest to the arctic design community and I hope my comments can contribute in some small way to improving the final product.

Sincerely,

James W. St. John
Project Manager

Authors' Reply to the Reviewer

Authors of the Project IV.3.4 "Arctic Environmental Law, Harmonization of Polar Ship Rules, International and National Provisions" have carefully studied the review of Mr James W. St. John (Project Manager of Arctic Technology Group from STC, USA) and are thankful to him for the high appraisal of the work performed in accordance with the Project and for valuable comments for its improvement.

As to certain controversial provisions pertaining to the ice classification of polar ships and appropriate rating criteria we consider it necessary to note the following.

The ice classification proposed in the Draft Code of IMO and in the unified IACS requirements for the safety of ships navigating in polar waters provides for the division of ships into classes according to navigational conditions in ice. Proceeding from these conditions the requirements are imposed to the ice strength of the ship's hull ensuring the needed structural safety of navigation for ships of each class. At the same time, one should accept that the safety of ice navigation depends not only on the ice strength, but also on the ship's ice propulsion.

Indeed, on the one hand, each polar ship in compliance with its purpose should possess needed power and accordingly the icebreaking capability to successfully fulfil its functions. So, a dedicated icebreaker has to support, under relevant conditions, efficient and safe ice escorting of cargo ships, ice cargo ships being economically feasible for the transportation of cargo.

On the other hand, the capability of ship to actively operate in ice affects its safety of navigation. Therefore chapter 7 of the draft of the Polar Code concerning requirements to the machinery states that power of the propulsion plant should be sufficient to ensure the safe navigation of ship without a risk of the pollution under anticipated ice, weather and operational conditions.

One can cite the following examples proving the dependence of the safety of the navigation of ship on the power of its propulsion plant:

- Ship with insufficient power, under certain ice and meteorological conditions, can be incapable of moving ahead and when in drifting ice swept aground or carried onto submerged rocks
- Ship ice-nipped because of the insufficient power, at low environmental temperature can freeze in and be held captive for the entire winter period running the danger of being crushed or holed under the impact of ice compacting;
- Under the effect of heavy ice compacting when sailing in convoy, cargo ships and icebreakers, helpless due to the insufficient power, can be pressed one to another and as a result of falling foul of ships their hulls may be severely damaged.

In the history of the polar navigation there is quite a number of similar examples.

And yet, as it is shown in the report being reviewed, ,the most appropriate ice propulsion characteristic is not power, but the icebreaking capability.

Bearing in mind the above stated, it is proposed to include the requirement to the icebreaking capability and at least to its admissible level for ships of each class into the classification of polar ships. Values of the icebreaking capability within a particular class given in the report are based on the experience of the safe operation of icebreakers and icebreaking cargo ships of the Russian arctic fleet.

As far as the requirements to the design ice thickness and speeds of the impact of hull against ice depending on the polar class of ship are concerned, it must be admitted that this problem is still debatable and needs further substantiation and explanations. Authors of the report considered it necessary only to outline the principles based on the domestic experience of the development of the ice classification and rating of the ice strength of ships (pp. 46-47).

The reviewer, James W. St. John, has quite correctly noted that process of the harmonization of the Rules of polar ships is going on. Accordingly, proposals on the requirements to the ice strength, structure and hull materials, ice propulsion and unsinkability of ships navigating in polar waters set forth in the report in question will require further development and refinement.

Specific remarks on separate items have been taken into account in the final wording of the report. Additional comments on these remarks are given below:

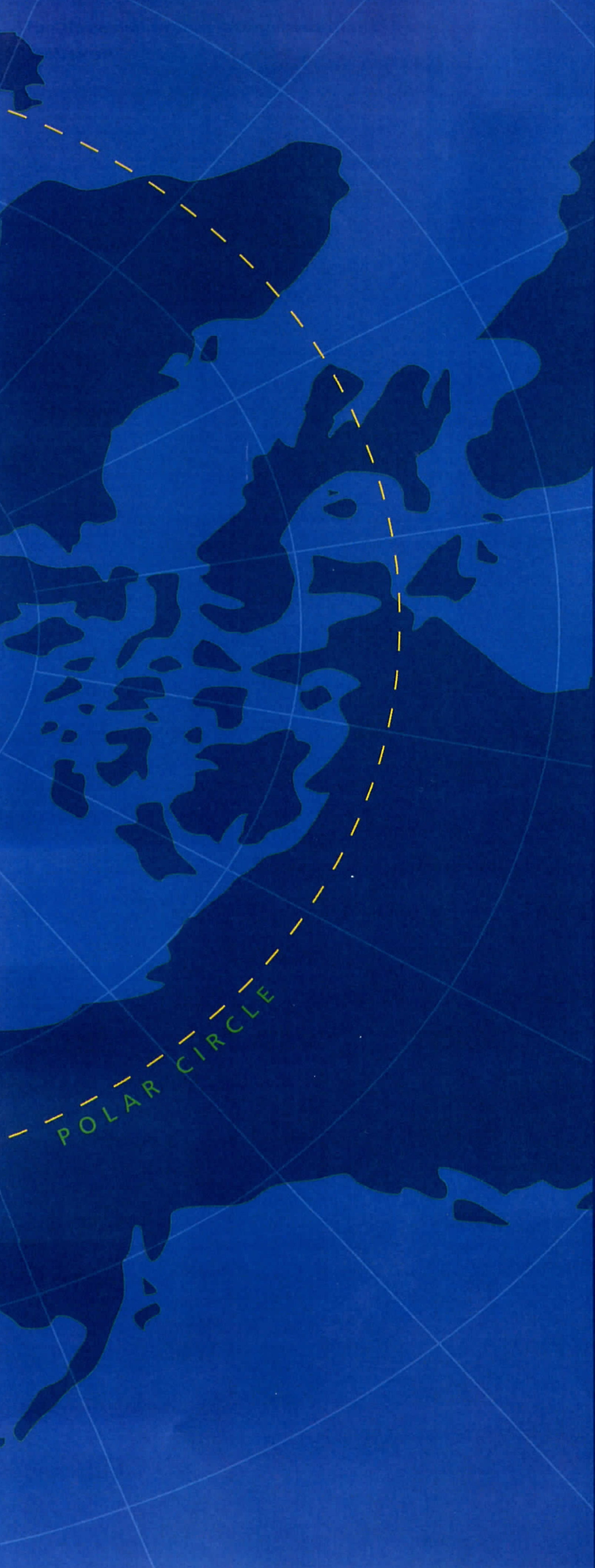
- Stressed state of structures shown in Table 2.1 was not noted because indicated damages occurred in the operation (pp.12, 13).
- For abovedeck structures of Table 2.1, steel "B" ($\mathbf{R}_{EH}$ = 235 MPa) is principally used, except ships *Ghizhiga* and *Ob* where deck is made out of steel of class E with $\mathbf{R}_{EH}$ = 315 MPa.
- Wear allowance (p. 15, Table 2.2) for the bilge strake is to be adopted as applicable to board areas below the ice belt.
- The upper edge $\mathbf{z}_u$ of ice damages including cracks in 2 % of cases lies above the waterline (p. 18, Fig. 3.4, or Fig.3.5 according to new numbering) the centre of breach being situated at the waterline. Maximum actual value in these cases is equal to $\mathbf{z}_u / \mathbf{d}_s \leq 1.2\ \mathbf{d}_s$. Separate representation of the cumulative distribution function of the nondimensional parameter of vertical damage location for upper and lower edges of damage, $\mathbf{F}(\mathbf{z}_u)$ and $\mathbf{F}(\mathbf{z}_l)$, we have adopted is, in our opinion, very useful and universal as it permits, if required, to determine location, extent and probability of damage.

Sincerely Yours,

Loly Tsoy

Supervisor of work, Head of the Laboratory of Icebreaking Technology

15 March 1999



The three main cooperating institutions of INSROP

Ship & Ocean Foundation (SOF), Tokyo, Japan.
SOF was established in 1975 as a non-profit organization to advance modernization and rationalization of Japan's shipbuilding and related industries, and to give assistance to non-profit organizations associated with these industries. SOF is provided with operation funds by the Nippon Foundation, the world's largest foundation operated with revenue from motorboat racing. An integral part of SOF, the Tsukuba Institute, carries out experimental research into ocean environment protection and ocean development.

Central Marine Research & Design Institute (CNIIMF), St. Petersburg, Russia.
CNIIMF was founded in 1929. The institute's research focus is applied and technological with four main goals: the improvment of merchant fleet efficiency; *shipping safety;* technical development of the merchant fleet; and design support for future fleet development. CNIIMF was a Russian state institution up to 1993, when it was converted into a stock-holding company.

The Fridtjof Nansen Institute (FNI), Lysaker, Norway.
FNI was founded in 1958 and is based at Polhøgda, the home of Fridtjof Nansen, famous Norwegian polar explorer, scientist, humanist and statesman. The institute spesializes in applied social science research, with special focus on international resource and environmental management. In addition to INSROP, the research is organized in six integrated programmes. Typical of FNI research is a multidisciplinary approach, entailing extensive cooperation with other research institutions both at home and abroad. The INSROP Secretariat is located at FNI.