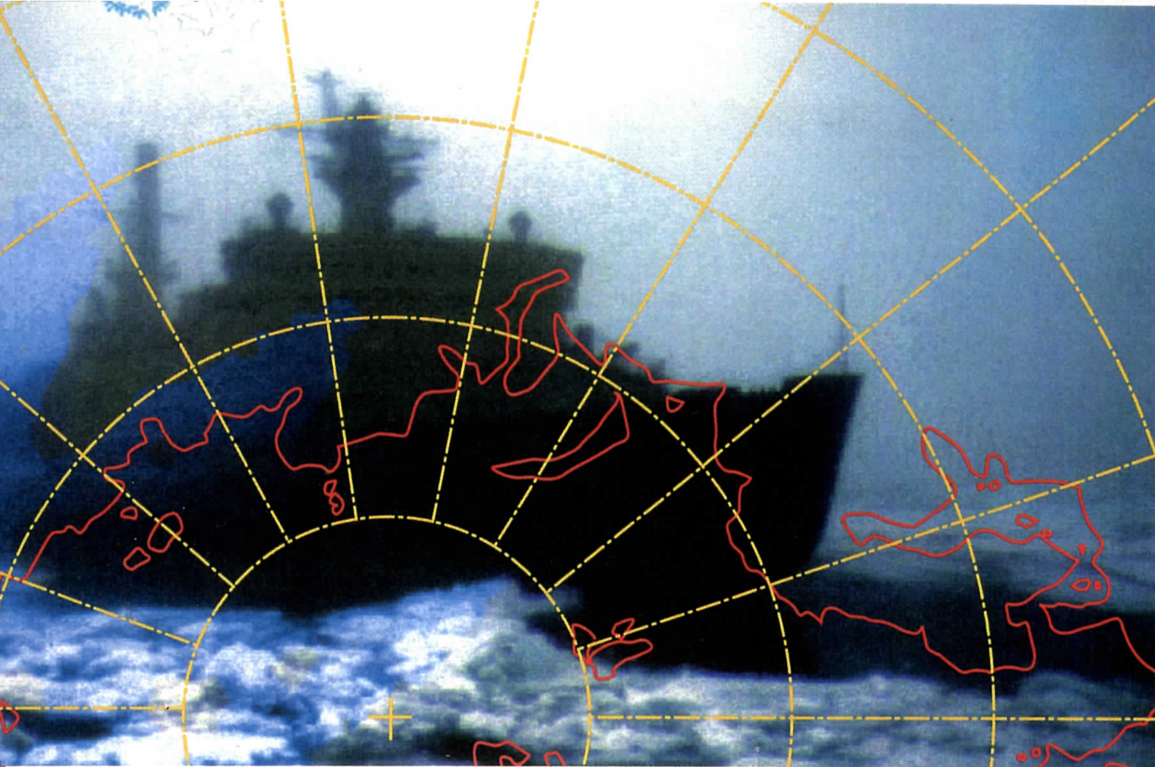

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NO. 34 - 1996, I.5.5

Planning and Risk Assessment

Volume 2 - 1994 project work

Alexander Brovin and Loly Tsoy et al.

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)

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Supervisors: Dr. Alexander Brovin, AARI and Dr. Loly Tsoy, CNIIMF.

Part I (AARI) by: Dr. A. I. Brovin, Dr. A. Ya. Buzuyev, V. Ye. Fedyakov, S. V. Frolov, S. V. Klyachkin, N. A. Krupina, Dr. V. A. Likhomanov, Dr. O. Ya. Timofeyev, A. V. Yulin and A. Ye. Klein.

Part II (CNIIMF) by: Dr. S. Karavanov and Yu. Glebko.

Addresses:
Arctic and Antarctic Research Institute (AARI), 38 Bering Street
199 397 St. Petersburg, The Russian Federation.

Central Marine Research and Design Institute (CNIIMF), Kavalergardskaya Street 6, 193 015 St. Petersburg, The Russian Federation.

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Reviewed by: Dr. Kazuhiko Kamesaki, Ice and Snow Engineering Laboratory, Tsu Research Laboratories, Engineering Research Center, NKK Corporation, Japan.

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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.

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- SINTEF NHL (Foundation for Scientific and Industrial Research - Norwegian Hydrotechnical Laboratory), Norway.

PROGRAMME COORDINATORS

- **Yuri Ivanov, CNIIMF**
  Kavalergardskaya Str.6
  St. Petersburg 193015, Russia
  Tel: 7 812 271 5633
  Fax: 7 812 274 3864
  Telex: 12 14 58 CNIMF SU
- **Willy Østreng, FNI**
  P.O. Box 326
  N-1324 Lysaker, Norway
  Tel: 47 67 53 89 12
  Fax: 47 67 12 50 47
  Telex: 79 965 nanse n
  E-mail: Elin.Dragland @fni. wpoffice.telemax.no
- **Masaru Sakuma, SOF**
  Senpaku Shinko Building
  15-16 Toranomon 1-chome
  Minato-ku, Tokyo 105, Japan
  Tel: 81 3 3502 2371
  Fax: 81 3 3502 2033
  Telex: J 23704

LIST OF INVESTIGATORS

Part I (AARI)

1. Dr. A.I. Brovin, Head of Laboratory - introduction, sections 1,2
2. Dr. A.Ya.Buzuyev - leading scientist - section 3
3. Mr. V.Ye. Fedyakov, senior scientist - section 3
4. Mr. S.V. Frolov, scientist - section 1,2,3
5. Mr. S.V. Klyachkin, senior scientist - sections 2.3
6. Mrs. N.A. Krupina, engineer - section 4
7. Dr. V.A. Likhomanov, Head of Dept. - section 4
8. Dr. O.Ya. Timofeyev, senior scientist - section 4
9. Mr. A.V. Yulin, senior scientist - sections 1,2
10. Mr. A.Ye. Klein, scientist - report drafting

Part II (CNIIMF)

1. Dr. S.Karavanov, senior scientist
2. Mr. Ju.Glebko, scientist

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PART I

ICE-NAVIGATION INFORMATION FOR PLANNING AND RISK ASSESSMENT OF NAVIGATION ALONG THE NSR

INTRODUCTION

The present Report of the second stage of the Russian Project I.5.5 "Planning and Risk Assessment" of the INSROP Subprogram is a continuation of the activities initiated in 1993-1994. It is devoted to specialized ice information for planning marine operations along the NSR and also to risk assessment for navigation of ships depending on ice conditions.

At the first stage (1993-1994) the main attention was paid to analysing the studies and activities of the previous years, including: development of specialized ice information for shipping, assessment of the influence of ice cover characteristics on the motion of ships, description of the method for a quantitative assessment of the difficulty of ice navigation ("QAD" model) and formulation of a general concept for creating the database on ice damages of ships.

At the second stage (1994-1995) the main stress is laid on the new studies in the indicated areas and evolvement of conceptual questions and generalizations of the methods representing a general situation in ice information development for planning of shipping along the NSR. In particular, a concept for a system of specialized ice information support to planning of marine operations along the NSR from 6 months to several days in advance has been developed. New approaches with regard to the methods for preparing specialized ice information for shipping are outlined in the indicated concept, as well as in the section devoted to types of ice navigation conditions along the NSR. The third section of the Report describes the development of the method for a quantitative assessment of the difficulty of navigation (QAD model) under most severe ice navigation conditions. The fourth section is devoted to the construction of software and description of the work variant of the database on ice damages to ships and their causes.

On the whole, the Reports of the first and second stages of Project I.5.5 allow one to gain a general impression about ice information required for planning of marine operations along the NSR, possibilities for its specialization for shipping, current specialization algorithm (QAD model) and possibilities for assessing the risk of ice damages to icebreakers and ships on the basis of a specialized database.

Further activities in this direction may be devoted to specific questions of creating a system for ice information support to a successive planning of marine operations along the NSR, in particular, obtaining of climatic estimates on ice navigation conditions on the segments and along the whole of the NSR (on the basis of actual voyages and the QAD model). It is also promising to obtain ice-navigation indicators (type of navigation, type of ice conditions of navigation) for the entire series of ice observations along the NSR (40-50 years). Also of importance are the questions of forecasting ice-navigation indicators and developing algorithms of navigation recommendations for specific marine operations.

1 A CONCEPT OF A SYSTEM FOR SPECIALIZED ICE INFORMATION SUPPORT TO SUCCESSIVE PLANNING OF MARINE OPERATIONS ALONG THE NSR

1.1 The need and a possibility for creating the system

During the last decades there has been an intensive development of the Arctic marine transport system the "Northern Sea Route" (NSR). A modern icebreaking and transport fleet has been created that allowed a significant extension of the navigation period along the NSR, on the whole, up to 5-6 months. On some segments such as westwards of Dudinka direction, navigation is all-year-round.

There is an increasing interest in conducting transit and coastwise voyages by foreign ships along the NSR. In this connection the INSROP Program is the first large international program to give a comprehensive assessment of a possible organization of regular and economically beneficial international shipping along the NSR. It includes a guaranteed implementation of different types of marine operations - from voyages of icebreakers and icebreaking ships during the navigation period extended to a maximum to transportation of objects of a poor shipping capability.

A solution of these objectives, as well as planning and fulfilment of specific marine operations along the NSR, should be based on a system for hydrometeorological and, first of all, ice information support to shipping. Such support should provide information about a principal possibility for a specific type of marine operation, its time frames, take into account stages of its planning and provide management of operations.

The hydrometeorological support to planning of marine operations is based on:

- climatic conclusions about natural conditions (ice cover, meteorological and oceanographic characteristics) in the regions and on the route of navigation:

- forecasting of natural conditions with different periods in advance (super long-range from 4 to 12 months, long-range - 1-3 months, medium-range - 1-30 days and short-range - up to 10 days);
- actual ice and hydrometeorological information.

The AARI carries out research in all these areas. Climatic handbooks are being created, methods for ice and hydrometeorological forecasting and techniques of full-scale observations are being developed and improved. Recent years have shown an intensive development in the area of specialized ice information for shipping. This information allows presenting the whole of the range of diverse ice conditions in ice-operating indicators reflecting transport capabilities of specific types of ships.

Assembling of such a vast amount of heterogeneous data differing by the methods of their collection into a common system is possible on the basis of addressing a specific practical objective that has a definite successive implementation.

An objective of a successive planning of marine operations along the NSR is to meet these requirements to a full extent.

An important aspect of the present concept is the need and possibility for obtaining interconnected ice information that is being supplemented and made more detailed at each successive level of realization.

1.2 Types of marine operations

Marine operations along the NSR can be divided at present into two main types: standard and nonstandard. The main differences lie in the character of operations, management techniques and duration.

Usually, specific voyages of ships that are fulfilled using standard management techniques are called standard marine operations (Makarov, 1994).

Let us note that management techniques of navigation along the NSR include some definite organization and information measures. These are: determination of the type of icebreaking support and its distribution along the segments of navigation, designation of convoy composition, determination of the type of hydrometeorological information support.

At the present stage of navigating the NSR standard marine operations play a decisive role with regard to cargo volume transportation.

Standard marine operations include:

- coastwise navigation (cargo transportation between the ports of the NSR);
- supply operations (supply of arctic settlements, airports, polar stations with fuel and other cargo necessary for functioning and life support of maintenance personnel).

Also, cargo loading-unloading at the destination points, as well as stationing and wintering of ships in equipped and safe areas of the ports, can be considered to be included as standard marine operations.

Coastwise navigation is being characterized by navigation of ships between the NSR ports along the routes more or less fixed in geographical respect. These routes are dependent on the location of the destination points, multiyear experience of operations and hydrographic support. Ice conditions on these routes are, as a rule, most favourable.

It should be noted that coastwise navigation of ships can take place in two ways: under the escort of icebreaker and unescorted.

There are several of icebreaker escort:

- a through icebreaking escort - type of icebreaking support when escorting is carried out along the whole of the route between the destination points. The convoy includes not more than 2 ships for one icebreaker. This type of escorting is usually used at the beginning of the navigation season and exceptionally in heavy ice conditions;

- mass icebreaking escort - marine operations are supported by icebreakers on separate segments of the route. The convoy includes more than 2 ships for one icebreaker;
- occasional icebreaking escort - icebreakers escort ships on some isthmus of close ice and provide recommendations to ships for independent motion on the route segment.

Unescorted navigation is a self-contained motion of ships on the NSR segments or along the whole of the NSR. This navigation type is determined according to the various ice classes to which the vessels belong.

While coastwise transportation along the NSR is characterized by a linear sailing (from a loading point to an unloading point), supply operations are characterized by rotation navigation organised as follows. A ship (convoy) that makes a supply cruise usually has several destination points, rather than one. The success of a supply operation depends upon reaching and fulfilling loading-unloading works at all planned points, but does not depend on the order of sequence of calls. The order of calling at the destination points is governed by the ice situation prevailing in the navigation region and distribution of cargo flow between the points. It can change at any time in the course of an operation.

The duration of standard marine operations is mainly governed by natural (ice) conditions. Also, a significant influence on the duration of operation is produced by the actual ice class of ships participating in the operation and by the icebreaking support provided.

As a rule, the duration of the main types of standard marine operations during the "warm" period of the year does not exceed 10-14 days.

Specific voyages of ships whose success is achieved by additional (special) organization and information measures are usually called nonstandard marine operations.

They include:

- transit navigation along the NSR;
- navigation of ships along non-traditional (high-latitudinal) variants of the NSR;

- supply operations to the points of difficult access (drifting stations "North Pole", some polar stations at archipelagos, etc.);
- navigation along the route segments (or along the whole extend of the NSR) by ships with restricted shipping capabilities;
- accident-rescue operations.

At the present stage of using, the NSR nonstandard marine operations are of occasional character. These operations can be fulfilled in the form of a specific icebreaking escort, independent voyage of ships of varying ice class, as well as self-contained sailing of icebreakers of varying power.

The icebreaking escorting is carried out, as a rule, by means of a special icebreaking support. Icebreaker (or several icebreakers) of specific power is assigned for the entire "ice" stage of the operation and is responsible for safety and effectiveness of travel of (ships).

For carrying out nonstandard marine operations a special system for hydrometeorological services is used. It is characterized by an additional volume of prognostic and actual information about the ice cover characteristics that have a considerable influence on the progress of a specific operation.

As a rule, nonstandard marine operations are fulfilled under heavy ice conditions. Examples of such operations are transit voyages on early (at the time of a significant development of ice cover) and late (during stable ice formation) dates, high-latitudinal voyages (to the North Pole and drifting stations).

In connection with this, the duration of these operations is longer than that of standard operations during similar navigation periods.

Data given in Table 1, indicate the duration of transit cruises both along the NSR and high-latitudinal routes to be mainly 12-26 days.

Table 1.1. Main stages and duration of non-standard marine operations (transit voyages along the NSR)

Convoy, year	Start and end points	Main stages of operations	Duration of operations
Nuclear-powered icebreaker "Lenin", icebreaker "Vladivostok, 1971	Murmansk port-Pevek port	27.05 - Murmansk port	26 days
		05.06 - Arktichesky cape	
		22.06 - Pevek port	
Nuclear-powered icebreaker "Sibir'", diesel-electric ship "Kapitan Myshevsky" 1978	Murmansk port Serdtse-Kamen'cape	26.05 - Murmansk port	19 days
		01.06 - Arktichesky cape	
		04.06 - Anisiy cape	
		13.06 - Serdtse-Kamen'cape	
Nuclear-powered icebreaker "Arktika", M/V "Monchegorsk" 1984	Murmansk port Pevek port	03.06 - Murmansk port	21 days
		19.06 - Cheluskin cape	
		24.06 - Pevek port	
Nuclear-powered icebreaker "Sibir'", M/V "Kola" 1985	Murmansk port Pevek port	12.06 - Murmansk port	13 days
		19.06 - Cheluskin cape	
		25.06 - Pevek port	
Nuclear-powered icebreaker "Rossiya", M/V "Monchegorsk" 1986	Murmansk port Pevek port	11.05 - Murmansk port	26 days
		19.05 - Cheluskin cape	
		25.05 - Vil'kitsky island	
		06.06 - Pevek port	
Nuclear-powered icebreaker "Arktika", Nuclear-powered icebreaker "Rossiya", M/V "Kola", 1987	Murmansk port Pevek port	14.05 - Murmansk port	33 days
		22.05 - fast ice of Vil'kitsky strait	
		16.06 - Pevek port	
Nuclear-powered icebreaker "Arktika", self-contained 1988	Murmansk port Vankarem cape	17.05 - Murmansk port	28 days
		20.05 - Dikson island	
		26.05 - Anisiy cape	
		04.06 - Vankarem cape	
Nuclear-powered icebreaker "Rossiya", self-contained 1989	Murmansk port Pevek port	28.05 - Murmansk port	10 days
		01.06 - Dikson island	
		06.06 - Pevek port	

Convoy, year	Start and end points	Main stages of operations	Duration of operations
Nuclear-powered icebreaker "Sovetsky Soyuz", self-contained 1991	Murmansk port Provideniya inlet	27.07 - Murmansk port	17 days
		30.07 - Franz-Josef Land archipelago	
		04.08 - North Pole	
		10.08 - De Long Islands	
		13.08 - Provideniya inlet	
Nuclear-powered icebreaker "Sovetsky Soyuz", self-contained 1992	Provideniya port - Murmansk port	17.08 - Provideniya port	14 days
		23.08 - North Pole	
		26.08 - archipelago Franz-Josef Land	
		31.08 - Murmansk port	
Nuclear-powered icebreaker "Yamal" self-contained 1993	Murmansk port - Provideniya port	30.7 - Murmansk port	20 days
		04.08 - archipelago Franz-Josef Land	
		08.08 - North Pole	
		11.08 - Arktichesky cape	
		19.08 - Provideniya port	

The whole complex of objectives for organization and planning of shipping in the Arctic region is divided into the following stages:

- perspective planning of shipping (estimates for the period from 3 to 25-30 years);
- preliminary planning of marine operations (3-6 months in advance);
- general planning of marine operations (1-3 months in advance);
- tactical planning of marine operations (10-30 days in advance);
- operational regulation (management) of marine operations (1-10 days in advance).

A specific range of objectives are addressed at each stage.

Perspective planning includes:

- designing and construction of icebreaking and transport fleet;
- designing and equipment of ports, places of moorage and unloading;
- determination of possible directions of cargo transportation in the Arctic region.

The objectives of a preliminary planning of marine operations are as follows:

- determination of the general directions and order of marine cargo transportation in the Arctic;
- preparation of the plan for the navigation period and its stages;
- updating of the plan of marine operations by the navigation stages;
- development of preliminary plans of nonstandard marine operations.

General planning of marine operations includes:

- preparation and updating of the plan-schedule of marine operations including supply operations;
- development of the plans of nonstandard marine operations.

Tactical planning of marine operations includes:

- correction of the plan-schedule of marine operations;
- updating of the plan of nonstandard marine operations;
- planning of a specific marine operation of a wide range (transportation, supply, some nonstandard operations, etc.).

A complex of objectives of operational regulation (management) of sea operations includes:

- updating of the plan for a specific marine operation (5-10 days in advance), designation of icebreakers and convoy composition;
- distribution of icebreakers on the route segments, determination of the convoy formation points;

- management of a specific marine operation (including nonstandard marine operations) 1-5 days in advance;
- selection of places for possible stationing of vessels on the NSR segments in the event of deterioration of ice situation.

The indicated stages in planning marine operations and the objectives of each stage allowed determining the corresponding spatial and temporal scales of the ice information presentation. They are discussed below.

1.3 Requirements for ice information that is used for successive planning of marine operations

An effective use of the information on the environmental state for successive planning of marine operations includes the fulfilment of two conditions:

- availability of information at the planning bodies, when required;
- consistency of the information model of the described natural phenomenon with its real state (within the required detailing and accuracy).

Traditionally, ice information is subdivided into general use information and specialized ice information for shipping.

The former presents a spatial distribution of ice cover characteristics (in the Arctic Seas on the whole, or over vast areas), or describes specific phenomena occurring in ice cover.

Specialized ice information for shipping covers (Brovin, 1994b):

- ice cover characteristics directly on the navigation routes of ships;
- operating motion characteristics of icebreakers and ships in ice (motion velocity, time consumption, etc.);
- ice-navigation indicators (type of ice navigation conditions along the NSR segments, type of navigation or its stage for the western and eastern NSR regions, etc.);
- navigation recommendations for specific types of marine operations.

All ice information is subdivided into three types: operational (data of current full-scale observations and operational calculations), regime (that generalizes full-scale data for the preceding years) and prognostic (ice forecasts with different periods in advance).

Similar to the general use information, specialized ice information for shipping is also subdivided into three types:

- operational that combines all data on current navigation conditions at the present moment;
- regime that contains evidence on the characteristics of ice conditions and operating navigation indicators along the different routes in the past;
- prognostic that contains evidence on ice conditions in the future with different periods in advance.

The need for a practical use of ice information for planning of marine operations along the NSR governs the requirements for its types, content and advance periods. Also, each type of ice information has corresponding requirements to the data accuracy and representativity for a definite space and time. These requirements are, on the one hand, connected with the specific shipping objectives, and on the other hand, are based on the accuracy and representativity of observations and methods for information processing.

In accordance with the successive planning of marine operations (see section 1.2), at the preliminary stage the main attention is devoted to regime ice information. At subsequent planning stages the prognostic ice information with different periods in adavnce becomes of major importance. For operational regulation (management) of shipping along with using prognostic information, the role of current ice information considerably increases.

At the stage of perspective planning ice information should contain:

- climatic estimates of ice conditions at the existing and perspective navigation routes for all years of available observations;

- conclusions about the character of climatic changes of ice cover along the navigation routes for the near years (from 3 to 25-30 years);
- periods of possible and guaranteed navigation of icebreakers and ships of specific types on the NSR segments and along possible transportation directions (probabilistic estimates).

It should be noted that at this planning stage in addition to background (climatic) prognostic estimates the regime information specialized at the stage of its collection and processing is used. This is regime information that refers to ice routes and takes into account the influence of natural navigation conditions on the use of operating and perspective icebreaking and transport fleet.

The objectives of the preliminary planning of marine operations require the following ice-navigation information:

- type of navigation (navigation period) by regions and on the whole along the NSR;
- mean monthly types of ice navigation conditions along the NSR segments with ice and operating characteristics;
- mean monthly position of the drifting ice edge, ice massifs, zones with inclusions of second-year and multiyear ice, fast ice boundaries;
- dates of the beginning of navigation (by the NSR segments);
- dates of the beginning of unescorted navigation for each category of ships of a different ice class (by the NSR segments);
- dates of the end of unescorted navigation (by the NSR segments);
- dates of the end of navigation by the segments and on the whole along the NSR.

At this planning stage long-range ice and specialized forecasts, as well as regime information, are used. Background characteristics are forecasted 6 months in advance and detailing and updating is peformed 1-4 months in advance.

The general planning objectives govern the acquisition of the following ice-navigation information 1-3 months in advance:

- updating of the type of the navigation period by regions and on the whole along the NSR;
- updating of the mean monthly types of ice navigation conditions by the NSR segments;
- position of ice edge, boundaries of ice massifs, zones including second-year and multiyear ice, fast ice for fixed dates;
- types of mean monthly ice and operating characteristics (length of the route in different ice, time consumption, motion velocity) along an optimal navigation variant on the NSR segments for icebreaker and standard convoy;
- dates of the beginning-end of the necessary ice disappearance in the regions of unloading during the supply operations;
- dates of the beginning of ice formation and ice reaching thicknesses that limit navigation for definite categories of ships;
- dates of a possible use (most economic) of specific types of icebreakers.

A complex of objectives that are addressed at the tactical planning stage (at a time interval 10-30 days) require the following ice-navigation information:

- boundaries of main ice formations and polynyas, position of the zones of discontinuities in ice cover;
- operating characteristics (motion velocity, time consumption) in specific ice zones, at the navigation variants, along the NSR segments;
- position of an optimal navigation variant along the NSR segments;
- updating of the dates of the beginning-end of the necessary ice disappearance in the regions of unloading during supply operations;
- dates of a stable ice disappearance on the NSR segments (for ships of a small ice class with limited shipping capabilities);
- updating of the dates of ice formation and ice reaching thicknesses limiting navigation of definite categories of ships.

Medium-range ice and specialized ice forecasts represent the indicated information. On the basis of the objectives addressed, the requirements to them govern the need for forecasting characteristics on the NSR segments for a month with a 10-day interval.

The objectives of the stage of the operational regulation (management) of marine operations (in a time interval of about 1-10 days) govern the need for obtaining the following ice-navigation information:

- change in the position of the boundaries of main ice formations, polynyas, zones of discontiuunuities in ice cover;
- preservation or change in the position of an optimal navigation variant along the NSR segments;
- motion velocity and time consumption for navigating specific ice zones along an optimal navigation variant;
- position of the edge and boundaries of ice of different concentration in the regions of unloading during supply operations, places of the formation of convoys and safe stationing of ships;
- periods of improvement and deterioration of ice situations (off-shore - on-shore character of the ice drift, compacting, diverging, ice pressure);
- preservation or change of the navigation variant in narrow places (straits);
- a composite chart of actual ice situations.

At the stage of the operational regulation (management) of marine operations ice and specialized ice forecasts 7-10 days in advance, short-range ice forecasts (1-3 days) and current (actual) ice information according to satellite data, data of airborne reconnaissance, shipborne observations and polar stations are used.

1.4 Specialized ice information for planning of shipping

Specialized ice information for shipping presents a set of ice, operating and ice-navigation indicators. They reflect ice conditions on the route of sailing and present a quantitative estimate of the effect of these conditions on the success of different types of navigation (Brovin, 1994a).

1.4.1 Acquisition of specialized ice information for shipping

There are two main ways for obtaining primary specialized ice information.

The first - includes observations (more often special ones) of ice cover characteristics on the ship's motion route, as well as operating indicators of moving in ice. And small-scale and specific ice phenomena connected with the ship's motion are recorded. For example, "ice river', ice adhesion to the ship's hull, etc.

Collection of this information, its processing and accumulation, as well as its comparison with a spatial distribution of ice cover allow obtaining dependencies of operating indicators on the total ice distribution characteristics. This is a basis for creating algorithms for specialization of the general geographic ice information for shipping. At present the model for a quantitative assessment of the difficulty of ice navigation (QAD model) developed at the AARI in the 80s can be considered as the most perfect specialization algorithm (Busuyev and Fedyakov, 1983; Brovin and Fedyakov, 1994). This model is based on the indicated dependencies.

The second way for the ice information specialization for shipping is an application of specialization algorithms (QAD model) to the general geographic information presented in the form of charts of a total ice cover distribution(an operational composite ice chart, charts of regime ice information, prognostic ice charts). At present, this is the main way for obtaining mass specialized ice information along the NSR.

In accordance with the significance of specific ice cover characteristics the general geographic ice information can be subdivided for specialization purposes into obligatory, additional and auxiliary (Fig. 1.1).

Obligatory information is information about ice cover characteristics without which its transformation into a specialized form is impossible.

Additional information is information about ice cover characteristics that significantly influence shipping, but their absence can be supplemented by climatic data. Availability of this information in the operational form significantly enhances the reliability and accuracy of specialized information.

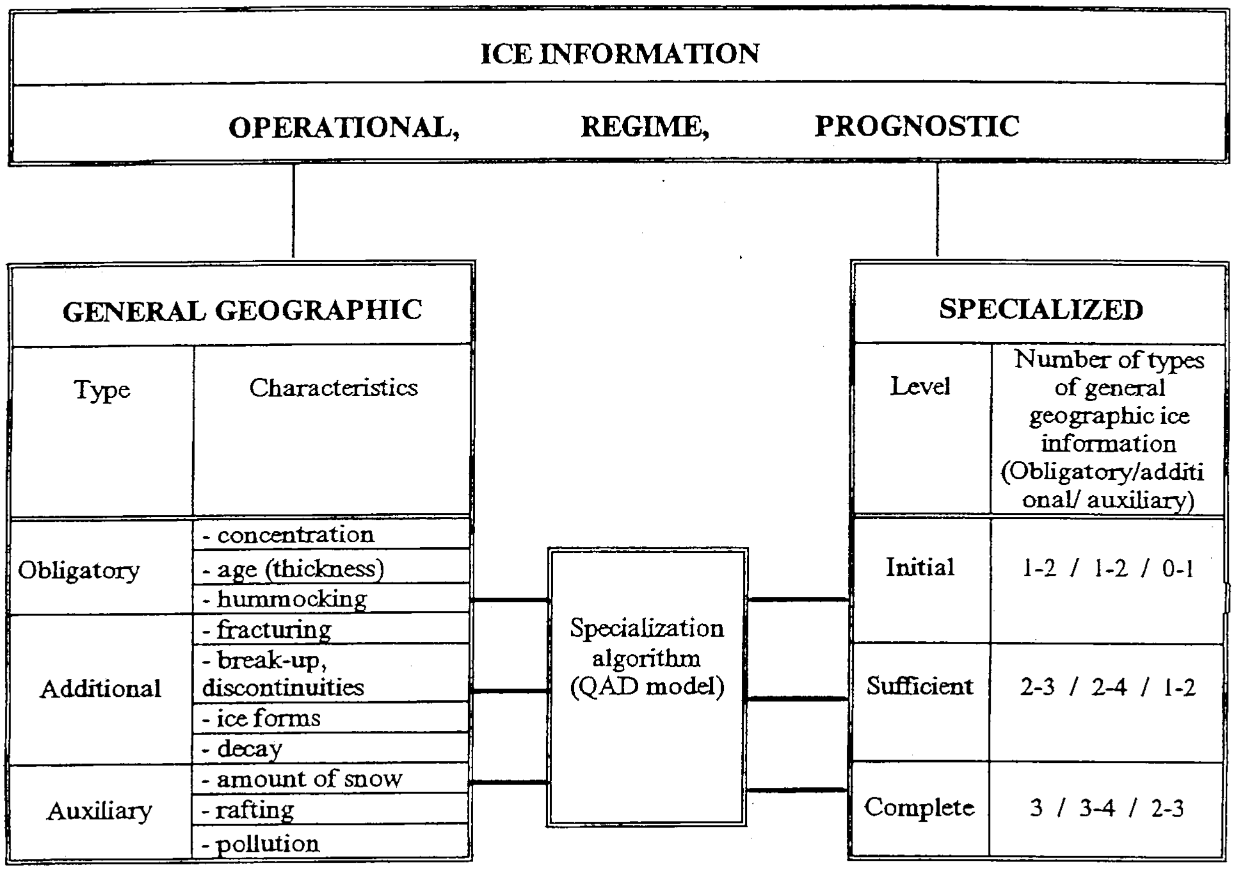


Fig. 1.1. Specialization of ice information for shipping

Auxiliary information includes ice cover characteristics whose influence on navigation of ships has been insufficiently studied and they are not used directly in the specialization algorithm.

Availability of this information contributes to specification and detailing of specialized ice information for developing navigation recommendations.

In accordance with the completeness of presenting ice cover characteristics in the form of the general geographic ice information (a composite ice chart, prognostic ice chart or charts of regime ice information) three specialization levels of ice information for shipping can be identified: initial, sufficient and complete (see Fig. 1.1).

1.4.2 Ice navigation characteristics for planning marine operations and a possibility for their forecasting

For each planning stage of marine operations along the NSR there are initial information bases (specialized and general geographic ice information), a general specialization algorithm of ice information (QAD model) and techniques for obtaining corresponding ice-navigation indicators.

Table 1.2 presents main ice-navigation indicators obtained by means of the "QAD" model on the basis of the general geographic information.

The preliminary planning stage of marine operations uses as the main ice-navigation indicator, the type of navigation (navigation period) for the NSR region that represents a probabilistic set of mean monthly or 10-day types of ice navigation conditions with a corresponding statistics of ice and operating indicators (see Table 1.2). See section 2.3 of the present Report for details.

At the present time there is a possibility for forecasting the type of navigation (a method for forecasting the type of navigation on the segment of the western MSR region in winter -the author - Brovin A.I.) or its indirect determination on the basis of a long-range forecasting of ice cover extent, location and area of ice massifs (for the segments of the western NSR region in summer - the authors - V.A.Spichkin and A.G.Yegorov).

As additional ice-navigation information, the physical-statistical forecasts of ice edge position and ice phenomena in the Arctic Seas (the authors - Ye. U.Mironov, V.A.Spichkin, I.D.Karelin, Ye.G.Kovalev, V.P.Karklin) can be used, as well as a numerical forecast of ice distribution (position of the ice edge and boundaries of ice of different concentration and boundaries of old ice - the authors - Z.M.Gudkovich, I.L.Appel', I.Ye.Frolov, V.M.Petrov). A description of specific methods of ice forecasts is given in INSROP Project I.6.1.

operating indicators of motion of icebreakers and ships used (see Table 1.2). Section 2.2. of the Report is devoted to the methods of subdividing ice conditions of navigation (T_{icn}) into types with a 10-day and monthly interval.

Table 1.2. Ice-navigation indicators and their characteristics

TYPE OF INFORMATION	CHARACTERISTICS
Length of the route in main ice formations L_i (miles)	- very open ice - open ice - ice massif (periphery, core) - polynya - open water
Length of the route in ice of different age categories L_j (miles)	- new ice (5-10 cm) - young ice (10-30 cm) - first-year thin ice (30-70 cm) - first-year medium ice (70-120 cm) - first-year thick ice (>120 cm) - second-year ice (up to 250 cm) - multiyear ice (>250 cm)
Motion velocity in specific ice zones	V_i, V_j - for types of ships and standard convoys
Time consumption in ice zones and on the NSR segment	T_i, T_j, ΣT (hours) - for types of ships and standard convoys
Position of an optimal navigation variant on the NSR segment	- one of the standard navigation variant - independent variant (coordinates)
T_{icn} - type of navigation conditions on the NSR segment	— — — — — — — L_i, L_j, V_i, V_j, T_i, T_j, ΣT - 10-day and monthly interval
Type of navigation (navigation period) for the NSR region	- a set of T_{icn} by the NSR segments

At present the method for forecasting mean monthly T_{icn} 1-3 months in advance has been developed for the western NSR segment for the winter period of navigation (the author - A.I. Brovin). A possibility for creating a similar forecasting method for the summer period is shown in INSROP-95 Project I.6.1 (Brovin and Yulin, 1995).

Also, forecasts of the dates of fast ice decay (the authors - V.A.Spichkin, I.D.Karelin, Ye.G. Kovalev), stable ice formation (author Krutskikh B.A.), ice thickness growth (the authors -

Also, forecasts of the dates of fast ice decay (the authors - V.A.Spichkin, I.D.Karelin, Ye.G. Kovalev), stable ice formation (author Krutskikh B.A.), ice thickness growth (the authors - Spichkin V.A. et al.) are used as the main ice-navigation information. The forecasted characteristics refer to the NSR segments and the regions of polar stations. These forecasts are prepared 2-5 months in advance.

As additional ice information for general planning of marine operations, one can use numerical forecasts of a spatial distribution of thickness and concentration of drifting ice for the wintertime up to 3-4 months in advance (the size of the grid area is 75 x 75 km). These forecasts cover at present all seas of the NSR except for the Laptev Sea (the authors of the forecasting method: Z.M.Gudkovich, I.L.Appel', I.Ye.Frolov, V.M.Petrov).

For the tactical planning stage of marine operations (10-30 days) the main ice-navigation information includes the position of an optimal variant of navigation, boundaries of ice zones and length of the route in main ice formations and ice of different age categories, operating characteristics of moving in ice. These characteristics should refer to the NSR segments and have an interval not less than 10 days.

At the present time there is being developed at the AARI a method for forecasting the position of an optimal navigation variant for the segment of the western NSR region (Dikson Island - Zhelaniya cape). There are methods for forecasting ice and operating characteristics over all segments of the western NSR region for summer navigation (the authors - A.I.Brovin, V.F.Dubovtsev, A.V.Yulin).

As additional ice information for tactical planning, numerical ice forecasts of a 10-day interval already mentioned at the general planning stage, can be used, as well as forecasts of the ice distribution in the Kara Sea in summer (the authors - V.A.Spichkin, A.G.Yegorov) and forecast of the change in ice decay in the Arctic Seas (the author - I.M.Kuznetsov).

A separate INSROP Project I.2.1 is devoted to ice-navigation information for operational regulation (management) of marine operations along the NSR. That is why this question is outlined here very briefly, as necessary for the concept.

For the operational regulation (management) stage of marine operations (usually, in the interval of 10 days) the main ice-navigation information includes actual ice situation (a composite ice chart), short-range forecasts of ice redistribution, discontinuities and ice pressures.

Composite ice charts are prepared at the SSC AARI (for the whole of the NSR) and Regional Centers of the Hydrometeorological Service (Dikson, Tiksi, Pevek) with an interval of 3-4 days. These charts contain ice information reported from different sources: satellites, visual and instrumental airborne ice reconnaissance, shipborne data, data of polar stations, as well as results of model calculations for reconstructing the fields of some ice elements.

For obtaining prognostic ice information numerical and physical-statistical methods for ice forecasting are used. They include: numerical methods for the redistribution of ice cover and ice pressure in the Kara and East-Siberian Seas for the summer period of navigation 7-8 days in advance with updating 3-4 days in advance, the size of the grid area being 50x50 km (the authors Z.M.Gudkovich, I.L.Appel', S.P.Pozdnyshev); a numerical forecast of discontinuities in ice cover (of prevailing orientation and dimensions) for the central Polar Basin (with a 200x200 km spacing) and for the Kara Sea (50x50 km) for the fall-winter period 7-8 days in advance and with updating 3-4 days in advance (the authors - Yu.A.Gorbunov, S.M.Losev, S.V.Brestkin); a forecast of ice-hydrological processes in the Arctic Seas (including ice pressures) in summer 7-8 days in advance and with updating 3-4 days in advance (the authors -B.A.Krutskikh, Yu. A.Vanda); a short-range forecast of ice distribution in the Arctic Seas of the NSR on the basis of the type subdivision and a method of analogues 10 days in advance and 1 day interval (the authors - Yu. A.Gorbunov, I.D.Karelin, I.M.Kuznetsov, S.M.Losev, A.L.Sokolov). See INSROP Project I.6.1, stage I for a more detailed description of the methods.

At present this ice information is converted into special purpose information by means of the "QAD" model. It allows selecting an optimal navigation route, calculating operating characteristics and developing navigation recommendations for specific marine operations.

1.5 Conclusion

A concept for a system of specialized ice information support to successive planning of marine operations along the NSR includes five planning stages (perspective, preliminary, general, tactical planning and operational regulation) for the existing types of marine operations. For each stage the main practical objectives are enumerated. The requirements to ice information are formulated. On their basis an analysis of necessary, as well as presently available operational (current), climatic amd prognostic ice information has been performed. In accordance with the planning objectives, main attention is devoted to prognostic ice information.

The questions of the methods for specialized ice information for shipping are of importance in the concept. The purpose of the specialization is to obtain such quantitative ice-navigation indicators that reflect well ice conditions of navigation and are applicable for the planning of marine operations.

A combination of different types of ice information (operational, regime, prognostic, general geographic and specialized) into one system allowed identification of the importance of each information type, as well as understanding of the need for creating new forecasting methods and improvement of their specialization for shipping.

Quite important for further work appears to be the creation of the algorithms of navigation recommendations for specific types of marine operations along the NSR.

The concept generalizes experience of the scientific-operational support to marine operations along the NSR, as well as experience in planning and supporting specific marine operations of the Murmansk and Far Eastern Shipping Companies where the AARI actively participated.

The authors of the concept consider a detailed discussion and improvement to be necessary taking into account the ongoing organizational changes in the Russian Arctic shipping companies. Also, practical interests and goals of the foreign companies and firms that plan marine operations along the NSR can contribute to the updating and development of the system for a specialized ice information support to planning along the NSR.

2 TYPES OF ICE CONDITIONS FOR NAVIGATION ALONG THE NSR

2.1 A review and analysis of the previous subdivisions into types of total ice cover distribution and ice conditions of navigation

The subdivisions of hydrometeorological processes, phenomena and objects, as well as their characteristics into types are governed by the need for their detailed investigation and forecasting on the basis of differentiating by similar indications. The division into types is usually used for studying hydrometeorological phenomena or objects that differ by a large variability. Any scheme for type subdivision is based on two main principles:

- similar indicators of an object are combined into one type;
- the similarity degree of the indicators of an object belonging to one type should be more than that of the indicators belonging to different types.

In accordance with these principles, the division into types is considered to be optimal when the largest uniformity is revealed within the types and the largest difference is between the types.

The generalization of the entire diversity of the ice cover in the Arctic Seas up to 3-4 type schemes is one of the main ways for presenting [illegible] ice data necessary for planning and management of marine operations. Multiyear [illegible] carried out at the AARI have allowed combining the variety of ice cover distribution in the Arctic Seas into several types. Also, meteorological and hydrological processes that form different types of ice distribution were investigated.

The first divisions of ice cover into types were performed in the 40s by V.Yu.Viese, M.M. Somov, D.B.Karelin, A.F.Treshnikov, N.A.Volkov, P.A.Gordiyenko. Then during the next 10-15 years the principles and methods for subdividing into types were further developed by A.A. Kirillov, A.P.Kozyrev, S.V. Mol'kentin, T.I.Slantsevich, Yu.A.Gorbunov, Ye.G.Kovalev. On the basis of type generalizations the methods for long-range forecasts of ice distribution in the Arctic Seas were developed (Gudkovich et al., 1972).

The use of the qualitative and quantitative indicators is common for most types of ice distribution in summer:

- geographical position and mutual location of ice massifs;
- values of ice cover extent (a relative sea area covered by ice) and areas of close ice.

As a result of the studies, the following types of ice cover distribution in the Arctic Seas were identified:

a. South-western Kara Sea

Viese (1944) identified three types of ice distribution in the given region: western (when the Novozemel'sky ice massif is located off the eastern coast of Novaya Zemlya), central and eastern. In subsequent works of M.M. Somov, V.M. Ivanov, A.A. Kirillov, etc. a great stability of the identified types during summer navigation was noted. It was found that the western type has the largest occurrence frequency (about 70%). Kirillov and Spichkin (1968) showed the formation of different types of ice distribution and its persistence during navigation to be governed by the direction and intensity of air transports in spring and water circulation system in the given region.

b. North-western Kara Sea

The first division of ice distribution into types in this region made by M.M. Somov in 1945 was of a qualitative character. Two main types were identified. The first type includes the years when Severozemel'sky and Central Kara massifs were separated by a zone of open water or very open ice. The second type includes the years when both massifs are combined with each other during navigation.

The identified types were specified by A.P.Kozyrev in 1959. He suggested the use of anomalies in ice cover extent as a quantitative criterion. Kozyrev divided the available observation series into 3 groups depending on the ice cover extent and delineated five main types of ice distribution in the north-eastern Kara Sea.

c. Laptev Sea

A.A. Kirillov in 1962 identified six types of ice cover distribution in summertime. The following criteria were used:

- position of the boundaries of close ice in the sea (latitudinal or meridional);
- amount of ice in the western and eastern sea regions in July-August (in three gradations: norm, more than the norm and less than the norm).

As shown by the study, the author found each type of ice distribution to be formed as a result of specific combinations of air transports that govern its stability in time, character of ice drift at sea and intensity of ice melting.

The division of ice distribution into types in the eastern Laptev Sea and western East-Siberian Seas by I.D. Karelin in 1969 is based on the characteristic changes of ice conditions at definite wind directions. For the period July-September five types of ice conditions are identified and a probability for the type to be preserved or changed from one 10-day period to another is calculated.

d. East-Siberian Sea

The first attempts at dividing ice conditions into types undertaken by S.V.Mol'kentin and A.A. Sokolov in the second half of the 50s resulted in 3 types of ice cover distribution: western, central and eastern.

The following criteria were used:

- position of the Aion massif;
- distance from the shore to the drifting ice edge and boundaries of close ice.

Ye.G.Kovalev in 1965 suggested 8 standard schemes of ice distribution in this region on the basis of different combinations of the position of the Aion massif and ice cover extent in the eastern sea region. They include: four eastern and four central, each, respectively, for small, medium, enhanced and large ice cover extent.

The division of ice conditions into types using methods for an objective statistical analysis was performed by A.V.Yulin in 1987 (Yulin, 1987). On the basis of a cluster analysis four types of the seasonal change in the area and position of the Aion ice massif and six types for the New-Siberian massif were identified.

e. Chukchi Sea

The divisions into types of a qualitative character made by N.A.Volkov in 1949 and Yu.A. Gorbunov in 1956 allowed an identification of three types of ice distribution:

- favourable when close ice of the Vrangel massif is located in the northern part of the Long strait;
- intermediate when close ice of the massif is in the central part of the strait;
- unfavourable when close ice is located in the southern part of the strait.

In 1964 T.I.Slantsevich suggested a new division into types for the whole of the Vrangel region (the eastern East-Siberian and western Chukchi Seas).

The following criteria were used:

- general ice distribution in the whole of the Vrangel region;
- assessment of ice-navigation conditions along the shipping route Uelen-Shelagsky cape;

- assessment of the trafficability of the indicated route by ships.

On the basis of the ratio between the anomalies in the areas of the Aion, Vrangel and northern Chukchi ice massifs Slantsevich identified eight types of general ice distribution in the Vrangel region.

Using the same principle, ice conditions for the route zone in this sea were divided into types. As a result, eight types of ice distribution on the indicated route were identified on the basis of a combination of the anomalies in close ice areas in some regions.

With regard to trafficability of ships the navigation conditions are divided into three types:

- unescorted navigation of ships;
- icebreaking escort;
- navigation is impossible.

A shortcoming of this division is a formal-schematic approach to identification of types when only signs of the anomalies rather than their values are taken into account.

The studies aimed at searching objective techniques for subdividing ice conditions into types were carried out by B.A.Krutskikh (Krutskikh, 1979). The identification of uniform hydrological regions has governed a new methodological approach to the division of ice conditions into types in the Arctic Seas. The author has identified 6 groups in the development of synoptic processes and corresponding uniaxial dynamic processes in the seas with an interval from 2-3 to 7-9 days. The period of a uniaxial dynamic process has been called a natural hydrological period.

It has been found that within one hydrological region there are 1-3 ice regions with ice characteristics that change little in space and that differ by a uniaxial change of ice conditions during a natural hydrological period. Such sea regions are called natural ice regions (Yegorov and Spichkin, 1990).

The division of ice distribution into types by concentration for easy, medium and heavy ice conditions has been made for each natural ice region. This division allows one to characterize in sufficient detail actual ice conditions in any region of the Arctic Seas on a common physical-statistical basis and forecast their changes on a synoptical spatial-temporal scale.

The enumerated divisions into types and methods for calculating and forecasting ice redistribution developed on their basis do not allow an identical assessment of the change in ice conditions directly on the navigation route of ships.

Regular studies in this direction were started in the 60s. One of the first divisions of ice navigation conditions into types was performed by P.A. Gordiyenko, A.Ya. Buzuyev, G.N. Sergeyev et al. in 1966 on the NSR segments for standard navigation variants for the period May-November. All diverse navigation conditions are differentiated into easy, medium and heavy types. This division is based on the coefficient of the navigation difficulty K_d (Buzuyev and Gordiyenko, 1976).

The division of navigation conditions along the "most easy" navigation variant along all NSR segments for summer was made by A.Ya.Buzuyev in 1977. As a criterion of this division into types, the duration of the navigation period that was determined taking into account changes in the coefficient of the navigation difficulty K_d was used.

The division of ice navigation conditions in winter (December-May) was performed by A.Ya. Buzuyev in 1980. All diverse ice conditions were subdivided into three types too: easy, medium and heavy. The division is based on a relative length of the route in two ice age gradations most difficult for navigation (first-year thick and medium ice) for each NSR segment. For each type of navigation conditions mean values of the extent of the route in ice of different age categories and its variability were calculated.

The division of navigation conditions along the route Shelagsky cape - Bering strait for the period June-September suggested by V.Ye.Fedyakov in 1983 developed further the previous approaches for solving this problem.

The following criteria were used:

- length of the route in ice of 7-10/10 concentration;
- variability of this length within the period under consideration;
- duration of the time when within the period under consideration there were observed favourable conditions on the route.

As a result of the study made, six types of ice navigation conditions were identified.

The developed subdivisions of ice navigation conditions into types are widely employed in resolving research and practical objectives. They include:

- study of hydrometeorological and ice navigation conditions along the NSR, determination of the main factors influencing the navigation conditions;
- forecasting of ice navigation conditions;
- use for planning in operational activities.

These subdivisions along with advantages, in particular, the development of a new methodological approach and a practical application for navigation were not free of disadvantages. The latter referred to the use of a large number of type indications and were sometimes insufficiently justified. This resulted in the creation of artificial rules for subdividing into types and ambiguous determination of operating motion characteristics of ships in ice.

2.2 Division of ice navigation conditions into types from several days to a month

In order to correctly identify the type of a hydrometeorological phenomenon (its state and changes) it is necessary to fulfil several standard procedures:

- select one or several parameters (indications) that reflect best of all the character of the phenomenon and its variability by the values of which the state of the phenomenon will refer to some type or other;

- define rules (criteria or boundaries) according to which the phenomenon can belong to this or that type;
- approximately identify an optimal number of the types that meet the objectives of the subdivision into types.

One of the most complicated and important stages of the subdivision is to select one or several indicators from a set of the characteristics describing the phenomenon, as a basis for the type subdivision.

The ice navigation conditions, as a study phenomenon are described by a set of indicators that represent two groups: ice indicators of navigation conditions and operating indicators. At present several subdivisions into types using ice or operating indicators have been developed.

These subdivisions use the following characteristics as ice indicators of navigation conditions: length of the route in close ice of older age categories beginning from first-year thick ice ($L_{9\text{-}10,\ thick}$), length of the route in ice massif ($L_{7\text{-}10}$), relative length of the route in most complicated ice conditions (S).

As operating indicators there are used:a coefficient of the difficulty of navigation (K_d), total time of navigation in ice (ΣT_{ice}), excess of total time for navigating the route segment as compared with the time for navigating this segment in open water (ΔT).

The next important stage of this subdivision is to determine the rules (criteria, boundaries) by which the navigation conditions will refer to some type or other. As mentioned in the publications devoted to the methods of classification (Yeliseyeva and Rukavishnikov, 1977, Spichkin, 1987; Brovin and Yulin, 1990) the main difficulty of determining the boundaries between different types is that so far there are no strict methods for identification of these criteria. They are usually prescribed sufficiently formally and subjectively on the basis of a theoretical concept and experience of investigators.

Usually, two techniques are used in the identification of the types of ice conditions for choosing criteria. The first technique is a prescription of the boundary values of indicators that are chosen on the basis of experience and practical considerations. In the second case, on the basis of the normal distribution function of most indicators of hydrometeorological conditions, such boundaries are established between the types that they include a definite number of the observed values of the indicators (for example, 50% of the values belong to a medium type and this corresponds to the interval $\pm 0.674\sigma$).

In all subdivisions of ice conditions of navigation into types three types are identified: easy, medium and heavy. This is connected with the length of the navigation series consisting, as a rule, of 40-50 values. The identified groups contain 10-25 values. This is a minimum necessary number of the values allowing for searching the typical features in the formation and variability of the similar types of navigation conditions. The attempts to identify a large number of the types resulted in insufficient filling of the groups and appearance of "empty" groups. An uncertainty in the identification of clear boundaries between the types was appearing.

The time interval of ice conditions that are subdivided into types depends on the period over which the indicators of navigation conditions were selected or averaged. At present there are regular observation series of ice conditions of navigation on all NSR segments with a 10-day or a monthly interval. The averaging intervals are related to a traditionally formed system for acquisition, generalization and accumulation of ice information.

The developed methods for subdividing ice conditions into types can be used for the observation series averaged over shorter time intervals - 2-3 days, 5 days. However, to estimate the conditions of navigating in ice, it is necessary to have regular ice information of this time scale, as an initial information specialization base.

At the present time the SSC AARI carries out collection and generalization of ice information for the period of 3-4 days for the Barents and south-western Kara Sea and for 7 days for the whole of the NSR. An increase in the length of the observation series up to 20-30 terms (20-30 years) will allow subdividing into types on this time scale.

Let us consider the subdivisions of ice conditions of navigation developed and used at the present time.

a. Division of navigation conditions into types on the basis of ice indicators

This subdivison is made by V.Ye.Fedyakov (SSC AARI) for the NSR segment western edge-Dikson with a 10-day interval for the summer navigation period (July-September). The length of the route in close ice (L_{7-10}) is used as the main indicator characterizing the navigation conditions in ice. All diverse navigation conditions in ice are divided into three types ("easy", "medium" and "heavy") on the basis of the following rules:

- "easy" type includes the years when in the first 10-day period of July close ice isthmus is observed in some places with a length less than 5% of the total route in ice and from the second 10-day period of July $L_{7-10} = 0$;
- "heavy" type includes the years when close ice is preserved on the route in June-August or there is a significant mean length of the route in close ice in June-July ($L_{7-10} \geq 200$ miles);
- other years refer to the "medium type".

The probability for the formation of easy, medium and heavy types of navigation conditions is equal, being about 30-40%. The filling of the groups is also approximately equal, consisting of 10-15 values.

For each type there were determined type coefficients of the navigation difficulty (K_d) for icebreakers of a different type and type lengths of the route in ice of 7-10/10 in concentration ($L_{7-10,\,type}$) for each 10-day summer period. The navigation difficulty coefficient K_d presents a ratio of the calculated time of navigation in the ice to the time for the same route without ice.

b. Division of ice navigation conditions into types on the basis of operating indicators

This subdivision was developed by A.I. Brovin (SSC AARI) for the western NSR region: western edge of drifting ice - Dikson and Cheluskin - Tiksi for the summer navigation period (June-October) with a 10-day interval.

This subdivision used the calculated time consumption for ice navigation of the nuclear icebreaker of the "Arktika" type (ΣT_i) as the main indicator of the navigation conditions in ice.

The processing of the calculation results ΣT_i has shown the distribution function of this indicator for the "warm" period of the year to be described by a truncated normal distribution.The boundaries between the types are determined from the condition that the medium type (interval) includes 50% of the values under consideration. For determining the upper boundary of each type there are used specific values of K_d as an additional condition. For the "easy" type $K_d \leq 3.0$, for the "medium" $K_d \leq 4.0$ and for the "heavy" type $K_d \leq 10.0$.

For all types there were obtained statistical characteristics of ice conditions of navigation for each 10-day summer period:

- length of the route in ice (L_{ice});
- length of the route in close ice (L_{7-10});
- length of the route in ice massif (L_m);
- length of the route in the ice massif core (L_{mc}).

c. Improvement of the division of ice navigation conditions into types on the basis of operating indicators

Regretfully, both of these subdivisions are not devoid of shortcomings. The first main indicator of the navigation conditions is an ice indicator - L_{7-10}, however, ice thickness and amount of hummocking are not taken into account. At equal values of L_{7-10} navigation can be in ice of different age categories and amount of hummocking. As a result, the navigation conditions belonging to one type can significantly differ by complexity. And the subdivision into types attains an unstable and ambiguous character.

The second subdivision into types is based on operating indicators - ΣT_i and K_d referring to an ice zone and not to the whole of the NSR segment. After the onset of a stable ice formation ΣT_i sharply increases; this, however, does not indicate the real changes in the complexity of the navigation conditions.

While eliminating the disadavantages of the latter subdivision, A.I.Brovin, V.F.Dubovtsev and A.V.Yulin developed a subdivision on the basis of the indicator reflecting an increase in time of navigation due to ice (ΔT) on the segment Dikson island - Cheluskin cape for summer navigation with a 10-day interval. The values of ΔT as an indicator of the type subdivision are calculated for the motion of the convoy - the icebreaker "Arktika" + ship of UL ice class along an optimal navigation variant. The boundaries of the types (easy, medium, heavy) are established assuming 50% of the values being in a medium interval.

For each 10-day summer period there were calculated mean typical ice and operating indicators of navigation conditions: length of the route in ice and close ice (Li, L_{7-10}), operating navigation velocities (V_{io}), total time consumption for travelling along the route segment (ΣT), coefficients of the navigation difficulty (K_d).

This subdivision into types differs by the use of one indicator for the characteristics of navigation conditions -ΔT. The use of additional indicators is not required. The subdivision has a stable and unambiguous character. On its basis the method for forecasting type of ice navigation conditions for the segment Dikson-Cheluskin cape one month in advance was developed (Brovin and Yulin, 1995).

In order to obtain the types of ice conditions of navigation with a monthly interval two approaches are used.

The first one is based on obtaining mean monthly values of the parameter of the type subdivision. The determination of the boundaries between the types is similar to the division into types with a 10-day interval.

The second approach is based on a combination of the types of ice conditions of navigation for a 10-day period. The mean monthly type (easy, medium, heavy) is determined by means of the prevailing (two and more) corresponding 10-day types.

2.3 Division of ice navigation conditions into types for seasons and navigation on the whole

The objectives of a preliminary and general planning of marine operations along the NSR govern the need for obtaining ice-navigation indicators on the scales: "the NSR region" (3-4000 km), the navigation period (4-6 months).

At present there are several subdivisions of ice navigation conditions into types for such spatial-temporal scales. Here a possibility for obtaining generalized ice-navigation indicators that are called the "navigation type" or the "type of the navigation period" is considered on the basis of the types of ice conditions of navigation on a smaller scale: the NSR segment (~ 1000 km), month or decade.

There are different methods for obtaining these generalized indicators. However, one should remember that forecasting of these indicators is an ultimate goal of type subdivisions. That is why the methods for obtaining them should not be strictly formal. Arbitrarily, these methods can be called: an empirical-statistical method and a method for objective analysis.

2.3.1 Division into types using an empirical-statistical approach

The division of ice conditions into types for winter navigation (January-May) on the segment from the western ice edge in the Barents Sea to Dikson island was carried out by A.I. Brovin on the basis of an empirical-statistical approach in 1987.

Five navigation types (easy - E, medium with a tendency for easy - M_E, medium - M, medium with a tendency for heavy - M_H, heavy - H), representing a set of mean monthly types of ice navigation conditions are identified (Table 2.1). On the basis of this subdivision a method for forecasting ice conditions of winter navigation 4-6 months in advance has been developed.

Table 2.1. Generalized type of the navigation period as a set of mean monthly types of navigation conditions in ice

T_n	Number of mean monthly T_{icn}		
	Easy	Medium	Heavy
E	3-4	0-1	0-1
M_E	2	1-2	0-1
M	0-2	0-4	0-2
M_H	0-1	1-2	2
H	0-1	0-1	3-4

2.3.2 Divisions into types using methods of objective analysis

Developing a traditional approach for obtaining navigation types along the NSR, S.V. Klyachkin applied in 1994 a method for classification of sets on the basis of the elements for pattern recognition (Tu and Gonsales, 1978) for dividing ice conditions of summer navigation into types in the western region of the NSR. This work shows the applicability of this approach being the first step for its implementation. Further, the statistics of ice-operating indicators by the identified navigation types should be obtained and a possibility for their forecasting considered.

a. Division into types on the basis of the types of ice conditions of a smaller scale (10-day interval)

This subdivision of the ice-navigation indicators (navigation types) has been carried out for the western NSR region (3 NSR segments of a total length 3-4 000 km) for the summer navigation period (July-October).

The earlier obtained types of ice conditions of navigation (T_{icn}) on a scale : "the NSR segment (about 1 000 km), a 10-day period for 1946-1984 were used as the initial database for a subdivision into types of a larger scale (see 2.2.b).

These initial data present a 3-dimensonal matrix $[T_{ijk}]$, where i=1...12 - No. of a 10-day period for a 4-month navigation period (July, August, September, October); j=1,2,3 - No. of the western region segment (western edge - Dikson island, Dikson island-Cheluskin cape, Cheluskin cape, Tiksi); k=1,...,39 - No. of the year for a 39-year series (1946-1984).

A three-dimensional matrix $[T_{ijk}]$ can be presented in the form of 39 two-dimensional matrices $[t_{ij}]$, each of them corresponding to the navigation period for a specific year. The values of the elements of each matrix can be equal: 1 - at easy; 2 - at medium; 3 - at heavy ice navigation conditions.

At the first stage all 39 two-dimensional matrices are compared to each other in pairs (each to each) and a degree of closeness or a degree of coincidence of the matrices is determined. As a result, a general matrix of coincidences of 39 x 39 in size is obtained. It is symmetrical relative to the main diagonal. At the second stage the groups of initial matrices similar to each other are formed by a general matrix of coincidences. As a result, a number of the navigation types are identified. And each type has its own occurrence and ice conditions of navigation on each NSR segment in each 10-day period (Table 2.2, 2.3).

Table 2.2. Occurrence frequency of the types of summer navigation in the western NSR region (western ice edge - Tiksi settlement), obtained by means of the elements of pattern recognition for the period 1946-1984

Navigation types	1	2	3	4	5
Occurrence frequency	0.34	0.18	0.12	0.10	0.15

Table 2.3. Distribution of ice conditions of navigation (e - easy conditions, m- medium, h- heavy T_{icn}) for five types of summer navigation in the western NSR region obtained by the pattern recognition method

	July			August			September			October		
	1-10	11-20	21-30	1-10	11-20	21-30	1-10	11-20	21-30	1-10	11-20	21-30
1 type												
Western edge-Dikson isl.	e	e	e	e	e	e	e	e	e	e	m	m
Dikson island-Cheluskin cape	m	m	m	m	e	e	e	e	e	e	m	m
Cheluskin cape - Tiksi	m	m	m	m	m	m	m	e	m	e	m	m
2 type												
Western edge- Dikson island	m	m	e	e	e	e	e	e	e	e	m	m
Dikson island-Cheluskin cape	m	m	m	m	m	m	h	h	m	h	h	m
Cheluskin cape - Tiksi	e	e	e	e	e	e	m	m	m	m	m	m
3 type												
Western edge- Dikson island	m	m	m	e	e	m	e	e	e	e	m	m
Dikson island-Cheluskin cape	m	m	m	m	m	h	m	m	m	m	h	h
Cheluskin cape - Tiksi	m	m	m	m	m	m	m	m	m	h	m	m
4 type												
Western edge- Dikson island	m	m	m	m	m	m	e	e	e	m	m	m
Dikson island-Cheluskin cape	h	m	m	m	m	m	e	m	m	h	m	m
Cheluskin cape - Tiksi	h	h	h	h	h	h	h	h	h	h	h	h
5 type												
Western edge- Dikson island	h	h	h	h	h	h	m	m	m	m	m	m
Dikson island-Cheluskin cape	h	h	h	h	h	h	h	h	h	h	h	h
Cheluskin cape - Tiksi	m	m	m	m	m	m	m	m	m	m	m	m

As is seen from the indicated tables, 5 types of navigation are identified; also, 4 navigation periods turned out to be "nonstandard" and were unsuitable for any of the 5 types identified. In principle, each of such anomalous navigation periods can be interpreted as a separate, rarely encountered, type. The first type has the largest occurrence frequency, i.e. being the most easy type of navigation. With complication of navigation conditions the occurrence decreases; however, the occurrence of the most complicated fifth type is a little higher.

The first - the most easy type is characterized by the complication of navigation conditions from west to east: on the first segment - from the ice edge to Dikson - almost all the time easy conditions are observed, on the third segment - from Cheluskin to Tiksi - medium ice conditions prevail.

The second type is characterized by prevailing more complicated navigation conditions on the second - central - segment (Dikson-Cheluskin), while more easy situations are observed on the western and eastern segments.

With the third type of navigation conditions an easy situation is observed only on the first segment, while medium ice conditions prevail on the second and third segments.

The fourth and fifth types are characterized by the most severe navigation conditions. At the fourth type the most complicated situation is observed on the third - eastern - segment. At the fifth type the eastern segment has relatively easier conditions, the main navigation difficulties falling on the western and central segments.

The reality of the identified types of ice navigation conditions can be controlled by subdividing into types using a different method. For example, by application of this approach to the ice-navigation indicators generalized for the whole of the NSR western region and over the whole of summer navigation for the available observation series.

b. Division into types on the basis of ice-navigation indicators for the whole of the navigation period

The same 10-day types of ice navigation conditions on the same segments of the NSR western region for the same time period (1946-1984) are used as initial data for this subdivision (see 2.2.b).

In accordance with the recommendations (see sections 2.2.c and 2.3.1 of the present Report) 10-day types of navigation conditions are reduced to monthly, monthly to seasonal and then by summation over the segments the integral characteristics of navigation conditions over the whole western sector for a specific navigation period are obtained (successive generalization method). Thus, an initial matrix $[T_{ijk}]$ is reduced to a time series $[L_k]$ where L - integral characteristics of navigation conditions along the whole of the western sector for the entire navigation period, k=1,...39 - No. of the year. Elements of the set $[L_k]$ are grouped by their absolute values. The number of the intervals at such grouping is selected to be equal to 5. This corresponds to the number of the types identified by the first division into types presented in the previous section. As a result, a time series $[L_k]$ is presented in the form of a histogram which is shown in Table 2.4.

Table 2.4. Occurrence frequency of the types of summer navigation in the western NSR region (western ice edge - Tiksi settlement), obtained by the successive generalization method for the period 1946-1984

Navigation types	1	2	3	4	5
Occurrence frequency	0.29	0.26	0.23	0.10	0.12

As is seen from Table 2.4, the character of the occurrence of the years with a different degree of complexity of ice navigation conditions is close to that presented in Table 2.2. The most easy ice conditions have the largest occurrence frequency, then with more complicated conditions the occurrence decreases; however, it slightly increases for the most complicated type.

Table 2.5. Distribution of ice conditions of navigation (e - easy conditions, m- medium, h- heavy T_{icn}) for five types of summer navigation in the western NSR region obtained by the successive generalization method

	July			August			September			October		
	1-10	11-20	21-30	1-10	11-20	21-30	1-10	11-21	21-30	1-10	11-21	21-30
1 type												
Western edge- Dikson island	e	e	e	e	e	e	e	e	e	e	e	m
Dikson island-Cheluskin cape	m	m	m	m	m	e	e	e	e	e	m	m
Cheluskin cape - Tiksi	m	m	m	e	e	e	e	e	e	e	m	m
2 type												
Western edge- Dikson island	m	m	e	e	e	e	e	e	e	e	m	m
Dikson island-Cheluskin cape	m	m	m	m	m	m	m	m	m	e	m	m
Cheluskin cape - Tiksi	m	m	m	m	m	m	m	m	m	m	m	m
3 type												
Western edge- Dikson island	m	m	m	m	e	m	e	e	e	e	m	m
Dikson island-Cheluskin cape	m	m	m	m	m	m	m	m	m	m	m	m
Cheluskin cape - Tiksi	m	m	m	m	m	m	m	m	m	m	m	m
4 type												
Western edge- Dikson island	h	h	h	h	h	h	m	m	m	h	h	m
Dikson island-Cheluskin cape	h	m	m	h	h	h	h	h	h	h	h	h
Cheluskin cape - Tiksi	h	h	h	m	m	m	h	h	h	m	m	m
5 type												
Western edge-Dikson isl.	h	h	h	h	h	m	h	m	m	m	m	m
Dikson island-Cheluskin cape	h	h	h	h	h	h	h	h	h	h	h	m
Cheluskin cape - Tiksi	m	m	m	m	m	m	m	m	m	h	m	m

The grouping of the navigation periods performed by absolute values of the integral characteristics of ice conditions of navigation also allows identification of the mean types of ice conditions by each 10-day period and each segment (Table 2.5). The data of Tables 2.3 and 2.5 are similar and since they are obtained by different independent methods, a comparison of these two tables is of some interest (Table 2.6). As is evident from Table 2.6, spatial-temporal distributions of ice conditions for types 1, 2, 3 and 5 obtained by two different methods are quite close to each other. Type 4 is an exception, the agreement between the results obtained by different methods being much worse. It is obvious, that these inconsistencies are related to the differences in the approaches used for the sudivisions into types. In the first case, the identification of the types is based on the spatial-temporal distributions of ice navigation conditions being close. In the second case, it is based on the closeness of absolute values of the degree of the navigation difficulty without taking into account a spatial distribution by segments and a temporal distribution by 10-day periods. Nevertheless, both results do not, on the whole, contradict each other, indicating that the identified types are real.

Table 2.6. A degree of coincidence of mean types of spatial-temporal distributions of navigation conditions obtained by two independent methods

Navigation Types	1	2	3	4	5
Occurrence frequency	0.81	0.72	0.86	0.22	0.92

2.4 Conclusions

The different subdivisions into types are successfully used for investigating and forecasting ice navigation conditions along the NSR.

At the present time there are some identifications of the types of ice cover distribution and methods for forecasting ice redistribution for most of the NSR regions developed on their basis. However, they do not always allow identical estimates of the state of ice conditions directly on the sailing route of ships. This fact governed the need for subdividing ice navigation conditions into types directly on the navigation route. Such subdivisions were developed at the AARI and they are used for planning and management of marine operations along the NSR.

An analysis of the previous subdivisions, the use of their advantages, consideration of practical and prognostic requirements allowed subdividing ice conditions into types for summer navigation with a 10-day interval (for the route segment Dikson island - Cheluskin cape). It can become a basis for subdividing ice conditions along all NSR segments. This subdivision serves as a basis of the method for forecasting ice conditions of navigation one month in advance.

The subdivisions are sucessfully used for generalized characteristics of ice conditions of navigation for large spatial-temporal scales - the NSR region (the entire route), the navigation period (the whole navigation period).

Such subdivison is performed for winter navigation in the western NSR region where sea transportation is all-year-round. Also, the present Report considers a possibility for obtaining generalized types of summer navigation for the winter NSR region on the basis of the methods for an objective analysis. We believe this approach can be extended over the whole zone of the NSR.

3 DEVELOPMENT AND IMPROVEMENT OF THE EMPIRICAL MODEL OF SHIP MOTION IN ICE

At the present time the empirical model of qualitative assesment of the difficulty of the ice navigation (the QAD model), which was developed by the authors more than 10 years ago, is extensively used. This model became the most popular "means" for calculation of operation indices: ice operation velocity (V_{io}), total consumption of time for fulfillment of a specific navigation operation (ΣT_i), estimates of navigation reliability along existing and prospective routes of shipping (Buzuyev, Fedyakov, 1983; Buzuyev, Likhomanov,1993). Interest in the empirical model of ice navigation was expressed by foreign specialists, in particular with reference to results of the first stage (Brovin, Fedyakov, 1994), the Japanese reviewer Dr. K.Kamesaki expressed his desire to get acquainted with the model more appropriately. We would point out that the model basis was formed by systematized data of special ice observations, made in the course of almost 20 years (1960-1980) on board icebreakers of different types in different regions and seasons of a year. In order to carry out these observations special methodology was developed (Instructions for observation, 1975). The main part of the initial data was collected in the Siberian shelf seas.

Therefore, strictly speaking, areas of application of this empirical model are limited by ice conditions and icebreaker types, for which data of the special observations are available.

The issue remains open, whether the model application is justified for the operation index calculation for the different ice conditions and types of icebreakers. It is clear, that for solving this problem and improvement of the model it is necessary to obtain the representative observation data for the ice conditions, which differ essentially from those of the Siberian shelf seas.

During a series of cruises of atomic icebreakers to the North Pole, early and late transit cruises along the NSR a vast amount of data was obtained on navigation peculiarities in the most complicated ice conditions. It should be especially noted, that the empirical model is used in practice of scientific-operative navigation support in the Western Arctic. Experience of this support testifies, that as a result of model "adjustment" to the peculiar ice conditions of the specific navigation, the calculation results are in good agreement with true course of operation (unfortunately some characteristics of the ice cover cannot be estimated objectively: snow amount, amount of hummocking, amount of rafting, presence of small-scale discontinuities, characteristics of strength etc.). For example, relation has been obtained for the winter period of the year 1985 for the case of piloting SA-15:

$$V_{io\ c} = 0.9\ V_{io\ a/i}$$

where $V_{io\ c}$ - caravan velocity,

$V_{io\ a/i}$ - self-contained velocity of the atomic icebreaker.

Results of generalization and analysis of the new observation data and desire to have more adaptable and universal "means" for objective estimates of the ice cover as a medium of the navigation served as prerequisites for the model improvement.

This work is carried out in the following directions. In the first place, the estimate of calculation precision of the operation indices (V_{io}, ΣT_i) was carried out for the cases of self-contained movement of the atomic icebreaker of the "Arktika" type in the multiyear (old) ice. In the second place, possibility of the model application for the calculation (V_{io}, ΣT_i) was justified not only for the icebreakers but also for transports.

Finally, investigations were started of possibility of application of the empirical model for the operation index calculation of the most complicated type of work in ice, namely of the icebreaker (or ship) movement by ramming. In this case, we assign to the operation indices determination of ice cover characteristics combination, under which this mode of operation should be fulfilled, relative extent of route in ice, when the movement by ramming is fulfilled with different probability and finally - the mean operation velocity at this route. Results of this work are discussed below.

In the first place, we shall discuss questions of the operation index calculation precision (V_{io}, ΣT_i) for the icebreaker of the "Arktika" type in self-contained navigation in multiyear (old) ice.

Initial data array collected during the cruises in the near-pole region in July and August (data for other seasons were not yet tested) encompassed nearly all possible combinations of the ice cover characteristics in the Arctic basin (table 3.1).It should be mentioned, that supplements were introduced in the wellknown methodology of the special ship observations (Instructions for observation, 1975). They were connected with navigation peculiarities in the Arctic basin.

In parallel with the traditional characteristics of the ice cover (International symbolic, 1984) presence of discontinuities in the ice cover -DIC (leads, fractures, cracks) in the navigation region and their orientation relative to the general course of theship's movement were fixed together with cases of movement across zones of decreased floe sizes.

The following navigation zones were marked out in the result of this work:

- Zone "Along" - orientation of DIC is mainly close to the ship's general course;
- Zone "Across" - orientation of DIC does not mainly coincide with the ship's general course;
- Zone "Age" - there are no DIC, the movement is carried out using the zones (incorporations) of decreased ice thickness background;
- Zone "Floe sizes" - the ship's movement is fulfilled across the zones (orientated as a rule) with the decreased floe sizes (number of floes less than 5 arbitrary units).

These peculiarities were taken into account during data processing (See Table 3.1)

The operation index calculations using the model (Buzuyev, Fedyakov, 1983) were fulfilled for all the zones with uniform ice conditions. When commenting on the obtained results (Table 3.2) one can assert, that the calculation precision is in the range obtained previously for the observation data for the Siberian shelf seas (Figure 3.1).

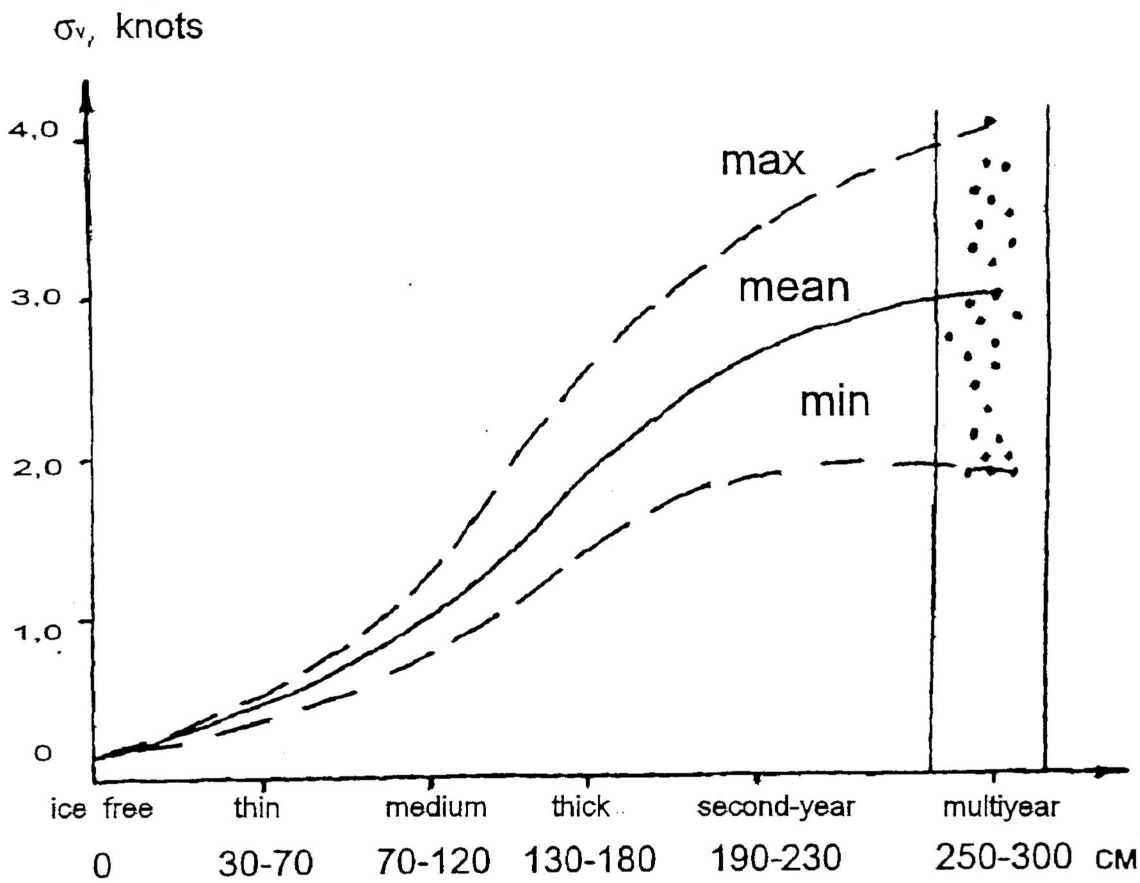
Table 3.1. The main elements of the database of the special ice observations fulfilled in July-August, 1987-1994, on board the "Arktika" atomic icebreaker (Frolov S.V., Makarov Ye.I.)

Characterictics of ice zone taking into account peculiarities of icebreaker movement		Number of zones/ total extent	For movement in ice									Range of thickness changes		Hummocks	Stage of melting	Compacting
			Total concentration					Multiyear ice concentration				Old	First-year			
			10	9-10	9	8;8-9	7-8	<3	3-5	5-8	>8					
Along	VII	39/153	-	30/ 119	8/32	1/2	-	6/28	4/18	13/48	16/74	210-360	105-190	0.5-3	0-3	0-2
	VIII	93/462	18/108	30/ 135	29/ 145	13/53	3/21	3/11	12/75	46/ 238	32/138	195-340	5-190	0.5-3	0-3	0-1.5
Across	VII	19/60	-	17/57	2/3	-	-	6/27	4/16	3/7	6/14	210-320	90-190	0.5-2.5	1.5-3	0-1
	VIII	135/711	41/284	53/ 261	35/ 141	5/24	1/1	3/13	19/ 102	65/ 379	49/221	200-350	5-190	0.5-3.5	0-3	0-1.5
Floe size	VII	33/135	-	17/72	15/55	1/8	-	6/27	9/48	9/35	9/46	210-345	110-190	0-3.5	1-3	0-2
	VIII	105/508	10/55	33/ 173	50/ 259	11/83	1/10	11/58	21/98	61/ 353	13/74	210-380	5-210	0.5-3.5	0-3	0-2
Age	VII	17/27	17/27	-	-	-	-	5/6	-	3/8	9/13	170-360	70-190	0.5-2	1-3	0-2
	VIII	7/22	7/22	-	-	-	-	1/10	-	1/1	5/11	210-270	95-190	1-3.5	0-1	0-0.5

Table 3.2. Comparison of the calculation results of the operation indices (V_{io}, ΣT_i, σ_v) for the atomic icebreaker of the "Arktika" type with the observation data during cruise in the arctic basin in the years 1987-1994 (July-August).

Characteristics of ice zone accounting for peculiarities of icebreaker movement	Observation data for multiyear ice concentration (arbitrary units)					Model calculation results data for multiyear ice concentration (arbitrary units)				
	<3	3-4.5	5-7.5	8-10	0-10	< 3	3-4.5	5-7.5	8-10	0-10
Distance, miles L	39.9	92.4	285.4	212.6	630.3	39.9	92.4	285.4	212.6	630.3
Time, hour ΣT	5	9.6	29.8	26.9	71.3	3.8	7.7	28.8	39.0	79.3
Velocity, V_{io}	8.0	9.6	9.6	7.9	8.8	10.5	12.0	9.9	5.5	7.9
σ_v	2.7	2.0	2.8	3.2	-	-	-	-	-	-
Distance, miles L	40.3	117.6	385.7	235.2	778.8	40.3	117.6	385.7	235.7	778.8
Time, hour ΣT	4.9	12.7	42.3	28.6	88.5	3.5	10.1	38.1	33.8	85.5
Velocity, V_{io}	8.2	9.2	9.1	8.2	8.8	11.5	11.6	10.1	7.0	9.1
σ_v	1.8	2.0	2.7	2.8	-	-	-	-	-	-
Distance, miles L	85.2	145.6	388.6	120.9	740.3	85.2	145.6	388.6	120.9	740.3
Time, hour ΣT	9.4	16.0	40.5	11.9	77.8	7.9	13.2	35.7	20.0	76.8
Velocity, V_{io}	9.1	9.1	9.6	10.2	9.5	10.8	11.0	10.9	6.8	9.6
σ_v	2.0	2.3	2.2	3.2	-	-	-	-	-	-
Distance, miles L	28.3	-	8	12.7	49.0	28.3	-	8	12.7	49.0
Time, hour ΣT	4.1	-	2.2	4.7	11.0	3.7	-	1	2.2	6.9
Velocity, V_{io}	6.9	-	3.6	2.2	4.5	7.6	-	8.0	5.8	7.1
σ_v	-	-	-	-	-	-	-	-	-	-

The empirical model of ice navigation can, therefore, serve as a reliable means for the operation index calculation of icebreaker movement in ice. It is well to bear in mind, however, that the calculation precision (variance of the calculated values (V_{io}, ΣT_i) depends on estimate precision of the sea ice characteristics (variance of the thickness, concentration, etc.) (See Fig. 3.1)



● observation data for the Arctic basin

Fig. 3.1. Variation of the mean square deviation of the ship's velocity (σv, knots) relative to the ice age (and the ice thickness)

Problem of possibility of adaptation for the active ice ship is doubtless of maximum interest.

The investigation was concerned with the ships of the "Norilsk" (SA-15) type and "Amguema" of the ULA-type.

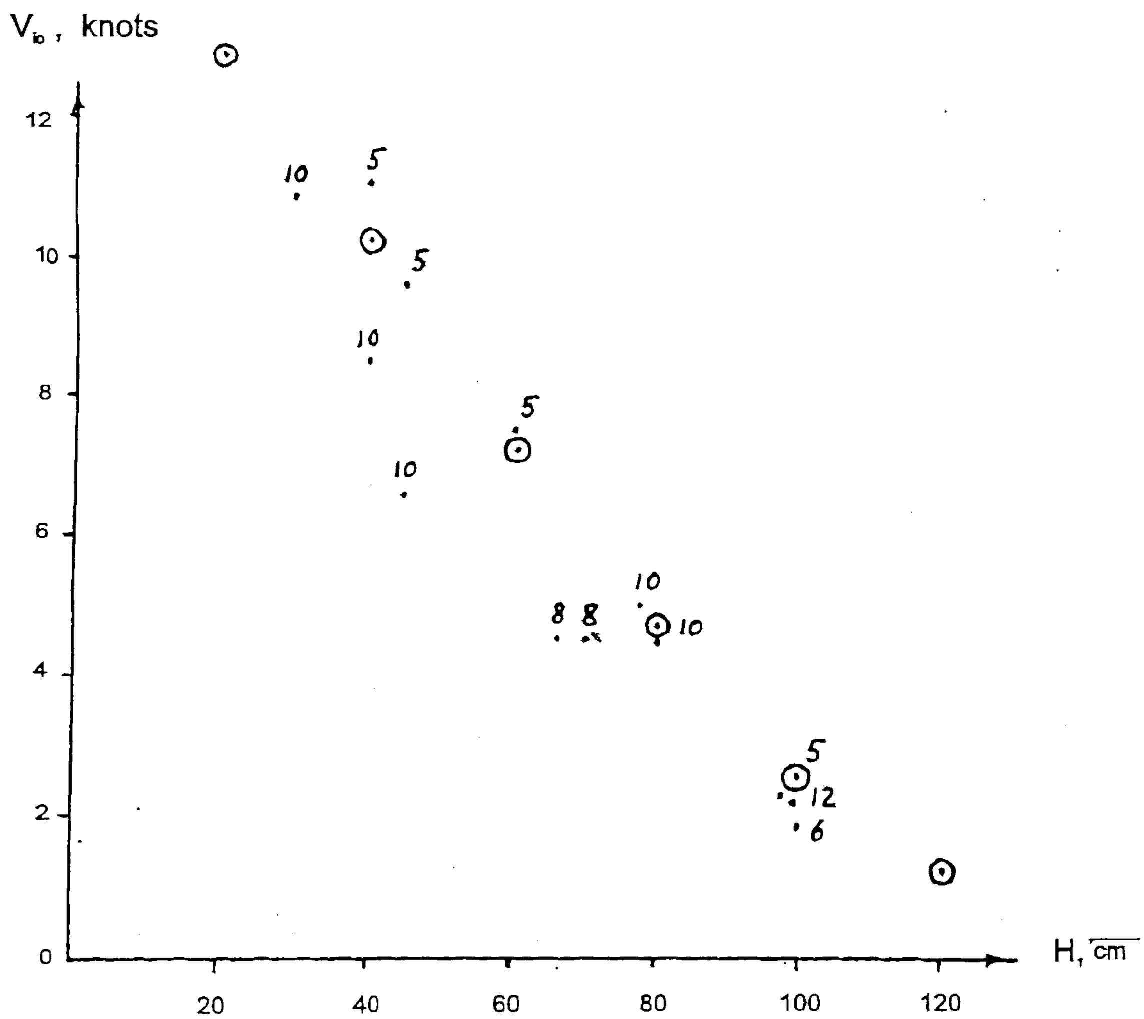
The SA-15 type ship is capable, under certain ice conditions, to carry out independent navigation and also to work actively together with the icebreaker as differentiated from the ships of that category ("Lena", "Amguema", etc.), which were in operation earlier and were oriented to the icebreaker piloting.

The model adjustment and its succeeding verification for the SA-15 type allowed us to formulate several concepts, which accounted for distinctions in calculation algorithm of the operation indices of the icebreakers and ships.

In the first place, new relationships were obtained for the empirical coefficient calculation, which were included in the main equation of the ice passage capability (Buzuyev, Fedyakov, 1983). Further on, attempts were made to take into account worse manoeuvre capabilities of the ships in comparison with the icebreakers. Finally some alterations were carried out in blocks describing the ice compacting. We do not dwell on more detailed description of the operation index calculation algorithm for the SA-15 ships, but it should be pointed out, that the calculation results, which were fulfilled for a wide range of ice cover characteristics in different regions and for different seasons are in a good agreement with the observation data. Such a correlation is presented, as an example, for the case of navigation in consolidated floating ice in winter (Figure 3.2) and in ice cake and small ice cake (including the lead behind the icebreaker) in the summer period (Figure 3.3).

More strict and universal approach should be used, therefore, for the operation index calculation of system "icebreaker-SA-15 type ship" instead of the previously obtained approximate relationships (Buzuyev, Fedyakov, 1983). Further still, the possibility of the operation index calculation for the SA-15 type ships for the given ice conditions allows one to develop criteria of efficiency of self-contained navigation or the piloting.

We should specially note, that along with the ship's velocity it is expedient to estimate the probability of hull damages on the basis of ice certificate recommendations and the calculations using the imitation model (Project I.1.2).



1 - ⊙ - model calculation
2 -●[10] - observation data (snow depth is given near dots)

Fig.3.2. Results of correlation of the V_{io} calculation (1) and the observation data for SA-15 ship navigation in consolidated floating ice (fast ice) of varions thicknesses (H, cm) in the winter period

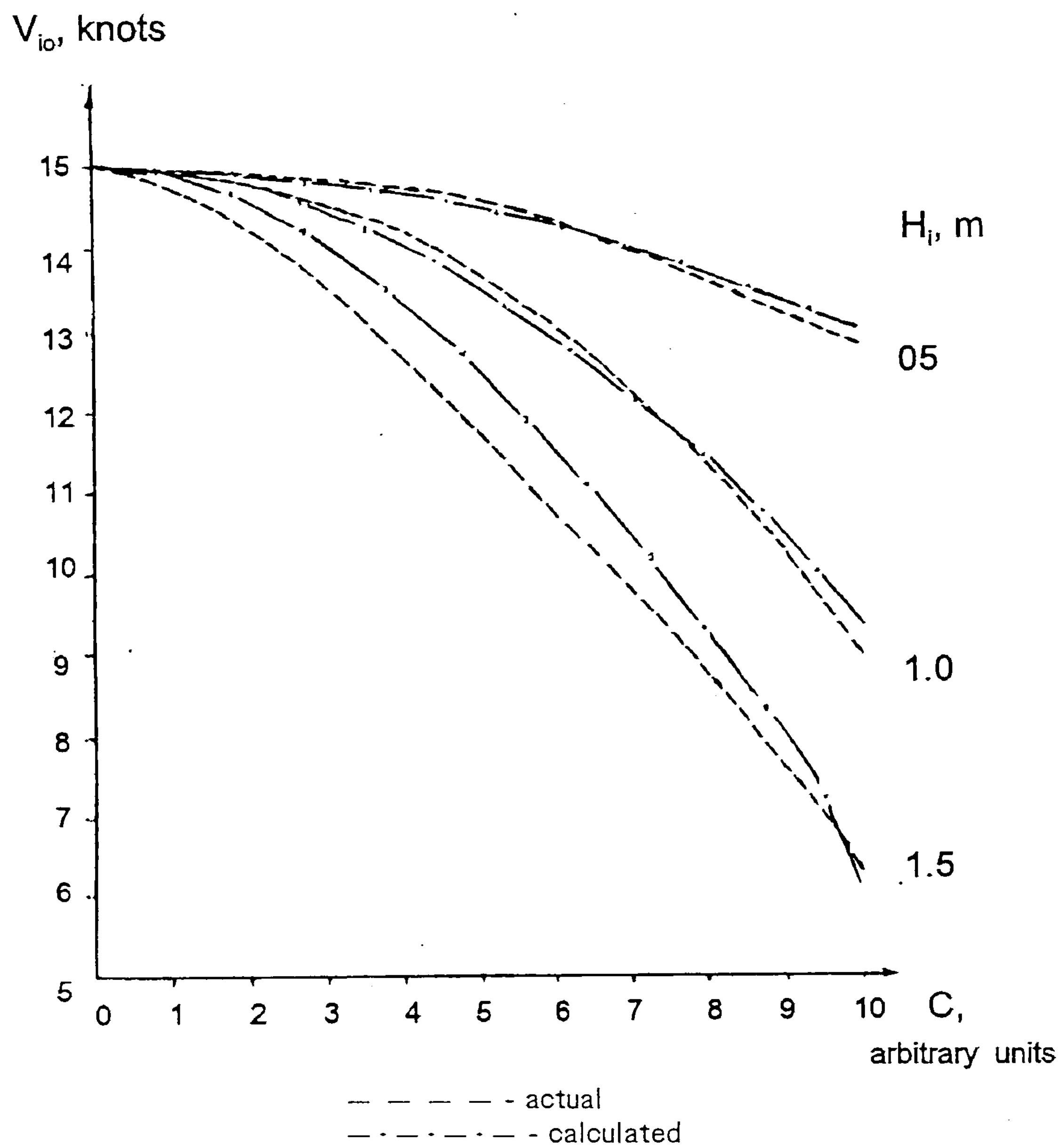


Fig.3.3. Influence of the ice concentration (C, in tenths) and thickness (Hi, m) on the SA-15 type ship velocity (V_{io}, knots) in the small floes, ice cake and small ice cake in the spring-summer period

Considerable opportunities appear, therefore, for the objective estimate of efficiency and safety of self-contained navigation and the icebreaker piloting of the ships (concentration, thickness, amount of hummocks etc.) In order to lend support to this thesis, we shall analyze preliminary results of subsequent work on the empirical model adaptation for the transport of active ice navigation (UL, ULA, different types). On the basis of observation data generalization regions of the limiting ice passage capability for a wide range of the main elements of particulars (length and width) and engine capacity (Figure 3.4). Ways are directed, therefore, for model use for expert estimates of the perspective ship operation indices.

In conclusion it should be noted, that model input parameters are practically nearly all the ice cover characteristics. Regularities of their influence on the ice operation velocity (V_{io}) are taken into account.

It is not improbable, that the empirical model may be used for the calculation of operation indices for ships and icebreakers with odd hull shapes. In this case, comparison studies should be carried out (as was done in due time by V. Kashtelyan, 1995) using the principle of "influence extent" of one or other characteristics on the operation indices of the "odd" ship in comparison with its progenitor with a classic hull shape.

In conclusion we shall consider principles of approach developed by the authors for the operation index calculation of the icebreaker (ship) work by ramming. There is certainly necessity for taking into special consideration peculiarities and efficiency of this work. Vastly irregular distribution of the ice cover characteristics, which determine ice navigation efficiency (thickness, amount of hummocks, etc.), is one of the main reasons of high event probability of conditions, when noninterrupted movement becomes impossible. The case in point is, of course, navigation in fast ice or very close floating ice (concentration exceeding 9/10).

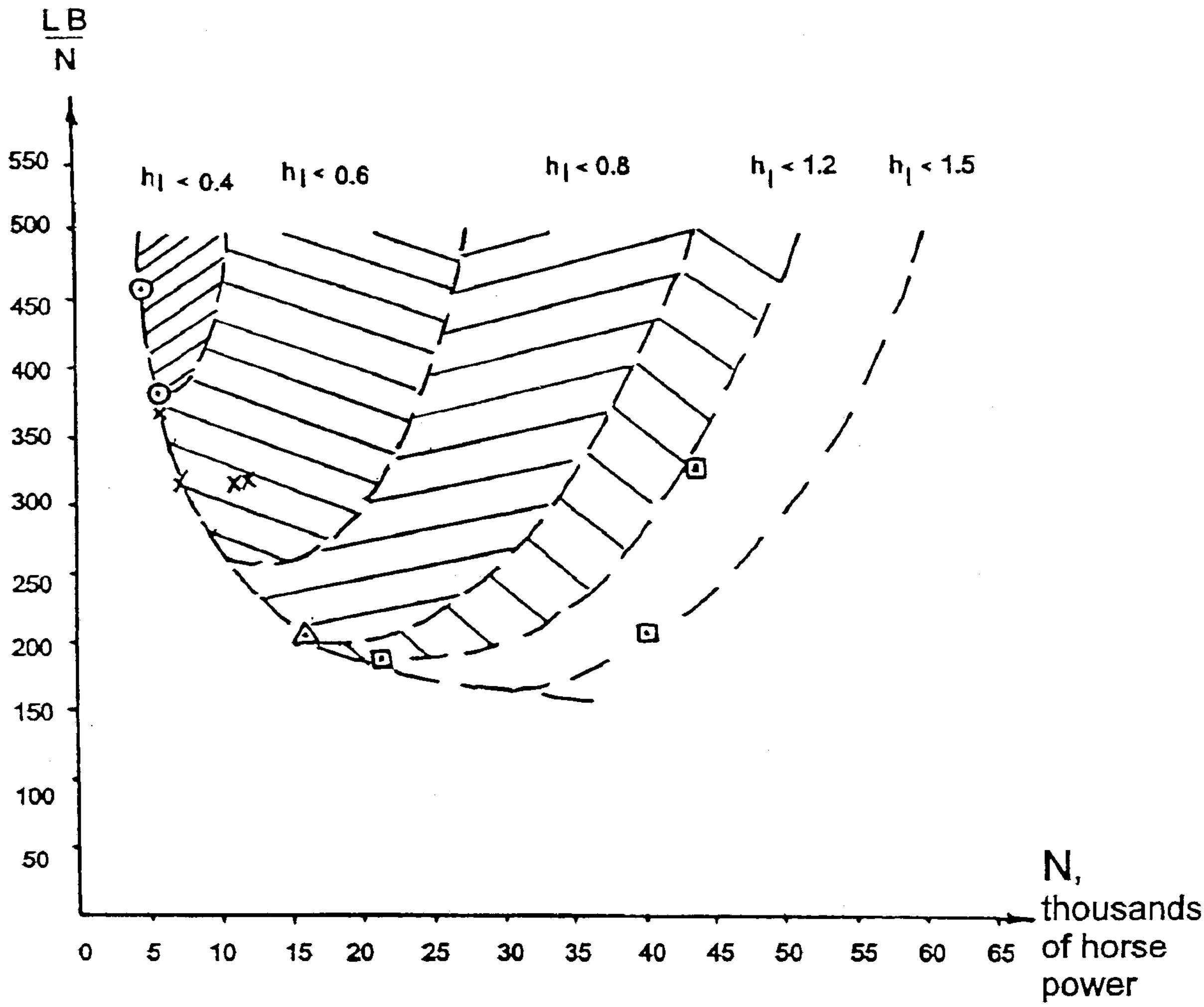


Fig.3.4. Relationship between the ship's particulars, the icebreaker engine capacity (N, thousands of horse power) and their ice passage capability (h_l) according to the observation data

⊙ - m.s "Volgoles", "Belomorskles",

* - "Pioner Moskwy", "Amguema", "D.Donskoy", "Samotlor",

Δ - "V. Bering",

☐ - "Norilsk", "Sevmorput", "Manhattan".

Unexpected forced stoppage in the ice (especially if the ship follows the icebreaker in the lead), necessity of reversing, when screw propellers work in the most unfavourable mode, and negative influence on all the icebreaker's systems, when hard ice isthmuses are breached by the ramming, serve as good reasons for avoiding, where possible, this type of ice navigation.

The ice conditions, when the icebreaker or transport are forced to convert from the uninterrupted movement to the episodical or continuous work by ramming may be formed under the broad range of combinations of the ice cover characteristics. Depending on specific navigation conditions contribution of different characteristics varies and often cannot be estimated. Efficiency of this type of work depends significantly on the experience, skill and facility of navigators, and these factors also cannot be objectively estimated.

As a consequence, in spite of great a body of observation data on the ice conditions, when noninterrupted ship movement becomes impossible, and on interaction processes of the ship and ice under these conditions, universal quantitative methods of determination of the operation indices have not yet been formulated for "interrupted" movement in ice. Observation results for a specific ship (icebreaker) for their work by a definite set of the ice cover characteristics are discussed at best (Rubanov,1991).

While proceeding to sowe of this very complicated problem, it is necessary to comment upon special features of our approach to its solution.

In the first place the random character of nearly all the factors, which cause necessity and efficiency of the work by ramming, explains the stochastic approach to the problem solution. Sufficiently representative observation data is necessary, therefore in order to make reliable conclusions and generalizations.

Further more, it is necessary to adequately define the "environmental" domain, for which search of the problem solution is carried out.

The observation data collected by now testify, that the variety of the ice conditions, under which the uninterrupted ship (or icebreaker) movement becomes impossible, can by convention be divided into two main parts:

1. The conditions, when the forced ship's stoppage (episodic or often) is caused by hull adhesion, ice compacting, intensive ice drift in the zone of the ship's movement.
2. The conditions, when the forced ship's stoppage is caused by significant ice thickness, which exceeds the ship's maximum ice passage capability. It should be pointed out, that included in the notion "ice thickness" is usually not only the ice thickness of natural growth, but also its increase due to dynamic factors (hummocking, rafting) and due to the snow cover (Gordienko et al., 1967). In other words, the case in point is ice "intensity" (Gudkovich, Romanov, 1970) or the equivalent thickness (Sergyev, 1978).

The second type of ice conditions is included in the present report because it is easier to quantify. This type is provided by very representative series of observation data. We expect, that results of our investigations will help us to transfer to the quantitative description of the operation indices for the first and more complicated type of navigation.

We shall thus consider the simplest case: - ship (icebreaker) movement in level consolidated floating ice: fast ice and big (vast) floes of drift ice, the amount of hummocking we assume to equal up to 1 arbitrary unit.

Rather irregular ice thickness distribution serves as a basis for the use of different statistical distribution for description of these characteristics (Buzuyev, 1968; Tunik, 1993). This peculiarity of ice cover structure is not usually accounted for. The mean ice thickness (expected value) is used both for scientific and practical problems. It is precisely in this way one proceeds at the present time while using the model for the calculation of V_{io}, ΣT_i, etc. In other words, the problem, what part of the route will be negotiated by ramming, and what is the probability of uninterrupted movement, is not discussed.

We shall use the observation data and published papers in order to outline the heart of the proposed approach for the problem solving.

The thickness distribution of the most typical for the NSR zone of first-year and second-year ice during melting stage were obtained during trials of the "Ermak" icebreaker (July 1974). Distribution general view is typical for the first-year and second-year ice and agrees with the previously obtained data (Buzuyev, 1968). We shall note one important peculiarity: the second-year and "older" ice have clearly pronounced distribution asymmetry (See Fig.3.5). As a consequence, the thickness having the maximum probability should be used instead of the mathematical expectation for the calculation of V_{io}, ΣT_i. In this case the calculation results are in better agreement with the observation data.

The mean ice operation velocity (V_{io}) with the probability of the work by ramming < 5% equals approximately 5 knots (Buzuyev, Fedyakov, 1981).

The subject of study is, therefore, influenced by the distribution peculiarities of the level ice thickness, which causes velocity variations up to the stoppage.

The minimum operation velocity ($V_{io\ min}$) with the probability of the work by ramming > 95%, when advance can be assumed by convention as efficient, equals > 0.1 knot (Kashtelyan et al., 1968). Precisely these minimum velocities were registered during lead breaking in fast ice of the second-year, and older ice in the presence of snow. Other value of $V_{io\ min}$ can be accepted undeniably as the minimum operation velocity for the icebreaker work by ramming, but the essence of the approach will not change.

In order to mark out the thickness domains, where the icebreaker work by ramming is carried out with the definite probability, we shall use results of statistical observation data processing. Analysis of this processing allowed us to formulate the following notions:

1. Route extent of the work by ramming or "potential" extent (L_{pe}) - is total length of section, where the ice cover thickness exceeds the limiting ice passage capability;

2. Time expenditure on the work by ramming for each zone with uniform ice conditions and on the whole for the sea route under consideration ($\Sigma T_i/\Sigma T$);
3. The probability of the work by ramming. It is one of the four characteristics, which is interpreted according to potential extent value (in parts of the total length, L_{pe}, %):

- non-stop movement ($L_{pe} < 10\%$);
- uninterrupted motion in combination with rammings ($65\% < L_{pe} < 10\%$);
- by ramming in combination with uninterrupted motion ($95\% < L_{pe} < 65\%$);
- by ramming only ($L_{pe} > 95\%$)

It should be noted, that the boundaries of the route extent with the work by ramming (L_{pe}) may be alternative (Rubanov, 1991), however, the differences are insignificant, and it does not change the essence of the approach to the problem solving.

It is necessary to calculate the probability exceeding of the ice thicknesses along the navigation route over the thicknesses for which non-stop movement is possible (for $V \approx 5.0$ knots) (Buzuyev, Fedyakov, 1981), in order to estimate the "potential" route extent, when the ship (icebreaker) is forced to work by ramming.

Having performed the calculations of probability mentioned above for the entire range of thicknesses, one can obtain a quantitative description of the extent of the most unfavourable route sections for navigation (Fig.3.5). Because specific variation limits are typical for different thickness values (Buzuyev, 1968), the range of relative extent variations, where movement by ramming will be fulfilled with varying probability, should be calculated in combination with the mean relative route extent itself (Fig.3.6). Furthermore, using this approach and specifying some confidence level, one can estimate velocity (or time expenditure) deviations from their mean values. One can judge, how it is important, using the following data. Preliminary observation data processing revealed that the variation range of the mean velocities (V_{io}) for the work by ramming only for the icebreakers of different types lies whithin the limits from 0.08 up to 3.50 knots.

For the cases, when the work by ramming is combined with uninterrupted motion, V_{io} = 1.1 - 6.6 knots.

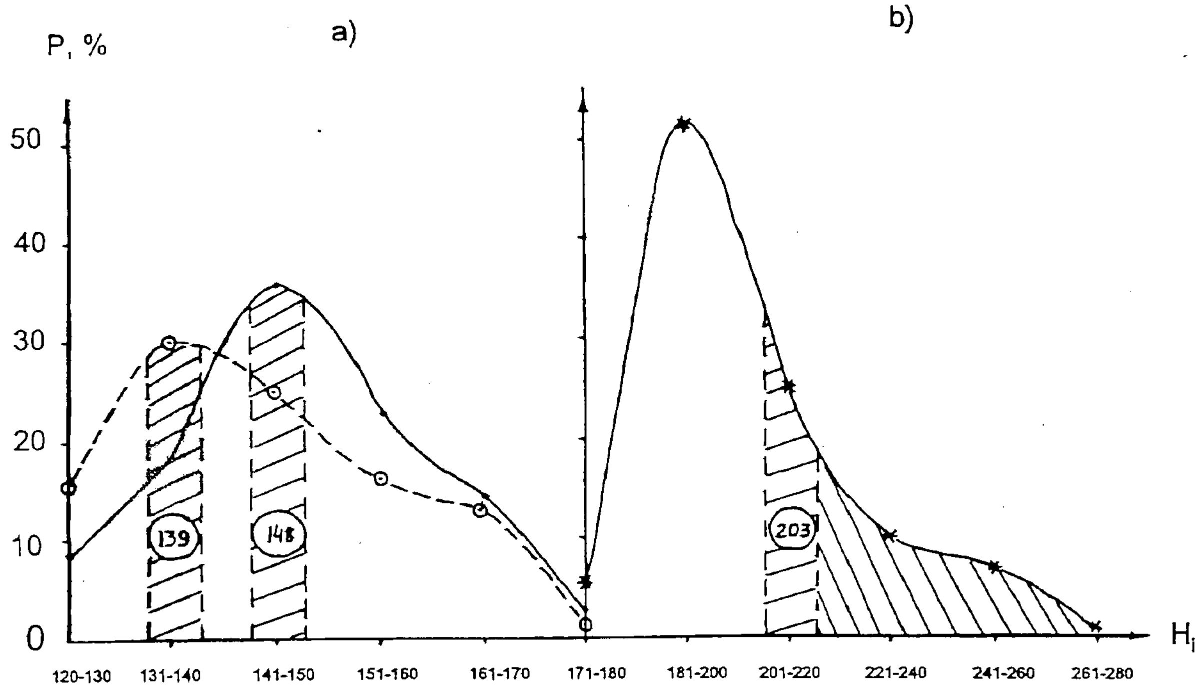


Fig.3.5. The ice thickness distribution for the ice of different age in the beginning of the melting stage (region III, 1974 (See Figure 1, Project I.1.2.) (using observation data of the Soviet-Finnish expedition)

O----O - Polygon 1, H= 139cm- thick first-year ice

O———O - Polygon 2, H=148 cm -thick first-year ice

——— - Polygon 3, H=203 cm -second-year ice

\\\\\\\\ - zone of the icebreaker work by ramming.

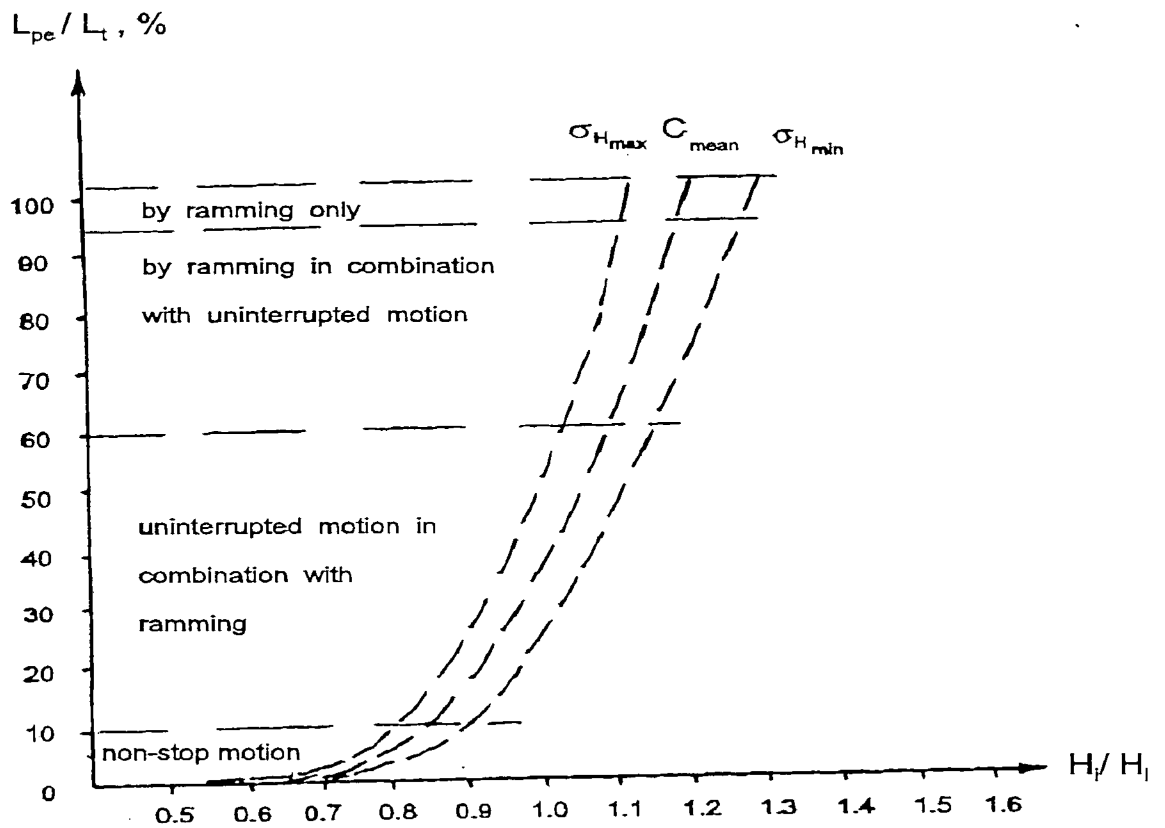


Fig.3.6. Calculation scheme of the mean (C_{mean}) and extreme (σ_{Hmax} and σ_{Hmin}) relative route extent with the work by ramming (L_{pe}/L_t) for the different thicknesses of the level ice (H_i/H_l)

In conclusion it should be noted, that a similar approach is developed also for the cases of icebreaker (ship) motion in the ice cover of the varying degrees (amounts) of hummocking. It was revealed by the results of the preliminary estimates, that the relative ice thickness (Rubanov, 1991) (H_i/H_l; where H_l- is the ice passage capability of this icebreaker), when the uninterrupted motion is possible (V_{io} > 5.0 knots), depends significantly on the amount of hummocks. When this characteristic equals 2 arbitrary units, $H_i/H_l \equiv 0.75$, for 3 arbitrary units - 0.60 and for 4 arbitrary units - $H_i/H_l \equiv 0.40$. Data systematization and searching for ways of model improvement as applied to the work by ramming are continued now for different combinations of ice cover characteristics.

4 DATABASE FOR SECURING OF CORRELATION DEPENDENCIES BETWEEN VESSEL DAMAGE PARAMETERS AND ICE CONDITIONS

The first program version of the database on vessel damages caused by ice and on conditions of their infliction has been prepared in the years 1994/95. Methodology of database creation was presented in the previous report. The first version of database management system allows one to solve the following problems:

1. Information input on the ice damages.
2. Information input on the conditions of the damage inflictions using both definite format and arbitrary narrative.
3. To scan the input and stored information on the ice damages and on the conditions of their infliction.
4. To edit the information on the damages.
5. To display graphically the information on the damages.

Further modification and extension of the system has been planned for the year 1995.

4.1 Composition of the program part of the database management system

All the program modules were written using the PASCAL programming language. Data are stored in the file Pildam.dat. The files f.dat, lidochka.dat, sf.dat contain text mask of the screen. The following procedures are included in the software:

1. SetCursor, NormCursor, NoCursor - Cursor management during the data input.
2. Zvuk - Sound signal management in case of error message output or warnings.
3. SaveScr - Integrity of screen image.
4. LoadScr - Loading of the screen image.
5. Dt - Symbol conversion into byte-code.
6. Code - byte-code conversion into the symbol.
7. Win - screen clearing.

8. Err, Err1, Err2, Err3, Err4 - error processing procedures.
9. War1, War2 - warning processing procedures.
10. MenuLine, MenuCol - Menu organization.
11. NK4 - main program.
12. Output_Rec - record output in the database.
13. Output_All_Rec - output of all the records in the database.
14. Find_Rec - record search in the database.
15. All_Pilf, Update_Rec, All_End_Rec, Structpd, Structod -record linking and decoding.
16. Podsk_uch, Pods_d - date input and check.
17. Podsk_cor1, Podsk_cor2 - data input according to their coordinates.
18. Podsk_1, Podsk_2, Podsk_3 - analysis of the input coordinates of the damages for their logical correspondence.
19. Rerd, Rdate, Rdam, Rdam0 - data input organization on damage types.
20. GrDam - mapping of the damages on the screen.

4.2 Database processing

The main menu of the database management system (Fig.4.1) allows one to fulfill the following functions:

- to obtain explanations on operations being fulfilled,
- to scan data on available outside plating stretching,
- to scan and to edit data on the damages,
- to put in data on the damages and on the conditions of their infliction.

Scanning of the database begins with the data input on a vessel (ship's name, name of the leading ship of this series), number of zones of navigation between input dates of inspections (Fig.4.2). Then comes request on the data input on the damages (Fig.4.3). Coordinates of quadrangle angles of damage region should be put in coordinate system of the outside plating stretching together with type and parameter of the damage.

It is possible to obtain data on the damages for a specific ship or for ship series (Fig.4.4). Before the data output information on available ship can be requested (Fig.4.5). Tables of the data on damage characteristics are presented in Fig.4.6 and 4.7. Information on the navigation zones in the period between docking is put out as shown in Fig.4.8. Check of the input information can be fulfilled with a help of information mapping (Fig. 4.9).

4.3 Conclusions

Presented description of the database management system on the ice damages and on the conditions of their infliction is only a part of work, which should be carried out for calculation of resulting statistical indices. Use of the database consists of two stages:

1. Data on the damage collection and input. It is a labour consuming and expensive work. Technical archives of steamship companies are the main source of this information. Contracts should be signed with these companies for information presentation.

2. Data processing and determination of statistical parameters of the damages according to ship series, to the navigation zones of the NSR etc. Calculation results can be used for estimating navigation difficulties in different zones of the NSR and for insuring ships and cargoes and to prepare a normative base for projection of ship hull constructions of ice ships and icebreakers.

Help	Scanning of DB on stretching of OP	Scanning and editing of DB on damages	Data input	Options	Data processing

File does not exist!
Should a new file be opend? (Y/N)

Fig.4.1. The main menù of the database management system

Help	Scanning of DB on stretching of OP	Scanning and editing of DB on damages	Data input	Options	Data processing

Ship's name	:	Akademik Fedorov
Name of leading ship of this series	:	Akademik Fedorov
Number of navigation zones	:	2
Date of inspection	:	17.10.94.
Date of previous inspection	:	13.09.93.

Date input in <.>

Fig.4.2. Data input on ship and date of inspection

Help	Scanning of DB on stretching of OP	Scanning and editing of DB on damages	Data input	Options	Data processing

Coordinates of the first damage	x1,y1	:	78.9	10.9
	x2,y2	:	78.0	19.8
	x3,y3	:	104.0	19.7
	x4,y4	:	104.0	11.0
Damage type		:	2	
Damage extent		:	60	

Fig.4.3. Data input on one damage

Help	Scanning of DB on stretching of OP	Scanning and editing of DB on damages	Data input	Options	Data processing

1 - Data scanning for the specific ship
2 - Data scanning for ship of the specific series

Press <F1> in order to get information on data available for ships

Fig.4.4. Menu of the data scanning on damages for ships or ship series

Help	Scanning of DB on stretching of OP	Scanning and editing of DB on damages	Data input	Options	Data processing

Name of the leading ship of this series:	Ship's name:
Akademik Fedorov	Akademik Fedorov
Stanislavskiy	Vasiliy Kachalov

Press any key to continue

Fig.4.5. Information on data available in the database on damages of the specific ships

Ship's name : Akademik Fedorov
Name of the leading ship of this series : Akademik Fedorov

Date of inspection:17.10.94 Date of previous inspection: 13.09.93

Damage coordinates								Damage type	Damage extent
x1	y1	x2	y2	x3	y3	x4	y4		
60.0	10.2	60.0	15.1	07.0	11.0	87.0	5.0	2	45.00
20.0	8.0	20.0	10.0	34.0	12.0	34.0	7.0	2	70.00

Press <END> for data scanning on damage locations
Press any key to continue
<TAB> - escape in editing mode

Fig.4.6. Data output on the damages of "Akademik Fedorov"

Ship's name : Vasiliy Kachalov
Name of the leading ship of this series : Stanislavskiy

Date of inspection: 17.11.80 Date of previous inspection:12.12.78

Damage coordinates								Damage type	Damage extent
x1	y1	x2	y2	x3	y3	x4	y4		
19.0	9.0	19.0	13.0	31.0	14.0	31.0	10.0	2	60.00
24.0	9.0	24.0	13.5	32.0	14.0	32.0	10.0	4	100.00
33.0	10.0	33.0	15.0	38.0	15.0	38.0	10.0	4	60.00
56.0	10.0	56.0	14.0	62.0	14.0	62.0	10.0	2	100.00
42.0	11.0	42.0	17.0	55.0	17.0	55.0	11.0	2	150.00
63.0	10.0	63.0	17.0	72.0	17.0	72.0	10.0	2	200.00
63.0	15.0	63.0	16.0	72.0	16.0	72.0	15.0	10	40.00
64.5	12.0	64.5	13.0	74.5	12.5	74.5	10.0	2	40.00
80.0	9.0	80.0	13.0	92.0	10.0	92.0	6.0	4	60.00

Press <END> for data scanning on damage locations
Press any key to continue
<TAB> - escape in editing mode

Fig.4.7. Data output on the "Vasiliy Kachalov" damages

Ship's name : Vasiliy Kachalov
Name of the leading ship of this series : Stanislavskiy

Date of inspection: 17.11.80 Date of previous inspection:12.12.78

	Navigation zone	Period of navigation		Duration of the movement (hours)
		start	end	
1	Dikson-Chelyuskin	01.06.80.	01.11.80.	700

Press <HOME> for data scanning on coordinates of damage infliction
Press any key to continue
<TAB> - escape in editing mode.

Fig.4.8. Information on navigation zones between dockings

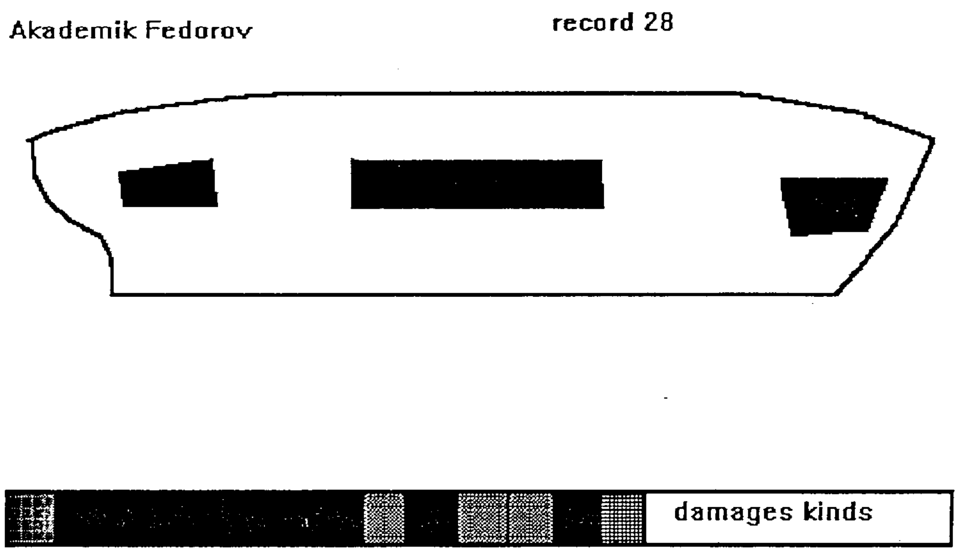


Fig.4.9. Graphic image of the registered damages on the stretching of the outside plating

REFERENCES

"Instructions for ice observations from ships" (1975), edited by Churkina N.A., L., AARI funds, 67 p.

"International symbolic for sea ice charts and sea ice nomenclature", L., Hydrometeoizdat, 1984, ed.by B.A. Krutskikh, 56p.

Brovin, A., Fedyakov, V. (1994): "Description of the empirical-statistical methods for a quantitative assessment of difficulty of ice navigation (the "QAD" model)", INSROP, Project 1.5.5, section 3.

Brovin, A.(1994 a): "The Concept for the Evolvement of Specialized Ice Information for Shipping in the Arctic", Proceedings of IAHR-94, pp. 941-949.

Brovin, A.I., Yulin, A.V. (1990): "On the problem of marking out of anomality extent gradations in series of hydrometeorological elements",L., Tr. of AARI, v. 423, pp. 84-88.

Brovin, A.I., Yulin,A.V.,(1994): "Specialized ice forecasts for navigation along the NSR", INSROP, Project, I.6.1., Section 5.

Brovin, A.I., Yulin,A.V.,(1995): "Specialized ice forecasts for navigation along the NSR", INSROP, Project, I.6.1., Section 5.

Brovin, A.I.(1994 b): "Main directions of the development of specialized ice information for the organization and planning of shipping along the NSR",INSROP, Project I.5.5, Section 1.

Buzuyev, A.Ya. (1968): "Some statistical regularities of multiyear ice thickness distribution", Tr. of AARI, v. 284, pp.76-83.

Buzuyev, A.Ya., Fedyakov V.Ye.(1983): "A comprehensive allowance for the characteristics of the ice cover state in the development of recommendations for navigation". In: Questions of enhancing the strength and reliability of sea port constructions", Soyuzmorniiproject, M., Transport, pp.89-97.

Buzuyev, A.Ya., Gordienko P.A. (1976): "Quantitative estimate of navigation difficulty in presence of ice", L. Hydrometeoizdat, Meteorology and Hydrology, No 9, pp. 60-66.

Buzuyev, A.Ya., Likhomanov, V. (1993): "Division into zones of the Northern Sea Route by difficulty and safety of navigation", POAC'93, Hamburg, vol. 1, pp. 393-402.

Buzuyev, A.Ya.,Fedyakov, V.Ye.(1981): "Ice conditions variability on navigation routes", Meteorology and hydrology, No 2, pp. 69-76.

Egorov,A.G., Spichkin, V.A. (1990): "Uniform ice regions of the north-eastern part of the Kara sea', L. Hydrometeoizdat, Tr. of AARI, v. 423, pp. 6-14.

Gorbunov, Yu.A., Karelin, I.D., Kusnetsov, I.M.,Losev,S.M., Sokolov,A.L. (1983): "The foundations of physic- statistical methods of ice forecasting and simulations for the arctic seas up to 30 days in advance", L., Hydrometeoizdat, 288 p.

Gordienko, P.A.,Buzuyev,A.Ya.,Sergyev, G.N. (1967):'Ice cover investigation as an environment of navigation", Problems of the Arctic and Antarctic, v.27, pp. 93-104.

Gudkovich, S.M., Romanov,M.A. (1970): "Calculation methods of ice thickness in the marginal seas in winter period", Tr. of AARI, v. 292, pp.4-38.

Gudkowich, S.M. et al. (1972): "The foundation of longterm ice forecasting methods of the arctic seas", L., Hydrometeoizdat, 348 p.

Kashtelyan V.I. (1995) "Estimate of ice capacities of icebreakers differing by hull shapes taking into account navigation in different ice conditions", Tr. of Nishegorodskiy Politechnical Institute (in press)

Kashtelyan V.I. et al. (1968): "Ice resistance to ship motion", Sudostroyenye, 238 p.

Kirilov, A.A., Spichkin, V.A. (1968): "Seasonal course of ice coverage and possibility of its forecasting", L., Hydrometeoizdat, Problems of the Arctic and Antarctic, v.29, pp.14-18

Krutskikh, B.A. (1979): "The main regularities of arctic seas conditions variability in natural hydrological periods", L. Hydrometeoizdat, 92 p.

Makarov, E.(1994): "Operational information on natural conditions", INSROP, Project I.2.1.

Rubanov, A.N. (1991): "Icebreaker motions in severe ice conditions", Problems of the Arctic and Antarctic, v. 65, pp.153-156.

Sergyev, G.N. (1978): "Usage of data on ice thicknesses for estimate of ice passage capability of ships", Problems of the Arctic and Antarctic, v. 54, pp. 52-56.

Spichkin, V.A. (1987): "Determination of criterion of great anomaly", L., Tr. of AARI, v. 402, pp. 15-19.

Tu,J., Gonsales, R. (1978): "Principles of pattern recognition", Moscow, 411 p.

Tunik, A. (1993): "Trafficability in the Arctic Ocean in Summer", St.Petersburg, Seminar Neva '93, 14-17 Sept.

Vise, V.Yu.(1944): "The foundations of longterm ice forecasts", Moscow, Publ. House Glavsevmorput, 273 p.

Yeliseeva, I.I., Rukavishnikov, V.O. (1977): "Grouping, correlation pattern recognition", Moscow, Statistics, 143 p.

Yulin, A.V. (1987): "Investigation of variability of ice massifs of the East Siberian sea using the cluster analysis method", L., "Actual problems of oceanography", p.98.

PART II

GENERALIZATION AND ANALYSIS OF STATISTICAL DATA ON HULL DAMAGES TO ICEBREAKERS WORKING ON THE NORTHERN SEA ROUTE

CNIIMF - March 1995

INTRODUCTION

As it follows from the multi-year experience of the operation of the Russian arctic fleet on the NSR the icebreakers escorting cargo ships along sections of the Route, providing for the passage of ships to ports, cargo handling onto the fast ice and other works suffer a considerable number of ice damages. Not infrequently the icebreaker ice damages are so serious that ships have to be withdrawn from service for repair in the course of navigation and this results in failure to adhere to the time schedule for delivery of cargo and the increased risk of heavy ice damages to cargo ships which could cause cargo degradation and loss. Therefore it seems very important on the basis of data on the operational damages of icebreakers to perform the assessments of the probability of suffering heavy ice damages while working in ice on the NSR and the comparison of these results with corresponding values of icebreaking cargo ships. This paper deals with the solution of these problems.

5 GENERALIZATION AND ANALYSIS OF STATISTICAL DATA ON HULL DAMAGES TO ICEBREAKERS WORKING ON THE NORTHERN SEA ROUTE

5.1 Generalization and analysis of ice damages to hulls of ships working on the NSR

5.1.1 General analysis of the character of ice damages to icebreaker hulls

Despite the fact that a number of icebreakers securing each year the arctic navigation does not exceed 3-4% of the total number of ships taking part in the navigation the icebreakers suffer for 10-15% of the totalamount of ice damages to the arctic fleet, fig.1.

Hull ice damages in the form of permanent deflections of shell plating and framing (bulges and dents) are concentrated on icebreakers mainly below the belt of changeable waterlines. Ice damages on icebreakers are mostly located in bottom, in bilge strakes, amidship and in hull areas transitional intermediates to the forebody.

Depending on the strength of hull elements (shell plating and framing) in a certain specific region, number of damages (bulges corrugation, dents) is differently distributed between the bilge strake, bottom, middle hull portion and bow area.

Shell plating damages (corrugation and bulges) of the flat and bilge bottom areas are observed over the whole hull length, but the largest number is concentrated 0.4L - 0.65L from the forward perpendicular, where the flat bottom surface becomes larger and the thickness of the shell plates on the majority of icebreakers is 26 mm or less. Over the intermediate area the corrugation within 10 mm is also observed in plates 20-25 mm thick and less.

A certain increase of plate damages within 0.80 - 0.95L can be explained by the sternward mode of operation and by the icebreaker turning manoeuvring during the breakage of the fast ice. The bottom framing (floors, stringers and longitudinal girders) is damaged over the whole length of the bottom, but the greatest number of damages are located in the intermediate and middle areas, the flat bottom being more damaged at the boundary between these areas.

The high rigidity of the icebreaker hull framing (frames, floors, stringers) in combination with small thickness of their walls (11-13 mm) leads to the fact that dents (detected in bottom and bilge strake) are caused principally due to the loss of stability of the wall sections adjacent to plating in the zone where ice loads are applied. Dents in the hulls just as bulges of icebreakers (unlike cargo ships) are located in the middle and transitional hull areas.

The prevalence of a certain type of hull damages depends on many factors: relative strength of separate structural elements, age of icebreaker (degree of the construction wear), purpose of an icebreaker and the compliance of its conditions of work in ice with the specification conditions.

As an example, the character of ice damages of different types of icebreakers working on the NSR is described below. On the oldest linear icebreakers of *Moskva* type built in the sixties (L x B x T = 112.4 x 23.5 x 10.5 m; D = 13000 t) ice damages were detected in bottom and bilge strakes practically over the whole length of ship. However the largest number of ice damages (up to 63%) were found in relativelly weak bottom grillage of the middle hull portion (transverse framing system, a_s = 800 mm, longitudinal rib-angle pieces 200 x 125 x 11, σ = 4000 kg/cm^2, floor and stringer thicknesses - 11-13 mm). Maximum permanent structural deflection f_{max}=100 - 140 mm. Dents are accompanied by bulging of floor wall sections and of bottom stringers at a height of 300-600 mm from the sheet plating.

On more recent LL2 category icebreakers of *Ermak* type built in 1974-76 (L x B x T = 130 x 25.6 x 11 m; D = 20000 t, N_s = 36000 h.p.) the character of the hull ice damages is as a whole the same except a relatively lesser extent of bottom structure damages in the middle portion and the occurrence of ice strake damages (*Admiral Makarov*, 1976 and 1989). Ice damages of the bottom grillage in the forebody of icebreakers (stiffeners 225 x 90 x 12; σ = 3400 kg/cm^2, b = 600 mm) are characterized by the predominance of dents over bulges and absence of corrugation (plating thickness forward of spacing 95 is 34-45 mm, σ = 2600 kg/cm^2). Framing dents both in the forebody and amidships (f_{max} = 100 - 150 mm) are of local character and accompanied by bulging of floor and stringer areas adjacent to the plating (t = 12, 13 mm) at a height of up to 450 - 500 mm, fig. 3 and 4. Sternward of spacing 95 (a_s = 800, b = 900 mm) bulges are observed over the whole flat section of the bottom.

Areas of bottom and bilge sections affected by ice damages on the above icebreakers reached 100 m^2 and over even after the first arctic navigations.

Summarizing the information on ice damages of linear icebreakers built in the sixties and seventies one may note that the most extensive damages of the bilge strake affect transitional area and the middle portion of the hull up to the midships ($\approx$ 0.25 - 0.5L). Bottom strakes are damaged over the whole length of the flat bottom. Despite the comparatively small sizes of permanent deflections $f_{max} < 150 - 180$ mm, dents in the bilge and bottom framing belong to the most labour-consuming as to the repairing work, because they are accompanied by plastic bulging of wall sections made of high-strength steel adjacent to the plating, floors, web frames and brackets at a height of up to 400 - 500 mm from the shell plating fig. 2, 3 and 4. For their repair it is necessary to cut out not only shell plates, but also deflected wall sections, to weld in new thicker plates, to fix additional strengthenings etc. This results in considerable expenditures for repair after each.arctic navigation.

A lot of hull ice damages, though to a lesser extent than on icebreakers of *Moskva* and *Ermak* types, can be observed on shallow draft (T = 8.5 m) LL3 category icebreakers of *Kapitan Sorokin* type (L x B x T = 121 x 25.6 x 8.5 m; D = 15000 t; the first icebreaker was built in 1977). Just as on other linear icebreakers the bulk of ice damages is concentrated in bilges (under the tube of the air bubbling system) and in adjacent bottom strakes. Major number of the structural ice damages are detected in the transitional forebody and midbody hull areas (fr. 70-140). Framing damages (dents) are accompanied by local bulging of the wall sections adjacent to the shell plating (of longitudinal bottom ribs - 180 x 10, floors, bilge brackets δ = 10 mm, 12 mm; σ = 3000 kg/cm^2; fig. 5 and 6).

It should be noted that on these icebreakers a better structural solution was found for bottom grillage (combination of longitidinal and transverse framing,use of high-strength steel) than on icebreakers of *Moskva* type. Therefore despite the fact that these icebreakers work mostly in shallow waters and estuary stretches of rivers, the extent of ice damages to their hulls is substantially lower and embraces principally bottom and bilge areas situated forward of the midship. Particular features of hull damages to icebreakers of *Kapitan Sorokin* type are bilge damages in the form of dents accompanied by the tumbling of longitudinal ribs placed along the bilge inclined to the shell plating (fig. 5 and 6).

Ice damages to icebreakers intended for operation in river mouths and port water areas (category LL4) are as a whole similar to those of linear icebreakers, the difference being that the major part of damages on port icebreakers is concentrated directly in the ice strake and this fact can be apparently explained by the use of these icebreakers in heavier ice conditions to escort ships along the NSR.

5.1.2 Determination of the ranges of changes in the icebreaker hull ice damage sizes

Systematization of the materials on ice damages to icebreaker hulls has shown that most damageable areas of the icebreaker hull are bilge and the adjacent bottom belt where, as a rule, damages of the largest size are detected.

Analysis of the size of damages has shown as well that largest values of dents and bulges do not exceed those observed on icebreaking cargo ships (category ULA) working on the NSR. Sizes of damages of linear icebreakers depend not only on structural characteristics and the degree of wear of structures, but to a greater extent on the ice conditions under which the icebreaker happens to be operating. It should be noted however that these conditions may vary very much not only during the navigation, but even during one voyage and within short periods of time. Therefore it seems not possible to classify damages by the conditions of ice situation and area of navigation and to establish between them a quantitative relationship.

Attempts to carry out such analysis during the full-scale experiments on icebreakers in the Arctic as well as to compare data of observations and ship's log records about the ice situation and the mode of movement of icebreaker with the results of inspection of bottom structures in docks or with the Register reports do not lead to the desirable results in this direction.

Ranges of the variation of ice damage sizes of hulls of different types of the linear icebreakers working at present on the NSR differ insignificantly. Average values of bulges of bilge strake plating amount to 25-35 mm with maximum values of 70-85 mm when, as a rule, cracks and leakages occur. Average depth of dents is 60-70 mm, while maximum values of separate dents may reach 140-180 mm.

Extent of dents in the longitudinal direction (l) may reach 3.5-4 m, average values being 2-2.5 m. Separate dents may be 1.5-2 m wide, see fig.7. However principally the width of dent is approximately one half as large as its longitudinal size.

Characteristics of the distribution of dents over the length and width of icebreaker hulls are shown in figs. 7-13. As noted above framing damages (dents) on our domestic icebreakers arise, as a rule, because of local bulging of framing wall sections adjacent to the shell plating.

On icebreakers *Ermak*, *Admiral Makarov*, *Kapitan Khlebnikov* and icebreakers of *Moskva* type, measurements of the parameters of the bulging area of framing walls and deflections of plating under the framing were made by the Far Eastern Polytechnical Institute.

Processing of these results has shown that at ratio of framing wall thickness (of stringers, floors) and panel thickness (a_s) isolated out of the wall by stiffening ribs being equal to 0.014-0.016 the average height of wall affected by a bulge is about 540 mm and if this ratio is about 0.02-0.025 it decreases down to $\approx$ 300 mm. At values of a 350 mm and a depth of bulge exceeding 40 mm, cracks in the framing occur. Maximum heights (from the shell plating) of the wall areas affected by such deflections are about 600 mm (at wall thickness of 11, 12 mm). This analysis confirms the conclusion we have obtained earlier while analysing similar damages to icebreaking cargo ships that for the reliable work of framing walls the ratio t / a_s should be taken not less than 0.025-0.03.

5.2 Probabilistic assessment of the occurrence of ice damages to hull structures of icebreakers operating on the NSR

5.2.1 Evaluation of the frequency of hull structure ice damages in different hull areas

As experience shows, due to the specific character of the work of icebreakers under heavy ice conditions, the level of damageability of their hulls is twice as high as that for icebreaking cargo ships, though, with all that, sizes of ice damages are considerably smaller. The analysis of the results of operation of the domestic arctic fleet shows that by contrast to transport ships the most damageable area of the icebreaker hull is not the forebody, but the middle portion of ship and the intermediate hull section.

Distribution of the frequency of ice damages between different areas of the underwater part of hull depends on a number of factors including conditions of work in ice and the hull shape. So, on light draft icebreakers and on those operating mainly in shallow water areas of the NSR the damageability of the flat bottom sections adjoining the bilge is relativery high. On the average, light draft icebreakers of *Kapitan Sorokin* type, the smooth lines shape of which increases the probability of ice getting under the hull, receive two or more dents for a navigation. At the same time, the icebreakers working mainly in deep water areas (for instance, icebreakers of *Ermak* type) have higher frequency of damages of side and bilge hull sections.

Characteristic distributions of the ice damage frequency over the underwater part of icebreaker hulls are given in figs. 10-13.

As one can see from figures, the hull damages of icebreakers most frequently occur in the middle part and in the transitional area. This may be attributed to the specific character of the work of icebreaker as a leading ship breaking a channel through heavy ice isthmuses as well as to the result of a repulsed impact. This hull area is affected by 50-60% of all damages occurred.

On port icebreakers with LL4 strengtheings and curvilinear lines (of *Vassily Pronchishev* type built at the beginning of sixties) the level of damageability of the area in question is close to values which characterize linear icebreakers, fig.13. However, besides the bottom and bilge, the zone of ice damages extends also to the ice strake. Distribution of the frequency of damages over the hull width of icebreakers is given in fig.7 and 9.

5.2.2 Comparative evaluation of the probability of heavy ice damages to underwater hull portion of icebreakers and icebreaking cargo ships

Summarizing results of the analysis of the character and sizes of ice damages of hull structures of icebreaking cargo ships and icebreakers working on the NSR one can notice a number of general rules and close quantitative characteristics of these groups of ships. Among these common features are the following:

- as to the length, the major part of ice damages occur in the midship areas and in those situated toward the bow of the middle; for cargo ships - over the whole forebody including forepeak, for icebreakers - in the transitional hull area fowards the forebody. In these areas 60-80% of all hull damages are concentrated;
- most frequently hull bilge areas and adjacent bottom plating belts are damaged;
- maximum sizes of dents caused by the ice impact are moderate enough-their depth does not exceed 200 mm the extension being 2 x 4 m;
- dents in the hull are mostly accompanied by a local deflection of the framing wall areas supporting the outer shell plating near dents.

Results of the comparative evalution of the probability of ice damages in the form of dents are shown in graphs, fig. 14, which represent functions $F = 1 - p$, where p - probability of the occurrence of a dent with a given bending deflection (f).

Bottom hull section (including bilge) in the middle and transition (towards the bow) ships areas were considered. While constructing curves, use was made of the results of processing of data on ice damages of ULA icebreaking transport ships (middle curve) and of icebreakers of LL3, LL2 classes, The upper curve is related to icebreakers of *Ermak* type. As one can see from graphs shown in fig. 14, the probability of heavy ice damages accompanied as a rule by water leakage (f > 100 mm) is sufficiently high both for icebreaking cargo ships and for icebreakers. Up to 20 and more per cent of dents in the bottom and bilge have bending deflection of 100 mm and over. Therefore in the design of ships of the active ice navigation and of icebreakers intended for sailing along the NSR, double structures (double sides or appropriate double bottom) should be provided in these areas.

CONCLUSION

The analysis of damages to arctic icebreakers justifies drawing the following conclusions:

1. Frequency of icebreaker damages substantially exceeds frequency of the damages to icebreaking cargo ships working on the Northern Sea Route.

2. Major number of icebreaker ice damages fall upon the intermediate area and the middle part of hull.

3. Ice damages to linear icebreakers are concentrated mainly in bilge strakes and in the flat bottom.

4. Greatest number of damages (bulges) are observed in the areas where the thickness of plating is less than 25 mm. Deepest dents do not exceed 200 mm.

5. Probability of the occurrence of heavy ice damages (150-200 mm and over) does not significantly differ for icebreakers and icebreaking cargo ships and is rather high (15-20% of dents are 100 mm deep and more). Therefore in the design of these ships it is necessary to provide double sides and double bottom in the area of cargo holds.

6. Main type of ice damages of the icebreaker hull are dents in the vicinity of which bulging of framing wall section adjacent to the shell plating is observed. Height of these sections measured from the plating is 300-500 mm.

7. For the secure strengthening of these sections of walls the ratio of wall thicknesses of stringers, floors, brackets etc. to the distance between supporting stiffeners should be not less than 0.025-0.03.

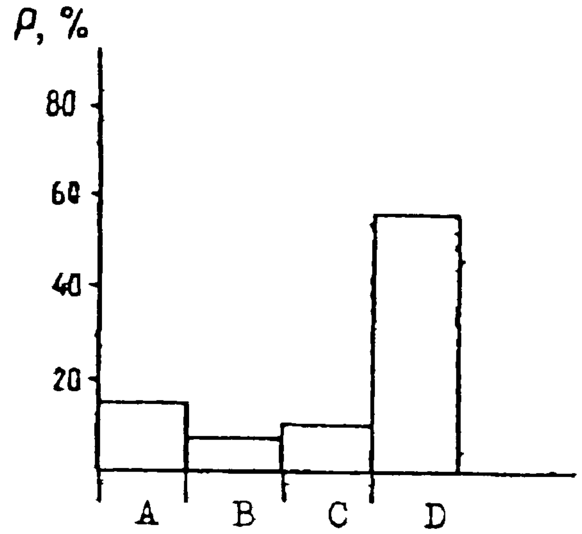


Fig. 1. Distribution of the level of damageability between icebreakers and other ships
A, B, C, D - icebreakers, ULA, UL, L1

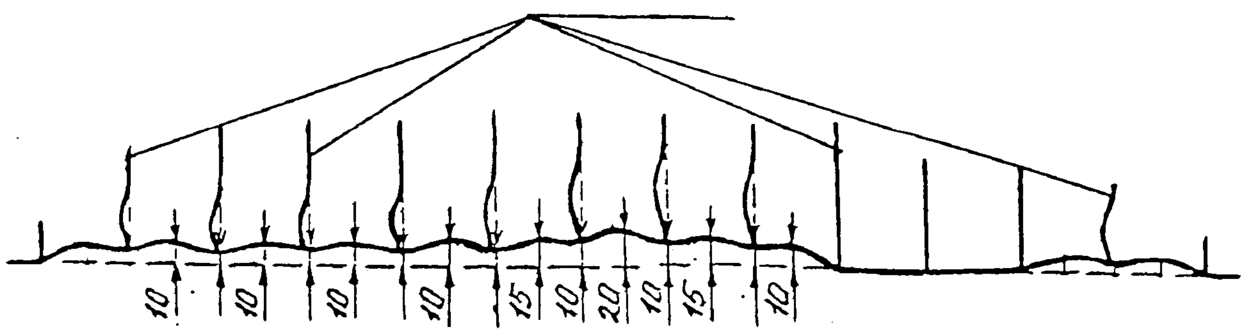


Fig. 2. Typical section across an extended dent in the bottom of arctic icebreaker

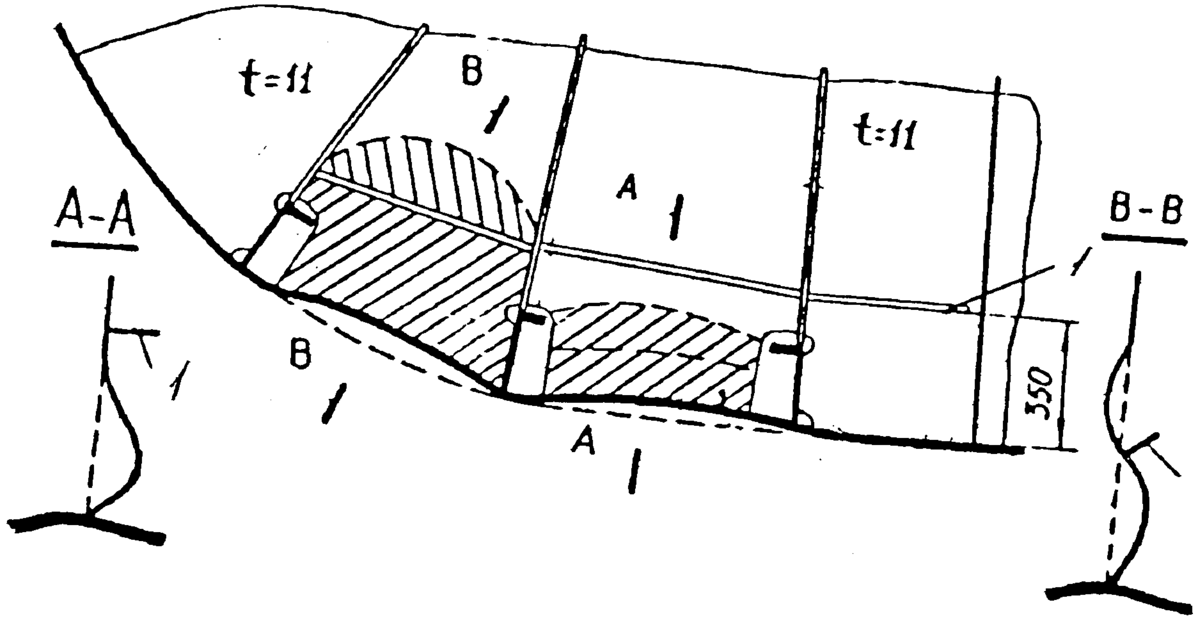


Fig. 3. Forms of buckling of a floor wall on icebreaker

1 - strengthening horizontal rib

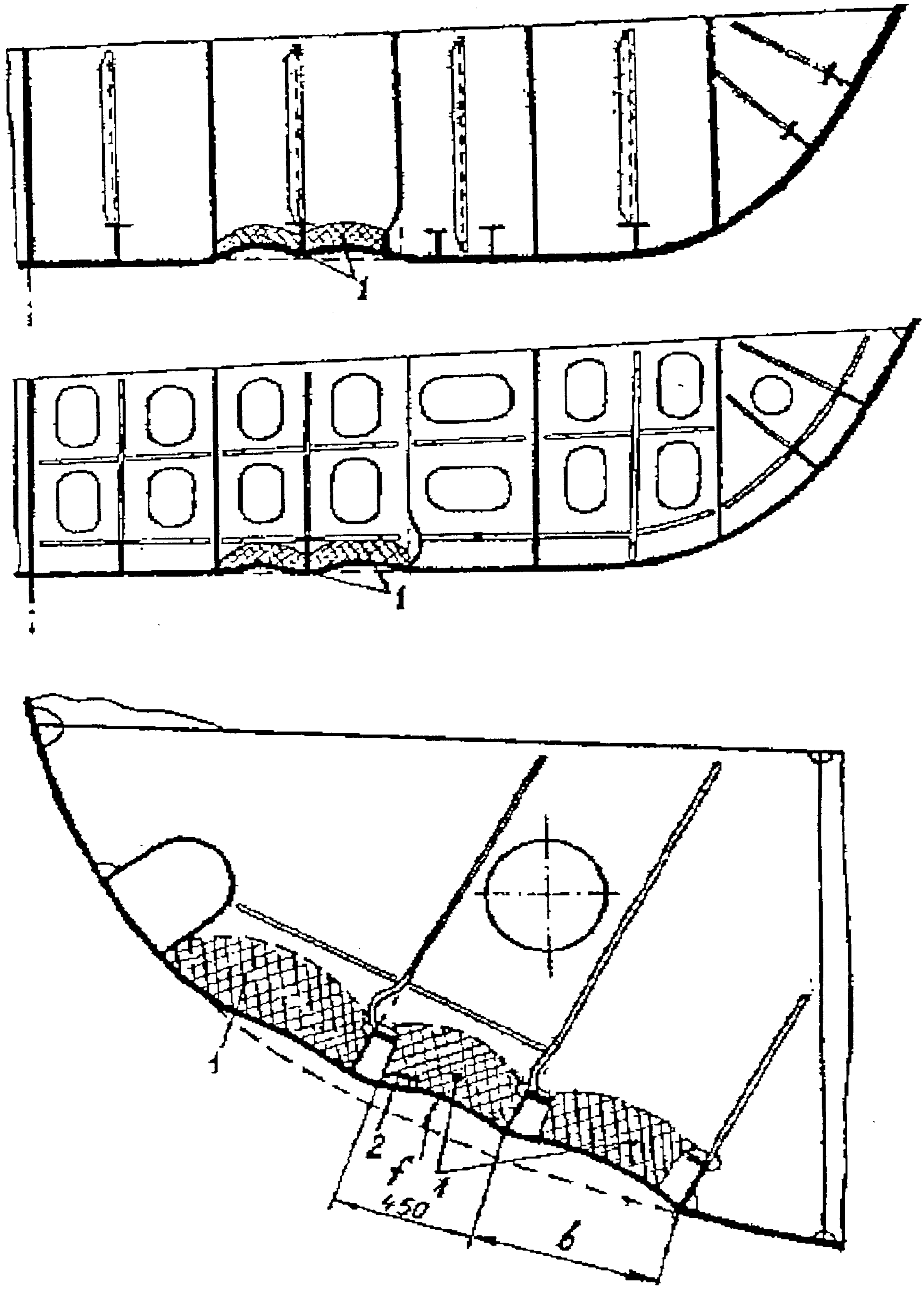


Fig.4. Typical damages to bottom framing walls of icebreakers of "Moskva" and "Ermak" types

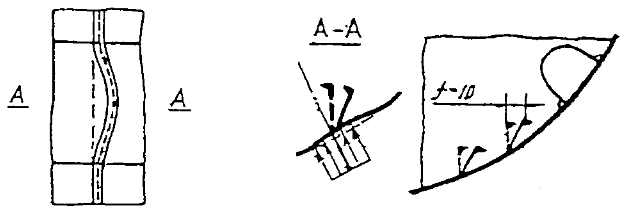


Fig. 5. Loss of stability of the flat form of bending of longitudinal bottom giders (icebreaker of "Kapitan Forokin" type)

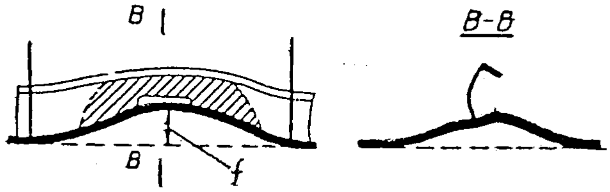


Fig. 6. Permanent deflection of longitudinal bottom girders with buckling

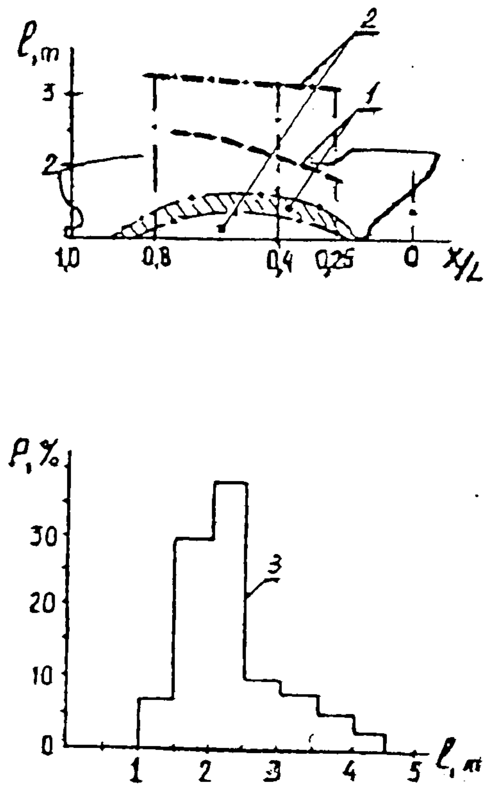


Fig. 7. Extension of dents of the bottom strafe of icebreakers of "Ermak" and "Kapitan Sorokin" type (generalized linear and frequency characteristics)

1, 2 - length of bilge and flat bottom dents,

3 - frequency of the realization of this length

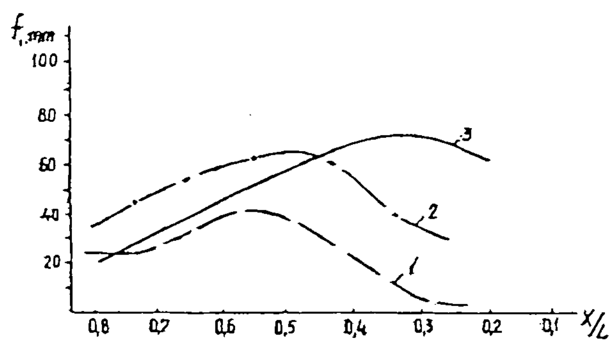


Fig. 8. Distribution of mean permanent deflections of framing and bottom plating over the length of icebreakers

1 - bulges, 2,3 - dents of the flat bottom and bilge

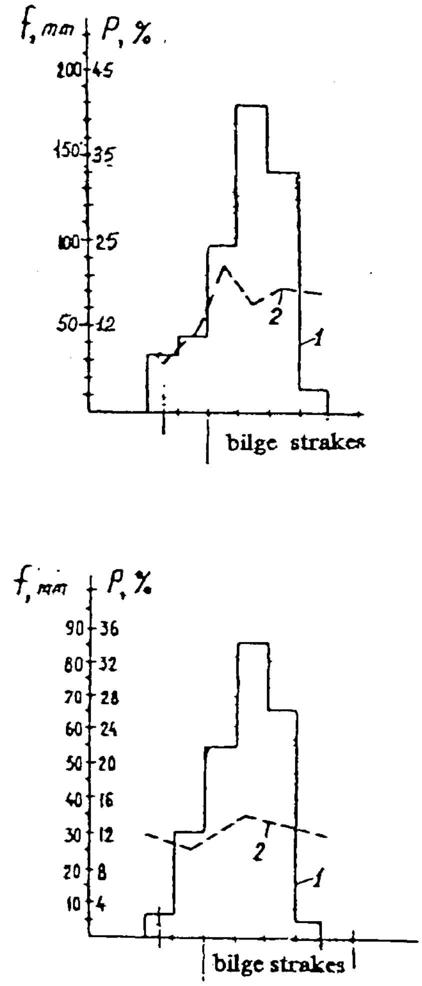


Fig. 9. Generalized distribution of depth values of dents and bulges over the bottom breadth of icebreakers

1, 2 - all values and averages

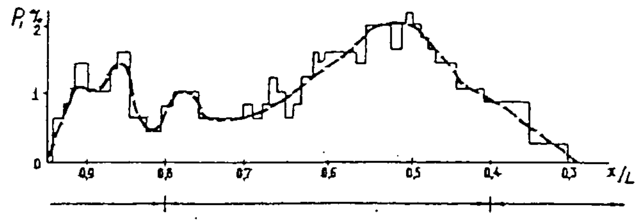


Fig. 10. Generalized distribution of deflection frequency of the bottom and bilge plating areas of the icebreakers of "Moskva", "Ermak" and "Kapitan Sorokin" types

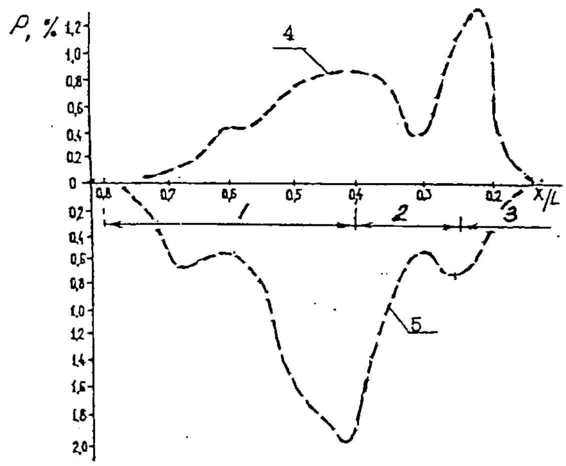


Fig. 11. Distribution of ice damage frequency over the hull length of the icebreakers of "Moskva" type

1, 2 - middle and intermediate areas, 3 - forebody, 4 - bilge, 5 - flat bottom

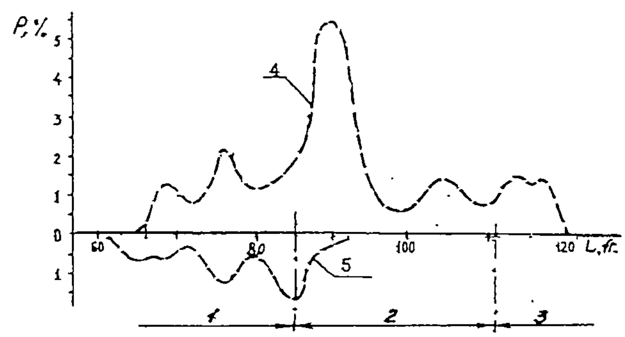


Fig. 12. Distribution of ice damage frequency over the hull length of the icebreakers of "Ermak" type

1, 2, 3 - middle, intermediate and bow areas, 4, 5 - bilge, flat bottom

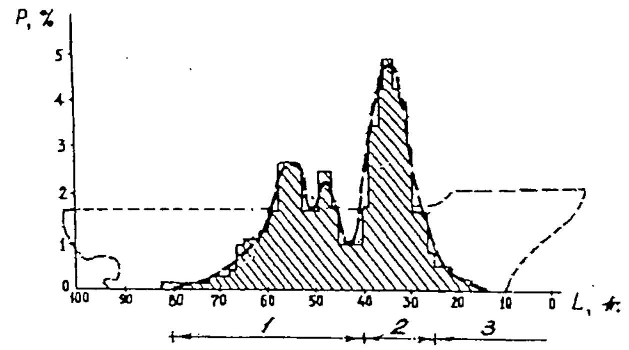


Fig. 13. Generalized frequency distribution of bottom structure damages of LL4 categorye icebreaker

1, 2, 3 - middle, intermediate and forebody areas

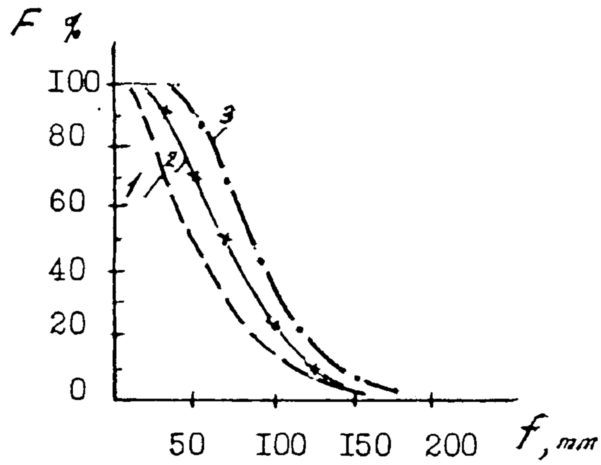


Fig. 14. Plots of function F = 1-p where p - is the probability of the occurrence of dent of a given depth in the bottom strake of the middle and intermediate hull areas

1, 2, 2 - ships of "Moskva", "Amguema", "Ermak" types

ANNEX A

Fra: (Kazuhiko Kamesaki)
Til: FNI_office.FNI_post(ED)
Dato: 24. juli 1995 1.59
Emne: Review comments for I.5.5. , Planning and risk assessment

I apologize the late response, so busy for sailing to NSR.
I attached Macintosh MS WORD- FILE, the contents are same as below.

Review comments for I.5.5. , Planning and risk assessment (1994 project work)

Reviewer:
Kazuhiko Kamesaki
ICE and SNOW Engineering Lab.
Engineering Research Center
NKK Corporation
1, Kumozu-Kokan-cho,Tsu City,Mie Pref,514-03
JAPAN

1. A concept of a system for specialized ice information support to successive planing along the NSR.

1-1. In terms of possibility and/ or feasibility for the ice information system requirement you proposed, you may pay attention and allocate pages whether the current ice forecast practice including satellite or air plane reconnaissance flight or hydrometeorological knowledge is sufficient to realize the requirements you proposed. For example, regarding perspective planning of shipping (estimates for the period from 3 to 25-30 years) or tactical planing of marine operations (10-30 days in advance), you should have argued that how accurate we can get ice forecast information you define at 1.3 according to the current the NSR ice forecast practice. If it does not comply with your requirement, you may discuss that what improvement is necessary against your requirement. We are interested in the discrepancy between the requirement and the reality.

1-2. Clarify the definition of initial, sufficient and complete and corresponding 1-2/1-2/0-1 and etc. in Fig.1.1.3.

1-3 In 1.2 Types of marine operation, you defined standard marine operation and non-standard operation. In general, standard means typical or common. But you mention that non-standard operation is often and occasional. It causes misunderstanding and contradiction. Replace appropriate wording.

2. Type Of Ice Condition Of Navigation Along The NSR

2-1. In Table 2.1, What E, ME , M, MH , H stand for ?. and what is the unit for 3-4, 0-1 etc. ?

2-2 In Table 2.3, clarify the definitions of easy, median and hard. I understood that these definitions are based on 2.2 a p.37. Is it true? It's not easy to distinguish. Refer the definition in Table 2.3 or in caption title of Table 2.3. As well as Table

2.3, in Table 2.5, it gives confusion regarding definition of c, m and h, because chapter title is "Division into types on the basis on the basis of ice-navigation indicators .... ". is its definition corresponding to 2.2 b p.38 ? I am anyhow confusing. More direct chapter title or wording is preferable. Also this assumption of the analysis is ambiguous, is this dataset applicable for the " Arktika" plus UL convoy ?

3. Development And Important Of The Empirical Model Of The Ice Navigation

3-1. What is the QAD model? Briefly discuss the theoretical background of QAD? Clarify that what empirical factors are incorporated.

3-2. In Table 3.1, clarify units and their definitions ,such as 30/119 or compacting 0-2 etc..

3-3. What is the ice condition of each dataset in Table 3.2? Table 3.1 has no relation with Table 3.2. Please clarify that. If it is true, attach the ice conditions of Table 3.2.

3-4. Clarify that how handle ramming in current QAD model.

4. Database For Securing Of Correlation Dependencies Between The Vessel Damage Parameters And The Ice Conditions.

4-1. This chapter is out of reviewing. In my sense, this is kind of software specification, and not survey paper. I am not interested in database construction and their design,¤B!! (But interested in how damage data is collected and processed in Russian ship society. Do not design database you cannot fulfill in a project period.

5. Others
This document needs a proof reading by native speaker, and still the expression is lengthy and may confused readers.

Kazuhiko KAMESAKI

Ice and Snow Labs.
Engineering Research Center
NKK Corporation
1,Kumozukokan-cho, Tsu City,Mie Pref.,513-03,JAPAN
Tel +81-592-46-3031
Fax +81-592-46-2790

COMMENTS

to the review of Dr. K. Kamesaki

Items 1-1

The main concept of the suggested system is that it is based on specialized ice information which includes ice navigation indicators directly applicable to planning and organization of shipping.

In this connection, the concept considers applicability of ice-navigation indicators for specific planning objectives. Also, a brief list of ice prognostic data is presented which supplements existing specialized information (item 1.4.2). The existing types of hydrometeorological ice forecasts for the NSR zone are considered in more detail in a separate project I.6.1 Operational Tools (I Step - Working Paper N 10, II Step - in print).

Current status of using prognostic and current ice information in operational practice is considered in project I.2.1 (Operational Information on Natural Conditions). Hence, we did not aim to analyse whether the existing types of ice information (current, climatic, prognostic) correspond to planning objectives. This would have clearly overloaded our concept making it difficult for perception.

However, if necessary we are ready to fulfil this work, provided there is time and finances.

Items 1-2

Levels of specialization of general geographical ice information.

Specialized ice information (Fig.1.1) which is obtained on the basis of general geographical information by using a specialization algorithm, has three levels: initial,sufficient and complete. The indicated levels represent a conventional qualitative estimate. Their quantitative interpretation was performed acording to the number of types of ice information used (1-2/1-2/0-1, etc.). It is desirable that data of current observations or prognostic characteristics were used as initial ice information and only if they are absent - climatic ice indicators.

Items 1-3

Page 11 gives a definition of a nonstandard sea operation - the main difference from a standard operation is in the use of additional organization and information means. These operations are not frequent.

Item 2

Changes and additions to the main text are made (a separate section 2.2.c. addition to section 2.3.1, the title of 2.3.2 is changed, as well as the titles of tables 2.2, 2.3, 2.4, 2.5).

Items 2-1

In Table 2.1 the measuring unit is the number of mean monthly T_{icn}, i.e. the number of months during navigation period when this type (T_n) was observed.

Items 2-2

Data of Tables 2.2-2.6 are obtained on the basis of the material of the initial division into types according to operating characteristics of the nuclear icebreaker "Arktika". However, for a typical convoy (nuclear/icebreaker "Arktika" + UL) they should not significantly change.

Item 3

Name of the chapter: Development and improvement of the empirical model of ship motion in the ice.

Items 3-1

The empirical model (QAD) presents data approximation of full-scale observations onboard icebreakers of different type over the entire range of ice conditions.

As reference data, data on ship motion in compact and close ice cake are used.

The empirical coefficients are used for the case of motion in the ice of different concentration, forms, thicknesses and pressures.

As the output of the model (QAD), the calculated operating velocity for any ice conditions on the basis of full-scale data is obtained.

Items 3-2

The left-hand side of Table 3.1 contains indicators characterizing the data volume for the types of ice zones identified where the numerator is the number of ice zones and the denominator is the total length of these zones in miles.

The right-hand side contains ranges of changes in ice cover characteristics for the types of ice zones identified: ice thicknesses in cm, amount of hummocking, degree of destruction and pressure in arbitrary units (in accordance with the Russian Sea-Ice Nomenclature).

Items 3-3

Table 3.1 contains information on the observation database, and Table 3.2 - results of calculations by means of the model (QAD), their comparison with actual motion velocities in the ice and time consumption.

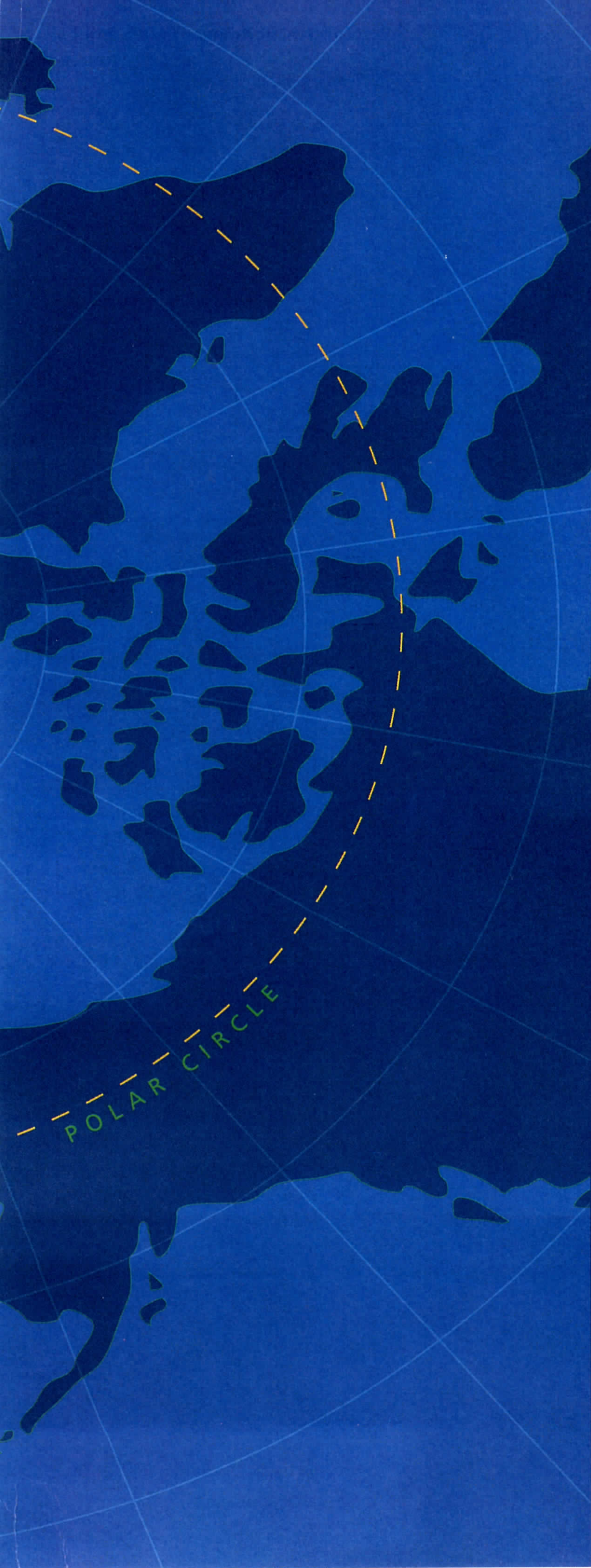
Items 3-4

The probability of operation by ramming is estimated depending on the value of the calculated operating velocity (by means of the current QAD model).

Item 4-1

In the framework of INSROP (Project I.5.5) only the methods for creating the database on ice damages of ships and icebreakers and partly its software are being developed. The implementation of the database is carried out according to the planned studies of the AARI.

Authors of Project I.5.5 are grateful to Dr.Kamesaki for his attention to our work and his comments which helped to improve it.



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 Sasakawa 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.