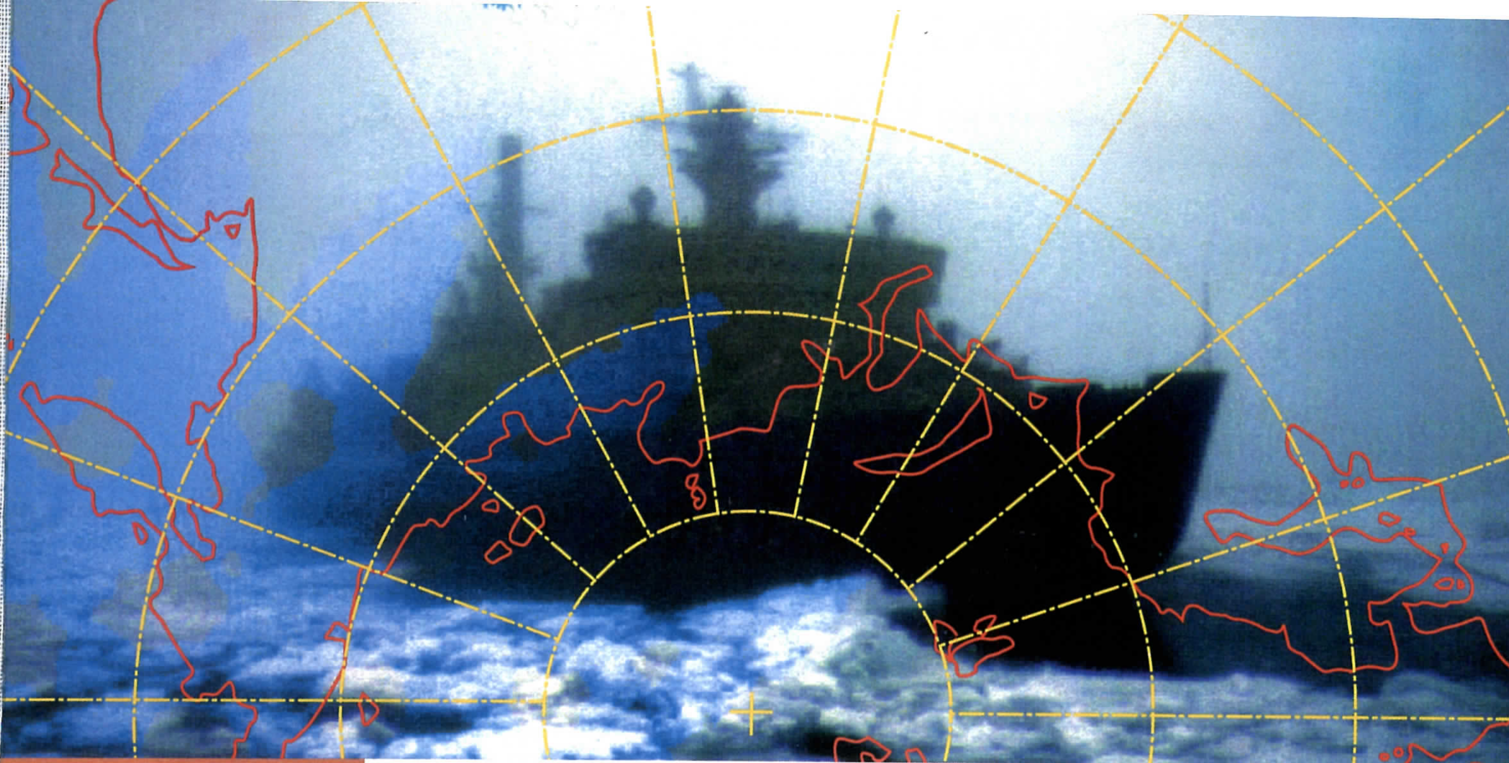
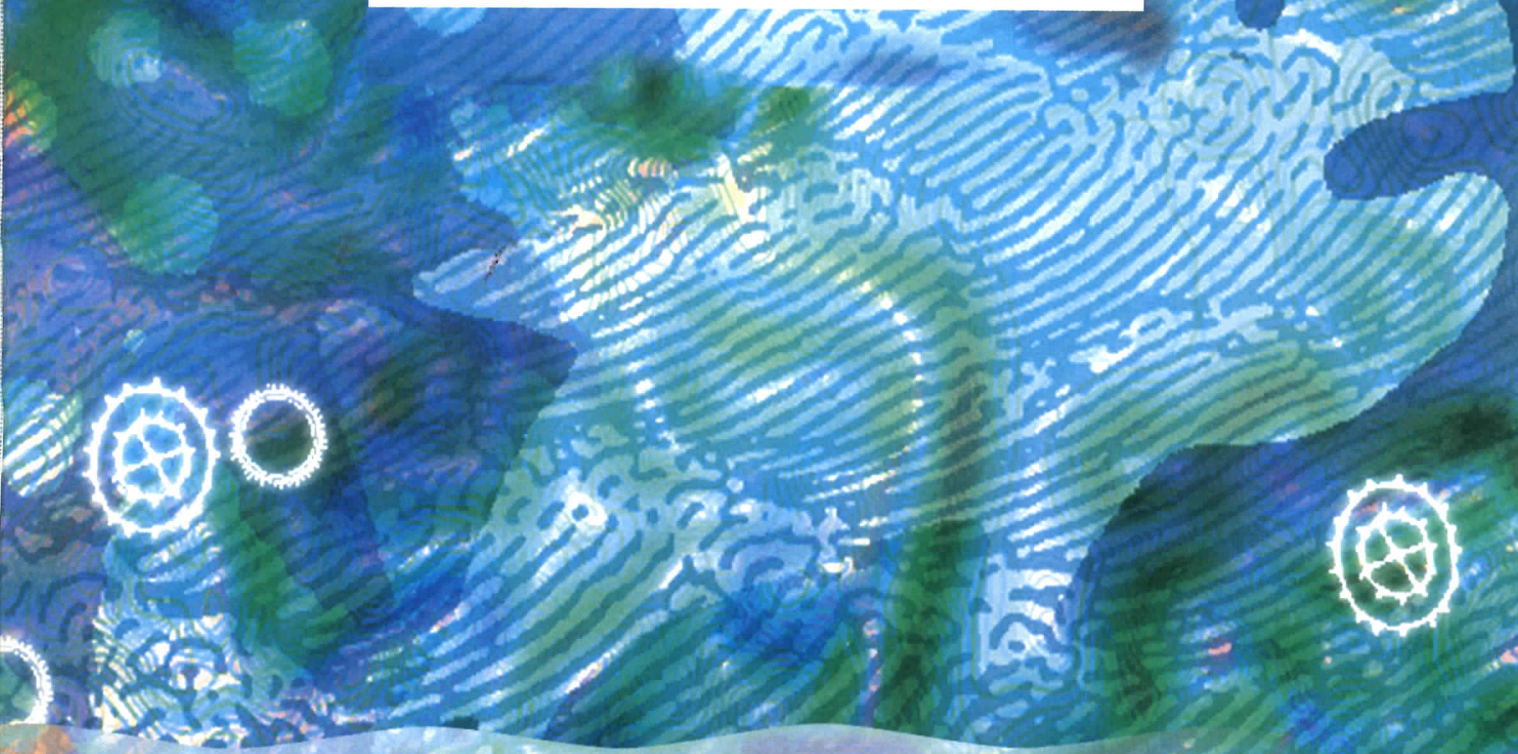


INSROP WORKING PAPER
NO. 23 - 1995, I.5.5

Planning and Risk Assessment
Volume 1 - 1993 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

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International Northern Sea Route Programme (INSROP)

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INSROP WORKING PAPER NO. 23-1995

Sub-programme I: Natural Conditions and Ice Navigation

Project I.5.5: Planning and Risk Assessment
Volume 1 - 1993 project work.

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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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SUMMARY

The aim of this project is to identify and estimate information required for the organization and planning of safe and effective navigation on the NSR.

The first part of the project considers natural ice conditions and primarily, ice conditions governing safe and effective navigation, presented in specialized form for shipping. These are ice cover characteristics on the motion route of ships which significantly affect shipping, operating parameters of ships navigating in ice and ice-navigation parameters that can be used for the organization and planning of shipping. A description of the method for a quantitative assessment of the difficulty of navigation developed at the AARI, is presented. The method is considered to be a major algorithm for specialized ice information allowing obtaining ice-navigation parameters on the basis of climatic, operational and prognostic information on the ice cover total distribution. The first part of the project is concluded by a detailed concept of the database on ice damages of ships which is most closely related to an analysis of ice navigation conditions.

The first part of the project is fulfilled by the specialists of the Laboratory for Ice Navigation Studies and the Department of Ship Ice Capabilities of the AARI.

In the process of work on project 1.5.5, part II (CNIIMF) the following investigations have been carried out:

- general analysis of a particular character of ice damages of ship hulls of the Russian Arctic fleet in the process of its operation on the NSR;
- detection of principal causes and conditions for the occurrence of ice damages of hull structures which are mainly associated with the use of ships in ice conditions beyond the capabilities of their class and unjustified deviations of structural characteristics from the requirements of the Rules for the construction and the Register classification;
- determination of ranges of changes in the extent of ice damages of the structure elements of the underwater portion of the ship hull; assessment of an occurrence

frequency of damages in different hull areas of ships of the main ice classes operating in the Arctic; it was found out in particular, that most damages occur in the forebody at the level of bilge strakes;

- construction of the distribution functions of permanent deflections of shell plating for different hull areas of the Arctic navigation ships;
- detection of the ship hull areas subjected to the heaviest ice damages during navigation in ice;
- determination of the influence of the operation area of ships on the extent of ice damages.

INSROP Project I.5.5 has been reviewed by Dr. Kazuhiko Kamesaki, Head of ICE and SNOW Engineering Laboratory, Engineering Research Center NKK Corporation, Japan (Appendix A).

Taking into account the comments and proposals of the Reviewer, some corrections and additions have been made in the text. The comments to the review are given in Appendix A.

KEY WORDS:

PART I: ice navigation conditions, ice cover characteristics, operating navigation indicators, specialized ice information for shipping, assessment of the ice navigation difficulty, optimal ice navigation variant, ice damages of ships.

PART II: ice damages, ice belt, ice navigation, arctic ships, hull structure, shell plating, framing, corrugation, bilge strakes, bottom strakes, bulge, dent, permanent set, permanent deflection.

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TABLE OF CONTENTS

PART I

SPECIALIZED ICE-OPERATING INFORMATION FOR PLANNING AND ASSESSMENT OF THE SHIPPING RISK ALONG THE NSR

LIST OF ARBITRARY DESIGNATIONS AND ABBREVIATIONS

QAD - a model (method) of a quantitative assessment of the difficulty of ice navigation;
K_d - a coefficient of ice navigation difficulty;
V_{io} - ice operating velocity of the ship (icebreaker);
V_{ip} - ice passport velocity;
V_{it} - ice technical velocity;
V_{iog} - general ice operating velocity;
$V_{it\ s/i}$ - ice technical velocity in solid ice;
$V_{it\ i/c}$ - ice technical velocity in ice cake;
$V_{it\ o}$ - ice technical velocity in open water;
Σt - total time on the NSR segment;
Σt_{ice} - total calculated navigation time in specific ice zones;
$\Delta\Sigma_{tice}$ - total increase of calculated navigation time due to ice;
t_r - time of progress by ramming;
$S_{ice\ i}$ - route in the ice of a specific age gradation;
L_s - the shortest distance between two route points;
L_a - actual distance passed between two route points;
K_m - a coefficient of meandering of the route;
K_p - a coefficient of ice pressure;
T_{icn} - type of ice conditions of navigation;
T_n - type of navigation;
L - length of an icebreaker;
l^* - horizontal dimensions of ice formations;
BSI - break-up in solid ice;
FZYI - flaw zones of young ice;
C_n - ice concentration on the navigation route;
C_r - ice concentration in the navigation region;
H_i - ice thickness;
H_l - ice limit thickness, passed by an icebreaker (ice passage capability);
h - snow depth;
R - amount of ridging;
R_n - amount of ridging on the navigation route;
R_v - amount of ridging within a visibility range;

1 MAIN DIRECTIONS OF DEVELOPING SPECIALIZED ICE INFORMATION FOR THE ORGANIZATION AND PLANNING OF SHIPPING ALONG THE NSR

Specialized ice information for shipping is considered to be a set of ice, operating and ice-navigation characteristics. They indicate ice conditions directly on the motion way (route) of ships and present a quantitative estimate of the effect of these conditions on the success of different types of navigation.

1.1 Background for the formation of specialized ice information for shipping

The development of specialized ice information for shipping is closely connected with support to navigation along the NSR. At the first stage approximately up to the 60s the investigation of navigation conditions was focussed on the studies of various natural features of the Arctic Seas. Already in those years a specialized form for the presentation of regime hydrometeorological summaries and ice forecasts - navigation recommendations was proposed. At first it was a qualitative estimate of the effect of expected ice conditions on the activity of the Arctic fleet. And it can be said that the studies of such prominent Russian scientists-oceanographers as Viese (1940, 1945), Zubov (1945) and their successors Somov (1940), Karelin (1940), Volkov (1964), Gordienko (1955, 1980) etc. have laid the foundation of the scientific support to navigation in the Arctic.

The beginning of the 60s has been a new stage in the ice navigation development along the NSR. The interests of the economic activity have required a significant extension of the navigation period in the Arctic Seas up to the organization of a regular all-year-round delivery of cargos at some specific transportation routes. In the light of the new goals the attitude to ice cover has changed - from the medium on the whole blocking navigation it was becoming an active shipping medium. Practical demands governed the need for a purposeful study of ice cover directly on the navigation route, development of techniques for a quantitative assessment of its effect on shipping.

By the mid 60s a new direction has been formed in ice research - the study of ice cover as a shipping medium. It developed from the three directions:

- ice research proper when general typical features of the formation, destruction and redistribution of ice cover in the ice-covered seas are investigated (Gudkovich et al. 1972);
- direction connected with determining the laws of ice resistance to the ship motion on the basis of theoretical studies. Modelling of the process of the ship motion and full-scale trials of ships navigating in ideal ice conditions (Kashtelyan et al., 1968; Ryvlin, Kheisin, 1980);
- direction connected with the organization, planning and operation of the fleet in ice taking into account existing information on navigation conditions (data of current observations, ice and meteorological forecasts, regime and reference data) (Volkov,1964; Gurevich, Nemchinov, 1972).

A scientific concept for the study of ice navigation conditions, features of methods for acquisition and procession of initial data, ways for the development of a new direction in ice research were considered by Gordienko, Buzuyev, Sergeyev (1967).

The ice cover in comparatively narrow natural zones - on the navigable routes has become the main geographical object of the studies.

The use of icebreaker as a specific tool in the study of ice conditions was an important component of the new direction. The speed of the ship's progress in ice in the course of operation has become an indicator of the navigation success of ship, as well as an indicator of difficult or relatively easy ice conditions in the interaction zone with ship. This allowed a quantitative expression of the ice cover influence by means of one operating characteristics (speed of the ship motion) as a set of a sufficiently large number of its physical parameters.

The study of ice cover as shipping medium includes the following:

- distribution features of ice cover characteristics producing a distinct effect on shipping directly on the ship navigation routes in different seasons of the year;
- relationship between navigation conditions on the explored and prospective shipping routes and total ice distribution in the Arctic Seas;
- dependency of the motion velocities of operating icebreakers and ships of different type on the ice cover characteristics on the navigation route;
- general principles for taking into account ice and hydrometeorological conditions in navigation recommendations.

The approach to the study of ice cover which combines a physical- geographical description of conditions on the navigation route with a quantitative estimate of the effect of these conditions on various navigation types has proved to be quite fruitful. It has allowed studies and comparisons between the conditions and the difficulty of navigating in ice of various regions of the Central Arctic, the Antarctic, in ice-infested non-Arctic Seas using conventional methods.It has also allowed identification of the main distribution features of ice cover characteristics at traditional (standard) navigation variants and at an optimal (as a rule, the easiest one) variant depending on the formation conditions and total ice distribution in the Arctic Seas. The latter has served as à basis for a wide use of traditional data on Arctic ice cover (maps of airborne ice reconnaissance, composite ice charts, etc.) for analyzing ice navigation conditions along the existing and prospective routes the year round for the entire ice observation series.

1.2 Ice conditions on the standard navigation variants along the NSR segments

On the basis of multiyear operating experience along the Northern Sea Route standard navigation variants along the main segments of the NSR have been determined indicating climatic features of ice distribution in the Arctic Seas. The dependence of the position of these navigation variants on ice conditions in the Arctic Seas during summer navigation was considered in detail by a number of investigators (Viese, Gordienko, Buzuyev, etc.). The standard navigation routes have a constant geographical position. This circumstance significantly simplifies a selection of ice characteristics for a specific navigation variant by means of airborne ice reconnaissance charts, composite ice charts for the available observation series and their statistical procession. The procession results allow determining the extent of specific ice zones, distribution of ice cover characteristics on standard variants, their seasonal and interannual variability, typical formation features depending on the total ice distribution at sea, assessment of the probable use of each of the standard variants. The traditional scheme of dividing the NSR into segments (western ice edge - Dikson island, Dikson island - Cheluskin Cape, Cheluskin Cape - Tiksi Bay, Tiksi Bay - Kolyma river, Kolyma river - Shelagsky Cape, Shelagsky Cape - Bering strait) is oriented to calls of ships to intermediate ports. The data on ice conditions at the standard variants for these segments can be used for estimating transit navigation on the NSR only as the most rough data. Such approach to estimating the ice cover state with regard to navigation does not quite well take into account a selective character of the progress of ships in ice, a possibility of choosing the most easy or an optimal navigation variant which can significantly differ from standard variants.

1.3 Distribution of ice cover characteristics on the navigation route and assessment of the effect of ice conditions on the navigation success

Method for a quantitative assessment of the difficulty of ice navigation. Special shipborne observations of the distribution of ice cover characteristics on the ship motion route were carried out for many years. Furthermore, these data were compared with the data of simultaneous airborne reconnaissance flights which reflect spatial distribution of ice cover over the navigation region. This has allowed one to find their differences and corresponding dependencies for specific ice cover characteristics. The indicated differences are governed by the selectivity of the motion in ice, as well as by different generalization scales of ice characteristics during shipborne and airborne observations (Buzuyev, 1975; Buzuyev, Fedyakov, 1981). Also, simultaneous observations aboard icebreakers and ships of different types on their operating characteristics allowed obtaining of quantitative dependencies of the motion velocities of ships in real ice conditions. Further studies allowed estimates of the effect of the entire range of the ice cover state characteristics on the motion velocity of ships (icebreakers), a detailed classification of ice cover as a shipping medium, estimate of its spatial inhomogeneity and seasonal variability (Buzuyev et al., 1982).

The creation of an empirical-statistical method for a quantitative assessment of the ice navigation difficulty in the early 80s under the supervision of Buzuyev has been a milestone for the development of the given research direction.

This method allows for the calculation of the operating velocity of icebreakers and ships of different types at any possible combination of ice cover characteristics presented at a traditional ice chart (from the data of ice airborne reconnaissance, satellites etc.). The method of a quantitative assessment of the difficulty of ice navigation ("QAD") appears to be a basis for the current specialization level of ice information for shipping. The implementation of the "QAD" method in the form of a mathematical model using modern computer means, contributed to its wide application in special research studies and operational practice of Arctic shipping.

The "QAD" method significantly extended a possibility of solving both purely scientific and applied problems related to the study of ice cover as shipping medium. In particular, in physical-geographical respects it allowed the studies of ice conditions and navigation difficulty with any possible navigation variants on the segments and the entire NSR in all seasons of the year, using an available set of traditional ice observations (charts of airborne ice reconnaisance, composite ice charts). Out of applied problems it is necessary to mention a possibility for an objective choice of an optimal variant and a quantitative assessment of the ice navigation difficulty depending on the composition of a real convoy. Also, a possibility for obtaining objective operating characteristics of navigation conditions (motion velocity, times of typical ships and convoys) has laid the foundation for specialized ice forecasts for shipping in their present form.

1.4 Standard-reference information on ice and operating characteristics at the optimal navigation variant

Up to the recent time the choice of an optimal navigation variant appeared to be a subjective process. It required assessment of numerous indicators of the ice cover state at their varying influence on the success of navigation in different ice conditions. Navigators using their experience, chose an optimal navigation route either in zones of more thin and young ice or kept to standard navigation variants, avoiding heavy ice zones or not penetrating far into them. In the 70s ice researchers suggested a general principle for selecting an optimal navigation way (Buzuyev et al., 1982). The progress is achieved using the shortest route through the zones in which:

- total ice concentration is minimum;
- the amount of the most young ice (in the fall-winter period) and the degree of ice destruction (in summer) are maximum;
- a minimum amount of hummocking and enhanced ice fracturing are observed.

The use, however, of only ice characteristics as criteria did not always permit determining an optimal motion route. The implementation of the concept of using a ship (icebreaker) as an instrument for estimating ice conditions and development of the method for a quantitative assessment of the ice navigation difficulty have allowed calculations of operating characteristics of ice navigation.

The transition to operating characteristics has allowed one to determine criteria which govern quantitatively an optimal navigation route. Such criteria include: navigation safety and economic effectiveness. The navigation safety can be determined by means of critical values of a maximum permissible technical velocity of the motion in ice. Economic effectiveness is determined by minimum transit times along the route under consideration (when the navigation safety criterion is fulfilled).

Taking into account that the success of the majority of transport operations on the NSR is governed by the technical capabilities of icebreakers (nuclear-powered icebreakers) of the "Arktika" type (75 000 hp) and also considering the minimum errors in determining their operating characteristics by the "QAD" model, it is the operating characteristics of the "Arktika" which were taken as the main criteria for choosing an optimal navigation variant. In particular:

- navigation safety is achieved provided technical velocity of a continuous motion of the "Arktika" in specific ice zones should not be less than 1/10 of its velocity in open water as stated in the passport (i.e. V_{min} > 2.1 knots);

- navigation effectiveness - achieved by observing minimum time consumption for sailing between the departure and destination points (along the traditional NSR segments).

The indicated approach to systematized initial ice information has allowed one to determine an optimal variant in a real ice situation all-year-round and obtain standard-reference information on the distribution of ice cover characteristics and operating characteristics for different kinds of icebreakers and ships. Systematized initial ice information includes composite ice charts compiled on the basis of airborne reconnaissance, satellite images and other sources collected during more than 40 years of ice observations along the NSR. For the summer-fall period information has a 10-day interval and for the winter-spring period it has a 1 month interval.

For the traditionally identified NSR segments (see section 1.2 of the Report) the following was obtained:

A. Occurrence frequency (probability) of the position of an optimal navigation variant (its identification with the existing standard variants) for the summer-fall navigation period, and for some NSR segments all-year-round.

B. Statistics of the length of the way in different ice zones identified as the main ones, in terms of their influence on shipping (identification criteria of ice zones are given in section 2.7.1).

To determine the state of the indicated ice zones and estimate the processes occurring in ice cover and significantly influencing shipping, the following main characteristics of the ice cover are used (Nomenclature, 1974):

- ice thickness (as a rule is determined in ice age gradations);
- total ice amount (total concentration);
- ice amount of a uniform age gradation (partial concentration - for drifting ice, partial distribution of ice of different age - for fast ice);
- amount of ice hummocking;

- amount of ice fracturing;
- ice pressure;
- degree of ice destruction (for summer).

C. Statistics of motion velocities and time consumption of a nuclear-powered icebreaker of the "Arktika" type and a standard convoy of a nuclear icebreaker of the "Arktika" type + M/V of the ULA class on the NSR segments.

Available standard-reference information to be used for the organization and planning of sea operations is obtained for the traditional scheme of subdividing the NSR for coastwise navigation (taking into account calls to the NSR ports). To obtain similar standard-reference information on ice conditions and operating characteristics of ships (standard convoys) for transit navigation along the NSR (taking into account a corresponding NSR division scheme) requires separate regime-reference activities, probably consistent with establishing the database on ice and operating characteristics mentioned.

1.5 Creation of a universal subdivision of ice navigation conditions by means of the "QAD" model

Regime information on ice conditions on the ice routes taking into account the effect of navigation conditions on the present-day and prospective fleet is used for long-range assessments, designing and prospective planning of shipping. It includes ice cover characteristics on the NSR segments taking into account the season, as well as operating characteristics of the ice connected with the organization and feasibility studies of shipping in the Arctic (Arikainen, 1990). However, the impossibility of taking into account simultaneously quite a large number of ice cover characteristics (thickness, concentration, amount of ice of different age categories, pressures, amount of hummocking, degree of destruction, amount of fracturing) considerably influencing the success of ice navigation of ships, long prevented the creation of a universal scheme of dividing ice navigation conditions into types.

Only the development of the method for a quantitative assessment of the navigation difficulty and a possibility of obtaining calculated operating characteristics indicating a total effect of all diverse ice cover characteristics on the success of navigation, allowed dividing ice cover into types using conventional methods in various NSR regions for the whole annual cycle (see section 2.7.3).

Types of ice navigation conditions (T_{icn}) - easy, medium, heavy obtained for the traditional NSR segments have ice characteristics in the form of statistics of the ice zone extent and operating characteristics for various types of ships and convoys. Statistical estimates of ice conditions and operating navigation characteristics, as well as estimates of the probability of their formation on the specific NSR segments in various seasons compose a standard-reference base of navigation conditions on the NSR.

The standard-reference base of ice-operating navigation conditions along the NSR is necessary for organizing shipping. It can also be used during preliminary planning of sea operations. And taking into account the possibility of forecasting generalized ice-operating characteristics of navigation conditions with different periods in advance (see Project I.6.1, section 5) it is possible to set up a system of hydrometeorological support for successive planning of sea operations along the NSR.

2 ANALYSIS OF ICE OPERATING AND ICE-NAVIGATION INDICATORS OF NAVIGATION CONDITIONS APPLICABLE FOR THE ORGANIZATION AND PLANNING OF SHIPPING ALONG THE NSR

2.1 Introduction

The main difficulties of navigation of ships in the Arctic Seas are governed by the presence of ice cover and the necessity to travel through it. That is why when implementing the program for the development of shipping along the NSR an important role is devoted to knowledge of natural and, primarily, ice conditions. And particularly important appears to be information on typical features of the distribution of ice characteristics on the sailing route.

It is known that the state of drifting and fast ice depends on a number of the "traditional" ice cover characteristics (concentration, thickness, amount of hummocking, degree of destruction, amount of ice fracturing, snow depth on ice) governing its resistance to the motion of ships. A set of such traditional characteristics describes main large-scale elements and formations of ice cover: drifting ice massifs, fast ice regions, flaw zones of young ice (polynyas), break-up zones in solid ice cover, zones of open and very open ice, etc. Their existence and position govern in many respects the success of marine operations.

It is also important to investigate ice cover characteristics indicating a dynamic interaction in the air-sea-ice cover system and which govern the success (and in some regions the possibility) of shipping. Such characteristics include: pressure (its intensity), ice adhesion, ice river and zones of drift boundaries.

To investigate ice navigation conditions on the NSR data from many sources have been used (Bushuyev, Loshilov, 1967;1977; Bushuyev, 1980;1983; Shil'nikov, 1973): satellite images, instrumental and visual airborne reconnaissance flights, observations at polar stations, standard and special shipborne observations. Up to the present the data of airborne reconnaissance and satellite images are considered to be the main information source on ice conditions in the shipping regions. At a non-uniform ice distribution usual for the Arctic Seas, airborne reconnaissance data can differ significantly from ice conditions encountered directly on the navigation route. That is why, knowledge of the extent of these differences, especially for ice characteristics that produce a significant effect on the motion of ships, is important for navigation.

Special shipborne observations are most detailed (maximum resolution) comparable with the dimensions of ships. (Instruction, 1975). The data, obtained during such observations served as a basis for the study of ice cover as a shipping medium (Gordienko et al, 1967). Special ice observations have provided a number of specialized characteristics of navigation conditions considerably facilitating planning and specific marine operations.

Implementation of the concept of using icebreaker as a specific tool for studying ice navigation conditions has allowed expressing the effect of diverse ice conditions by means of operating characteristics. Numerous full-scale observations and studies of ice cover as a shipping medium have allowed one to find an application area for traditional characteristics (motion velocity, time consumption). It also allowed finding out new specific operating characteristics of ice navigation, for example, time spent for progress by ramming, coefficient of the way meandering, etc.

Among numerous indicators of ice navigation conditions ice-navigation characteristics are especially important. They allow identification of the features and differentiation of ice navigation conditions and can also be forecasted with a different period in advance. These characteristics can be used directly for the organization and planning of marine operations on the NSR.

2.2 Traditional ice cover characteristics significantly affecting shipping

2.2.1 Concentration and amount of ice of different age categories

Out of the diverse navigation parameters of ice navigation conditions, ice concentration is most important. It governs, as a rule, the choice of an optimal navigation variant under real shipping conditions (Busuyev and Gordienko, 1976; Borodachev, 1974). The specific values of ice cover concentration are often used as a criterion of the conditions of icebreaking support (unescorted navigation of ships, icebreaking support, the possibility of routing by small-powered icebreakers, etc.). During planning and provision of scientific-operational support to summer navigation main attention is given to the collection of actual data on the boundaries of ice of different concentration. Also, during ice forecasting a great deal of attention is given to these characteristics(Gudkovich et al., 1972).

In spite of a considerable volume of information on the distribution of ice of different concentration, the quality and the resolution of this information does not always meet the shipping requirements, and, in particular, its operational management. This is connected with a significant spatial inhomogeneity and temporal variability of concentration, a subjective way of its assessment by observer, as well as averaging and generalization on the chart, partial inconsistency of airborne data with real navigation conditions (Buzuyev, 1975; Buzuyev and Fedyakov, 1981).

It has been found that in winter variability of the given characteristics is small, that is why its values recorded by means of airborne reconnaissance, are in a good agreement with shipborne data (Table 2.1). In spring and then also in summertime there is increased inhomogeneity of the ice cover distribution resulting in a noticeable discrepancy between the concentration values recorded over the region and those directly on the navigation route (Buzuyev, 1975).

Table 2.1. A ratio between the length of the segments with different ice concentration on the navigation route (C_n) and over the navigation region (C_r) in different navigation periods (%) for all segments of the NSR (Borodachev, 1974)

C_r in tenths	C_n, in tenths								
	fall-winter			spring			summer		
	0-3	4-6	7-10	0-3	4-6	7-10	0-3	4-6	7-10
0-3	100	-	-	100	-	-	100	-	-
4-6	5	95	-	96	4	-	70	28	2
7-10	-	-	100	22	5	73	27	45	28

On the basis of special shipborne observations data the following estimates of the effect of concentration of the motion in the ice are made (Gordienko et al., 1967; Borodachev, 1974): within the ice thickness gradations requiring icebreaking routing, the velocity of the routing decreases with a concentration increase. In the ice of these thicknesses the concentration increase by 1/10 is accompanied by a velocity decrease by 10% on the average (Fig.2.1). In thinner ice the velocity decrease due to its compacting is significantly less.

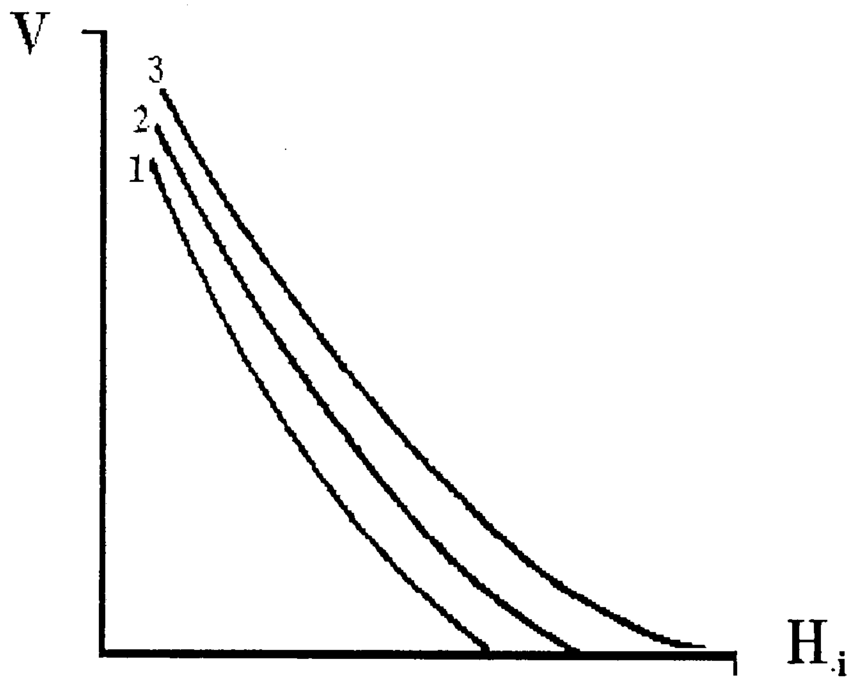

Fig.2.1. The character of the dependency of the ship's motion velocity on ice thickness and concentration

1 - concentration - 10/10,

2 - concentration - 8/10,

3 - concentration - 5/10.

2.2.2 Ice thickness

Among numerous characteristics governing the ice cover state, most significant appears to be the ice thickness. It is not by chance that many publications are devoted to the questions of ice thickness change and to methods of its calculation. Practically, all publications are devoted to ice formation, ice thickness growth or decrease at a specific geographic point on the basis of solving snow and ice heat conductivity equation. There are comparatively few studies analyzing spatial ice thickness variability (Buzuyev, 1966; 1968; Buzuyev and Dubovtsev, 1971).

The data on the ice age categories from airborne reconnaissance flights, satellite images allow an assessment of its thickness (Handbook,1981). This assessment, however, is rough, at least for first-year ice of medium thickness and first-year thick ice, and it is these age gradations that govern shipping conditions, as they prevail on shipping routes.

During the study of ice cover as a shipping medium, there are however, objective grounds to take into account a non-uniform character in the thickness distribution. The use of mean ice thicknesses without taking into consideration its spatial distribution is principally wrong when selecting test grounds for new icebreakers and ships, calculating scales of difficulties for breaking channels in fast ice, estimating the bearing capacity of ice cover (its carrying capacity) etc.

The measurements (Fig.2.2) carried out by Buzuyev in the Dikson Inlet illustrate the proportion between actual thickness distribution, data reported from polar stations and mean ice thickness.

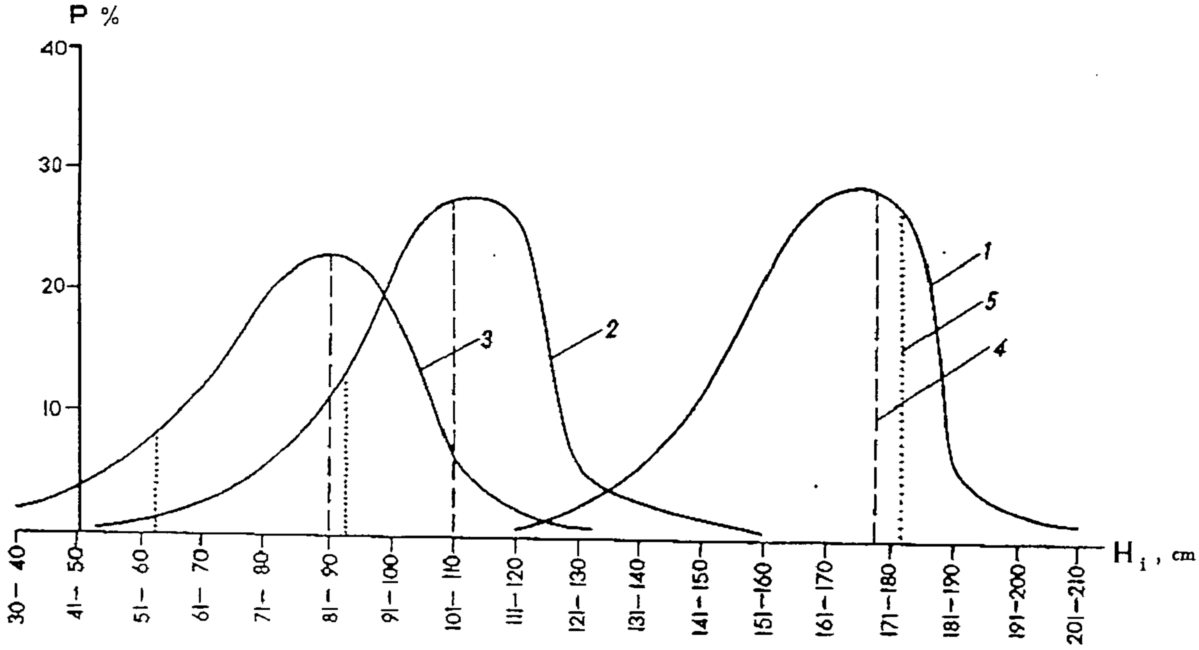

Fig.2.2. Occurrence frequency P (%) of measured values of thickness H_i of "level" ice

1 - before the onset of melting,

2 - at a degree of destruction of 3 arbitrary units,

3 - at a degree of destruction of 3-4 arbitrary units,

4 - mean ice thickness from the en-route data,

5 - ice thickness from the data of polar stations for the same period.

It has been found out (Buzuyev, 1966; 1968) that in most cases the ice thickness distribution fulfils quite well the Charlier function which is expressed by a ratio

$$F(x) \approx F_0(t) - \frac{S}{6}\varphi_2(t - \frac{E}{24}\varphi_3(t), \qquad (2.1)$$

where $F_0(t)$ - integral function of normal distribution,

S - assymetry coefficient,

E - excess coefficient

φ_2, φ_3 - second and third derivatives from F0 (t),

$t=(x-x)/\sigma$ - a random value on the standard scale,

σ - mean square deviation,

x_0 - arithmetic mean

x_i - random value

Density of the distribution probability

$$\varphi(x) \approx \frac{1}{\sigma}\left[\varphi_0(t) - \frac{S}{6}\varphi_3(t) - \frac{E}{24}\varphi_4(t)\right], \qquad (2.2)$$

where φ_0 (t) - function of a normal distribution,

φ_4 (t) - the fourth derivative of the normal distribution function.

The empirical functions of the thickness distribution of ice of different age categories are obtained from processed data of the observations carried out in the Arctic seas and also, on fast ice in Antarctica (Buzuyev,1968; Romanov and Ulitin, 1970).

A comparison of an empirical distribution with a theoretical one using Kolmogorov's criterion has shown their satisfactory agreement for multiyear (old) and first-year ice (Buzuyev, 1968; Buzuyev and Dubovtsev, 1971).

The measured thicknesses of first-year thin and medium ice, are as a rule, in a narrow range allowing the use of mean thicknesses for each of these age categories when addressing the applied goals.

As a result of some studies (Buzuyev and Dubovtsev, 1971;1978), a "contribution" of snow depth, amount of hummocking and degree of destruction into mean square deviation σ_n - quantitative characteristics of an inhomogeneous distribution of level ice thickness has been determined in the first approximation. It has been found that an increase of snow amount and hummocked ice increase the σ_n value. The changes of the value σ_n, due to irregular ice melting follow the general typical pattern.That is, when ice destruction is up to 2-3 arbitrary units σ_n increases, a further increase in destruction results in a decrease of σ_n. This is connected with the process of appearance, development and disappearance of thaw holes.

As has been indicated above, ice thickness along with concentration is considered to be one of the most important characteristics of the ice cover significantly affecting ice resistance to the ship's motion. Naturally, the more the ice thickness, the lower the ship's motion velocity.

A typical dependency of the motion velocity of an icebreaker in solid "level" ice during the spring-summer melting and fall-winter growth is given in Fig.2.3.

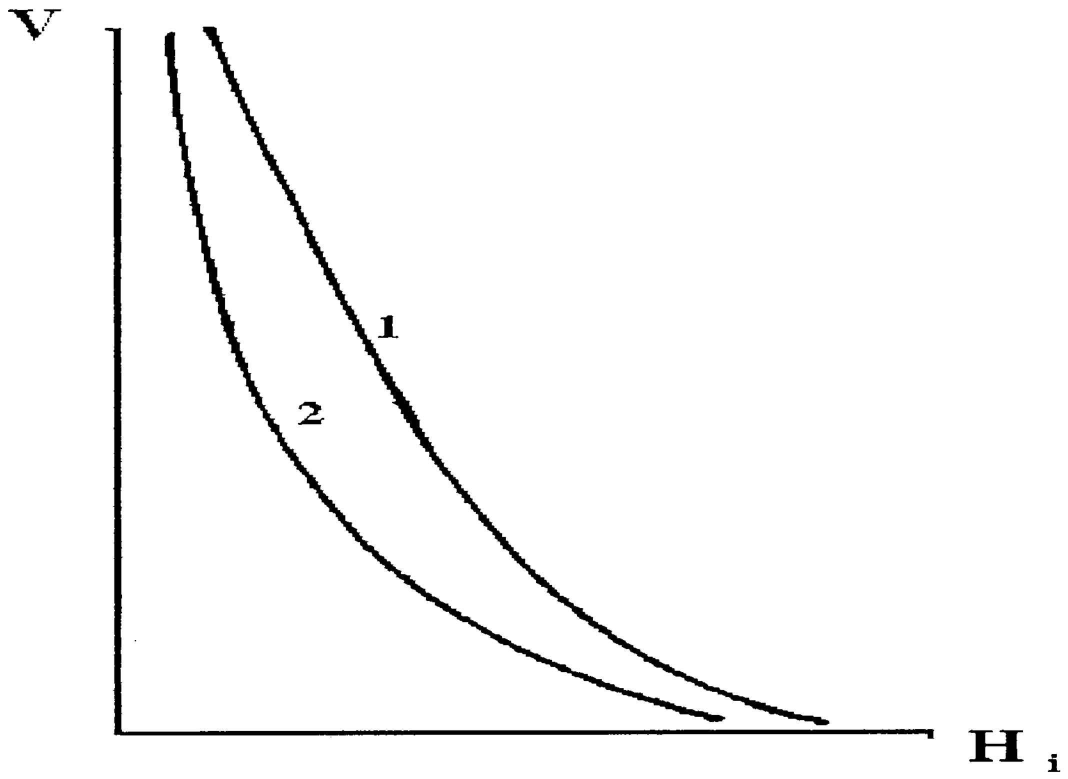

Fig.2.3. Dependency of the icebreaker motion velocity in solid ice in spring (1) and fall (2) on its thickness (Gordienko et al., 1967)

As can be seen from the diagram, the motion velocity of an icebreaker in the spring-summer period is higher than that during the fall-winter ice growth at the same thickness.

The studies (Sergeyev, 1978) carried out for the fall-winter period have shown an icebreaker to move with larger velocities in ice breccia consisting of ice of different age categories, than in level ice of the same age category and mean thickness corresponding to mean weighted ice breccia thickness.

2.2.3 Snow depth

Under natural conditions a ship is known to penetrate the whole snow-ice cover thickness. The knowledge of typical features of the distribution and variability of the snow depth on ice can significantly help in choosing the test site for full-scale tests of ships and assessment of their ice passage capability (Ryvlin and Kheisin, 1980). It is found that the presence of snow cover on ice is one of the most important conditions for the occurrence of a particularly dangerous phenomenon for shipping - ship adhesion (during the formation of the snow-ice "cushion") (Voyevodin, 1973).

Before the period of active navigation the observations of snow cover formation on ice in the fall-winter period were carried out occasionally. The studies were restricted to mean values of snow depth determined with a number of allowances (Gudkovich et al., 1972). Thus, for the Kara Sea mean snow depth on drifting ice is found to be less than on fast ice by a factor of 3.

An intensive development of shipping in the fall-winter period in the Kara Sea, super early transit cruises along the NSR during a maximum development of snow-ice cover resulted in enhanced interest to the study of features of the snow depth on ice. It is found that the variability of the snow depth on ice in the regions of traditional shipping in the Arctic is governed by the background of snow accumulation (mean snow depth $\bar{h}$). Within each region histograms are constructed and distribution parameters of the value $\Delta h_i = h_i - \bar{h}$ by groups depending on the level of mean snow depth (Buzuyev et al., 1979) (Fig.2.4), are calculated.

It has been found (Buzuyev et al., 1979) that having data on mean snow depths one can determine features of snow distribution on level ice, using the law of a normal truncated distribution:

$$\varphi(h) = \frac{C}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(h_i - \bar{h})^2}{2\sigma^2} \right], \qquad (2.3)$$

where c - proportionality coefficient close to 1.

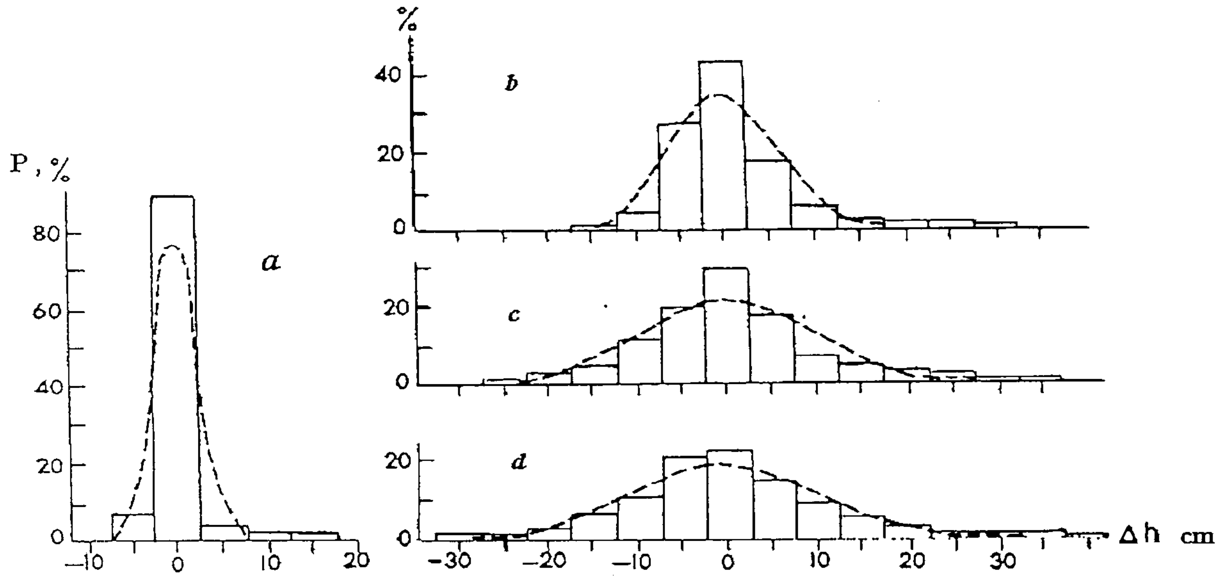

Fig. 2.4. Distribution histograms and their approximation (dotted line) of the value $\Delta h_i = h_i$ - for mean snow depth

a - $\bar{h}$ = 0-5 cm

b - $\bar{h}$ = 10-15 cm

c - $\bar{h}$ = 20-25 cm

d - $\bar{h}$ = 30-35 cm

The dependency between the height of hummocks h_{hum} and the snow depth h is approximated by the ratio:

$$h = 0{,}11\, h_{hum}^{1{,}30} \qquad (2.4)$$

Taking into account the distribution features of the height of hummocked formations an expression has been obtained which describes in the general form snow distribution in the zones of hummocked formations:

$$\varphi(h) = \frac{119{,}81\, h^{1{,}31}}{\sigma^3_{hum}} \sqrt{\frac{2}{\pi}} \cdot e^{-\frac{28{,}94\, h^{1{,}54}}{2\sigma^2_{hum}}} \qquad (2.5)$$

As a result, the distribution of snow depth on first-year ice, prevailing on the navigable segments of the NSR in the regions with a different amount of hummocking is governed by the dependency:

$$\psi(h) = \varphi(h)\, S_{hum} + \varphi(h)\,(1 - S_{hum}), \qquad (2.6)$$

where S_{hum} - hummocked ice area,

$\varphi(h)$ - snow distribution on level segments.

As a ship overcomes a total thickness of ice and snow, the distribution features of this value are considered (Buzuyev and Dubovtsev, 1978). And it is concluded that the variability of the thickness of total ice and snow layer is, as a rule, smaller than that of the components. The procession results indicate that the distribution of total thickness of "thick" (H more than 120 cm) ice and snow is approximated by the Sharlier law, of "thin" (H=30-70 cm) ice and snow - by a normal distribution law.

Due to the fact that snow cover on ice is distributed non-uniformly the use of full-scale observations of ice with a different combination of ice thickness and snow depth resulted in different conclusions with regard to its effect on the ship's motion velocity.

There are several methods of a similar assessment, the main point being that the snow cover effect on the ship's motion velocity is similar to an additional ice layer:

$\Delta H = h$ (Svistunov, 1973) (2.7)

$\Delta H = 1{,}5h$ at $V \leq 2$ knots (Kashtelyan et al.,1968) (2.8)

$\Delta H = 0$ at $h < 5\text{-}10$ cm,

$\Delta H = h$ at $h = 20\text{-}30$ cm,

$\Delta H = 1{,}5h$ at $h > 40$ cm (Sergeyev ,1979) (2.9) where h - snow depth,

ΔH - additional ice layer value.

In spite of the indicated differences in quantitative estimates, the effect of snow cover can be considered as an increase in ice cover thickness penetrated by a ship, by the value proportional to the snow cover depth.

2.2.4 Degree of ice destruction

The degree of ice destruction characterizes changes in the ice cover state related to the melting processes. As a result of melting, puddles and thaw holes are formed which break the continuity of ice cover significantly decreasing ice resistance to the motion of ships (Kashtelyan et al., 1968).

The appearance of ice melting features in the shipping regions is noted as a rule, 10 days later than in the coastal ones (at polar stations). The process of ice destruction is more intensive in the regions affected by run-off of the Siberian rivers. However, the differences in chronological variations of the degree of destruction over some regions are comparatively small being within the variability range of the considered characteristics for a 10-day period. This is governed by the factors which have the same values over extensive territories (air temperature, total radiation, etc.) When addressing the objectives of the support to shipping, the data on the degree of destruction provide a possibility to roughly estimate the ice thickness in the spring-summer period (Fig.2.5).

As has already been mentioned, the degree of destruction reflects a number of changes occurring in ice cover as a result of the melting process (strength decrease, change of the coefficient of friction, viscosity, etc.). An increase in destruction up to 2-3 arbitrary units and more induces occurrence of through thaw holes. Thus, at increased ice destruction the process of icebreaking by icebreaker attains an increasingly selective character: the areas of a more destructed and thin ice are subjected to breaking and thick ice is pushed aside by the icebreaker's hull (Kashtelyan et al., 1968).

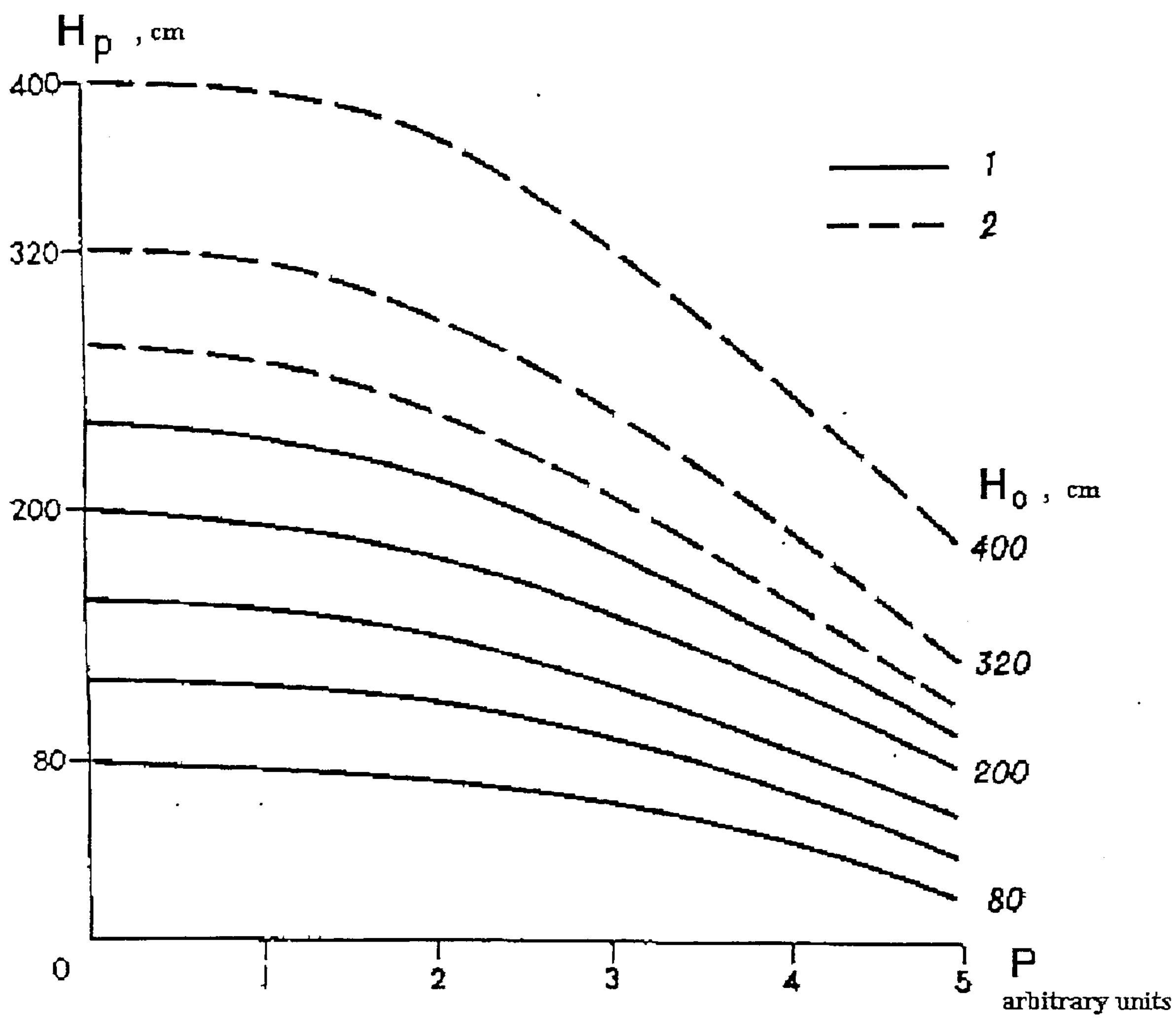

Fig.2.5. A nomogram of the ice thickness ratio during melting and destruction D at ice thickness at the end of the period of growth (from the data of Buzuyev)

For an icebreaker of the "Moscow' type (16.2 MW power) it is found that in fast ice and among big drifting ice floes an increase in destruction by 1 arbitrary unit (at an equal mean ice thickness) results in an increase in the ship's motion velocity by 15-20% (Gordiyenko et al., 1967).

2.2.5 Amount of ice hummocking

The presence of hummocked formations is a typical feature of sea ice. Hummocked formations significantly affect the ship's motion in ice being a serious, and sometimes impenetratable obstacle to shipping.

The observations of hummmocked formations are carried out in two main directions:

a. the amount of humocking is assessed by a 5 unit scale as a relative area occupied by hummocked formations (A Handbook, 1975);
b. the forms, dimensions and distribution of hummocked formations along the route are determined by means of special measurements.

A procession of spring shipborne observations has shown the probability of the coincidence of the amount of hummocking recorded within the visibility range, and directly along the motion course to decrease with an increase in the values of the amount of hummocking. This is related to a possibility of a selective motion of an icebreaker (Table 2.2). This ratio is characteristic of all segments of the NSR.

Table 2.3. A relative length of the way in the ice of a different amount of hummocking (R_w) depending on the amount of hummocking within the visibility range in the navigation region (R_v) in spring (%) (Buzuyev, 1975)

R_v, arbitrary units	R_w, arbitrary units				
	0-1	1-2	2-3	3-4	4-5
0-1	97	3	-	-	-
1-2	44	54	2	-	-
2-3	24	48	25	3	-
3-4	22	16	32	30	-
4-5	23	3	3	51	20

The values of the amount of hummocking in summertime from different observation types are consistent. This is connected with melting and destruction of parts of more thin and level ice.

In winter the values of the amount of hummocking differ with an increase in the daytime duration (increasing a possibility of a selective motion).

In recent years instrumental methods for determining the parameters of hummocked formations, their spatial distribution has become widely used. These studies were particularly intensive in the USA by means of laser profilometers and sonars installed onboard nuclear submarines.

In one of the basic works in this area (Hibler et al., 1972) a theoretical distribution of the ridge heights is inferred from a hypothesis of the chaotic location of hummocks. The system of ridges is described by two parameters: mean number of hummocks per a length unit (μ) and mean hummock height (h).

Mock (Mock et al., 1972) makes a conclusion that the ridge frequency (μ) is the best one-parametric characteristic, as it directly provides a good estimate of the distribution function of the ridge extent, correlates well with the ridge height, and is easily identified from aerial photography and laser profiles.

The questions of spatial-temporal variability of the amount of hummocking on the basis of laser profiling data are considered by Week (Week et al., 1980) and Wadhams (Wadhams, 1976; 1983). They make a conclusion about the presence of a significant seasonal variability both in the ridge number and height.

The procession of measurement data has allowed determining height distribution of ridges depending on the formation conditions, and approximating some of them by the Maxwell distribution. Its differential expression has the form (Klimovich, 1972; Buzuyev, 1975):

$$\varphi(h_i) = \sqrt{\frac{2}{\pi} \cdot \frac{h_{hum}^2}{\alpha^3}} \cdot e^{-\frac{h_{hum}^2}{2\alpha^2}}, \qquad (2.10)$$

where h_{hum} - a single value of the ridge height

$\alpha = 0.627\ \bar{h}_{hum}$ - distribution parameter.

A statistical analysis of the ridge distribution has shown (Mock et al., 1972) that it can be approximated by the Poisson's distribution, its parameter being determined from the measurement data.

A certain relationship has been established between the ridge height and the thickness of ice composing hummocked formations (Gordienko, 1967).

When studying the effect of the amount of hummocking on the motion of ships, the objective is usually to determine an equivalent ice thickness. From full-scale data on the motion of icebreakers (Sergeyev and Khromov, 1980) it is found that the motion velocity in level ice of a prescribed thickness does not practically differ from the velocity in hummocked ice of the same equivalent thickness. Thus, for estimating ice cover as shipping medium the amount of hummocking can be considered in the form of corrections to the level ice thickness. An increase in the amount of hummocking by 1 arbitrary unit results on the average in the growth of the equivalent ice thickness by 25%.

As a result of processing the data of a complex of observations, Buzuyev has obtained the proportion allowing an assessment of the time required by icebreaker to pass the ridges which cause her to stop:

$$T = \sum^{\mu} 4{,}07\, L_{hum} \cdot \frac{h^{0{,}466}}{\cos\beta}, \tag{2.11}$$

where μ - number of ridges per a route unit,

L_{hum} - width of hummocked zone,

h - mean ridge height,

β - icebreaker's attack angle of the ridge (an angle between the normal to the general ridge direction and the ship's diametral plane).

This ratio can be used when instrumental observation data of the ridge distribution are available.

2.2.6 Amount of fracturing

In the fall-winter and spring periods when the prevailing concentration of drifting ice is 9-10/10, the amount of ice fracturing is considered to be an important navigation characteristic characterizing the intensity of dynamic processes in the ice cover. The amount of fracturing is measured in arbitrary units according to a 10 unit scale (A Handbook, 1981). 0 - corresponds to solid fast ice and gigantic ice floes, and 10 - to small ice cakes. Suffice it to note that the velocity of a self-contained motion of icebreaker increases two-four-fold with a change in the amount of fracturing from 5 to 10 units depending on ice thickness, the other conditions being equal.

The shipborne ice observations do not envisage records of the amount of fracturing, however, the data on the ice forms allow a rough estimate of the values of this element.

The distribution of the horizontal floe dimensions on the sailing route is connected with a selective character of the ship's motion: the way of icebreaker is selected along the zones of the largest amount of fracturing. Due to this the most probable ("equivalent") dimensions of ice formations on the navigation route are distinctly smaller than mean values of the horizontal dimensions of the ice forms indicated in the "Nomenclature" (Nomenclature, 1974). On the basis of summarized data of shipborne observations in summertime the values of the "equivalent" dimensions of ice formations for ice of different age categories were obtained (Table 2.4), (Buzuyev and Fedyakov, 1983).

In the fall-winter period, when the prevaiing ice concentration in the Arctic seas is equal to 9-10/10 or more, the amount of ice fracturing becomes particularly important. As a result of analyzing the ice survey charts and the observation data charts of mean and extreme values of the amount of ice fracturing, as well as charts of mean square deviation α_r for February, March and April are plotted. The most significant features of spatial-temporal variability of the considered characteristics, mainly for the regions of the navigable routes are found out.

Table 2.3. "Equivalent" dimensions of ice formations passed by icebreaker in summer (meters)

Ice age category	FORMS				
	Vast floes, floes	floes	floes, medium floes	medium floes, broken	broken, ice cake
young, first-year thin	500	300	200	150	30
first-year medium	300	200	150	125	30
first-year thick	200	175	125	100	30
second-year, pack ice	175	150	100	50	30

For the fall-winter period an approximate estimate of the "equivalent" dimensions is obtained by multiplying the value given in Table 2.4 by the coefficient found empirically and which is equal to 1.5 in January-February, 1.4 - in December and March, 1.3 - in April and November, 1.2 - in May and October.

As has been mentioned above, full-scale observation data indicate that horizontal floe dimensions have a significant influence on the motion velocity of ships. At other equal conditions the minimum velocity values are noted in fast ice and gigantic (vast) floes of drifting ice, and the maximum velocities are recorded at the motion in ice cake and small ice cake. The evidently missing observation data, however, still limit the solution of the problem of using quantitative methods to assess the effect of the amount of fracturing on shipping.

2.3 Ice formations as a shipping medium

It is known that the entire ice cover of the Arctic Seas is subdivided into two main types: drifting ice and stationary ice (fast ice).

Drifting ice can also be subdivided into several main types of ice formations, their state being governed by a number of "traditional"ice cover characteristics.

Ice massifs appear to be the largest of such formations (Gudkovich et al., 1972). Ice massifs, as conglomerations of strong compact ice, stable in time and space, (the main quantitative characteristics of the massif - ice thickness more than 30 cm, concentration - more than 7/10) are considered to be a significant obstacle for navigation of ships of any class. Within the boundaries of the massif it is of particular difficulty to penetrate through the so-called core of the massif (ice thickness is more than 120 cm, concentration -more than 7/10). The position and size of ice massifs depend mainly on a combined effect of the wind and currents being therefore, subjected to significant interannual fluctuations (Gudkovich et al., 1972). Multiyear data on the dynamics of ice massifs are important as they are used for choosing an optimal route and determining the dates of different ice navigation types of ships.

The length of the way in the ice of 7-10/10 concentration serves as a criterion of the complicated ice navigation conditions.

Outside the limits of ice massifs, mainly in summertime there are zones of open (4-6/10 concentration) and very open (1-3/10 concentration) ice. The presence of such zones, where navigation is connected with much less difficulties, than in ice massifs, significantly facilitates the choice of an optimal variant of the transit cruises on the NSR.

All Arctic Seas are characterized by the existence of areas of ice-free water in the spring-summer period and young ice (less than 30 cm thick) in wintertime observed behind fast ice (the so called flaw polynyas or flaw zones of young ice - FZYI).

The experience of the scientific-operational support to navigation of ships indicates that these formations appear to be one of the main constant factors governing both the optimal navigation variants and directly the route of ships. The most full information on flaw polynyas in the Arctic seas and the main features of their regime are presented by Zakharov, who makes zonation of polynyas. By analyzing occurrence frequency (P) all polynyas are differentiated into three types: recurring (P more than 50%), seasonal and temporal (P less than 50%). The conclusion is made that the formation of recurring polynyas is related to the dominance of the off-shore ice drift relative to the fast ice edge, (Kupetsky, 1958; Zakharov, 1966; Arikainen, 1981). The enumerated studies, however, were based on the visual airborne reconnaissance that up to the 80s was carried out in the winter-spring period once a month. In recent years due to the introduction of instrumental methods of ice cover diagnostics (primarily, with the use of satellites), a possibility has arisen to track the evolution of FZYI. Adamovich obtained data which allow when necessary, an estimate of the most favourable months for escorting ships along the flaw zones of young ice of the western NSR segment. The FZYI areas and the development coefficient indicating the presence of the isthmus of "older" ice (H more than 30 cm) have been used as their natural navigation characteristics.

The presence of break-up in solid ice cover (BSI) is considered to be a typical feature of drifting ice of the Arctic Seas in winter. This term means most often cracks, leads and fractures in compact ice.

Lately, the nature of the break-up in solid ice in wintertime has been largely investigated. The results of these studies have allowed a conclusion that the main reason for the appearance of discontinuities and formation of the break-up system is spatial variability of the ice drift governed by a non-uniform wind field and the mainland distribution features (Losev, 1975; Karelin, 1985). Three main types of the system of break-ups have been observed: radially bent, linear quasiparallel and polygonal ones (Karelin, 1985). It has been found that the formation of the break-up begins when ice breccia becomes stable and reaches a maximum development and orderliness in April-May. With the onset of melting the destruction of ice breccia takes place governing disintegration of BSI systems.

The study of the system of discontinuities has allowed one to determine their main characteristics: prevailing directions, frequency, etc.

The direction of large break-ups (300 m wide and more)in ice cover has a large temporal stability (up to 10 days and more) (Karelin, 1985).

The experience of winter navigation on the western NSR segment shows the effectiveness of using the system of break-ups when choosing an optimal navigation variant. Knowledge of the typical features of the formation of the break-up system has allowed one to introduce the non-traditional navigation variants. This resulted in increased velocity of the routing, and reduced length of the route in ice. An objective assessment of the effect of the break-up in solid ice is still to be made. However, special shipborne observations showed that when the icebreaker's motion course coincides with the orientation of the break-ups the motion velocity increases by 1.5-2 times as compared with the motion when the orientation of the break-up does not coincide with the general course).

With the use of powerful icebreakers of the "Arktika" type fast ice has become an active shipping medium. When navigating along the Northern Sea Route by the guaranteed depths (more than 20 m) the north-eastern Kara Sea is the only region where the route can be along the fast ice. The difficulties related to breaking the channel in the springtime (during the maximum growth of the ice cover thickness) are compensated to a great extent due to an effective routing along the channel. The use of fast ice allows a significant increase in the duration of navigation, organization of cargo delivery to an unequipped coast.

Numerous studies are devoted to the fast ice formation features, spatial distribution of its main characteristics and destruction. The main features of fast ice as shipping medium are considered by Gordienko and Buzuyev. It is found (Gordienko et al., 1967) that the effectiveness of the icebreaker's motion in fast ice depends on ice thickness, amount of ice hummocking, amount of snow and destruction degree, amount of inclusions of remaining ice.

It should be noted that usually fast ice formation in the north-eastern Kara Sea is extended in time (from the date of a stable ice formation to fast ice formation there is more than a month) (Buzuyev, 1975). This fact makes possible a redistribution of drifting ice which later forms fast ice resulting in a distinct non-uniformity of the fast ice thickness already at the time of its formation. Thus, even at the moment of a maximum ice growth there are sufficiently extensive areas with both enhanced and reduced background of ice thickness, although according to the" Sea-Ice Nomenclature" this ice mainly consists of first-year thick ice. This feature of fast ice should be taken into account for planning navigation in the indicated region (Buzuyev et al., 1989).

Fast ice is a monolithic ice plate. It is characterized by the presence of stationary cracks and break-ups (Komov and Kupetsky, 1975; Losev, 1975). Their use for breaking the channel significantly increases the effectiveness of icebreaking operation. Also, in the process of the fast ice "life" the cracks and break-ups can diverge up to the width comparable with that of the icebreaker's hull. This leads to the formation of oriented insertions with a decreased background of ice thickness in fast ice. The use of similar insertions in May of 1989 allowed the nuclear icebreaker "Rossya" to travel in the fast ice area of the north-eastern Kara Sea for 25.5 hours. Mean times to traverse this region (without the use of oriented insertions) constitute 60-70 hours (Buzuyev et al., 1989).

Rapid ice freezing together in the channel is one of the features of navigating in fast ice in the fall-winter period. That is why the motion velocity along the channel made is governed by the "age" of the channel, amount of snow and thickness of fast ice. In spring navigation in fast ice along the broken channel is made at large velocities, as there is no ice freezing together.

2.4 Ice phenomena governed by the dynamic processes in ice cover

2.4.1 Ice pressures

Ice cover compacting appears to be one of the main characteristics governing navigation conditions in the Arctic seas, especially in winter. Pressures result in a sharp deterioration of navigation conditions, often turning out to be the cause of the forced drift of the ships and ice damages (Voyevodin and Kashtelyan, 1979; Voyevodin, 1981). The wind is known to be the main cause for ice pressures in the Arctic seas. The study of the occurrence of ice compacting on the navigation route depending on wind regime features in winter has allowed developing methods for estimating the conditions at which compacting is possible. Estimates of the intensity of this phenomenon were obtained for various NSR segments (Buzuyev and Fedyakov, 1979). From the obtained data it follows that weak pressures (0-1, 1 arbitrary unit) prevail in the Arctic Seas. This fact is confirmed also in the data of air - and shipborne observations. In the coastal zone of the seas, however, the pressures at on-shore winds can be very intensive, being one of the reasons for making the ship escort along the coast difficult. The generalization of shipborne data has allowed the study of some features of spatial-temporal variability of the phenomenon under consideration. Three types of spatial distribution of ice pressures are identified: local(source), zonal (compacting "strips") and regional (Voyevodin, 1978). The variability limits of the occurrence and duration of pressures of a definite intensity are found out.

A large occurrence frequency of strong winds during a frequent passage of air pressure systems governs a high occurrence frequency of pressures in the fall-winter period. A short analysis of a spatial extent of ice compacting zones and variability of its intensity during winter has been made by Adamovich from the results of generalized standard shipborne observations.

Although wind-induced ice pressures prevail in the Arctic seas, however, under specific conditions shipping is significantly affected by tidal pressures. They are most pronounced when navigating in the ice with concentration of 9-10/10, 10/10 and more than 70 cm thick (Report of the scientific-operational hydrometeorological support, 1988). To characterize the change of the motion velocity of ships in prescribed ice conditions due to compacting of different intensity the coefficient K_p is used which is equal to the ratio of the ice velocity during compacting to the ice velocity in the ice of the same characteristics but without compacting. Sergeyev has found a dependency of K_p on the thickness and prevailing ice forms in summertime. The use of the K_p coefficient has allowed estimating seasonal changes of the effect of compacting on the velocity of a self-contained motion of icebreakers in ice and of an icebreaking escort of ships.

It is found that the effect of compacting on the motion velocity of icebreaker depends on the icebreaker type and capacity of its power plant. It is known, however, that strong pressures can lead to forced drift of even modern powerful icebreakers. It follows from the above that pressures (as one of the dynamic deformation processes of drifting ice of the Arctic Seas) should be carefully studied.

Deformations and horizontal shifts of fast ice are much less investigated (Kulakov and Legen'kov, 1981; Skokov, 1981; Dickins, 1981). Such deformation processes result in the navigable channel becoming more narrow, as observed in wintertime. This phenomenon is accompanied by convergence of the broken channel edges and formation of separate ridges. This makes the routing of ships rather difficult and results in some cases in damage to ships.

The procession of shipborne observation data by Adamovich has allowed an assessment in the first approximation of occurrence frequency of significant deformations, as well as their effect on shipping in fast ice of the Yenisey Bay.

The results of this study indicate the deformations of fast ice in the mouth area of the Yenisey river and resulting convergence of the broken channel to be related mainly to air temperature variations. The dominating role of air temperature variations in the deformations and stresses of fast ice is also mentioned by Dickins (1981). No direct dependence of pressures on level oscillations was observed. It is found out that occurrence frequency of the phenomenon dramatically increases with an approach of spring (March-May) - up to 28% in some zones of fast ice region. As a quantitative expression of the extent of the influence of channel convergence on the motion of ships, the value of a relative navigation velocity decrease is suggested. It depends on the value of linear ice deformation and on the type of the convoy moving in ice. According to Adamovich, for the convoy including: icebreaker of the "Kapitan Sorokin" type (16.2 MW) and one UL ship, the value of a relative velocity drop was 40%. Naturally, these estimates characterize the effect of the channel convergence only in the given area. However, the obtained dependencies should be considered for planning and organization of voyages in fast ice regions of the NSR.

2.4.2 Ice adhesion of ships

During the fall-winter period one observes occasionally a phenomenon of ice and snow adhesion to the hull of ships. The essence of this phenomenon is in phase transformations of supercooled ice, snow and water mass at an increase of pressure in the contact zones with the ship's hull (Voyevodin, 1973; Voyevodin et al., 1981). Under certain conditions a sharp drop in the ship's velocity induced by adhesion - formation of the snow-ice "cushion" on the hull, can lead to an accident.

One distinguishes three gradations of adhesion intensity depending on the thickness of the snow-ice cushion: weak (1-2 m), moderate (2-5 m) and strong (more than 5 m).

Adamovich suggested to assess the adhesion intensity by the value of a relative drop of the ice velocity (Fig.2.6).

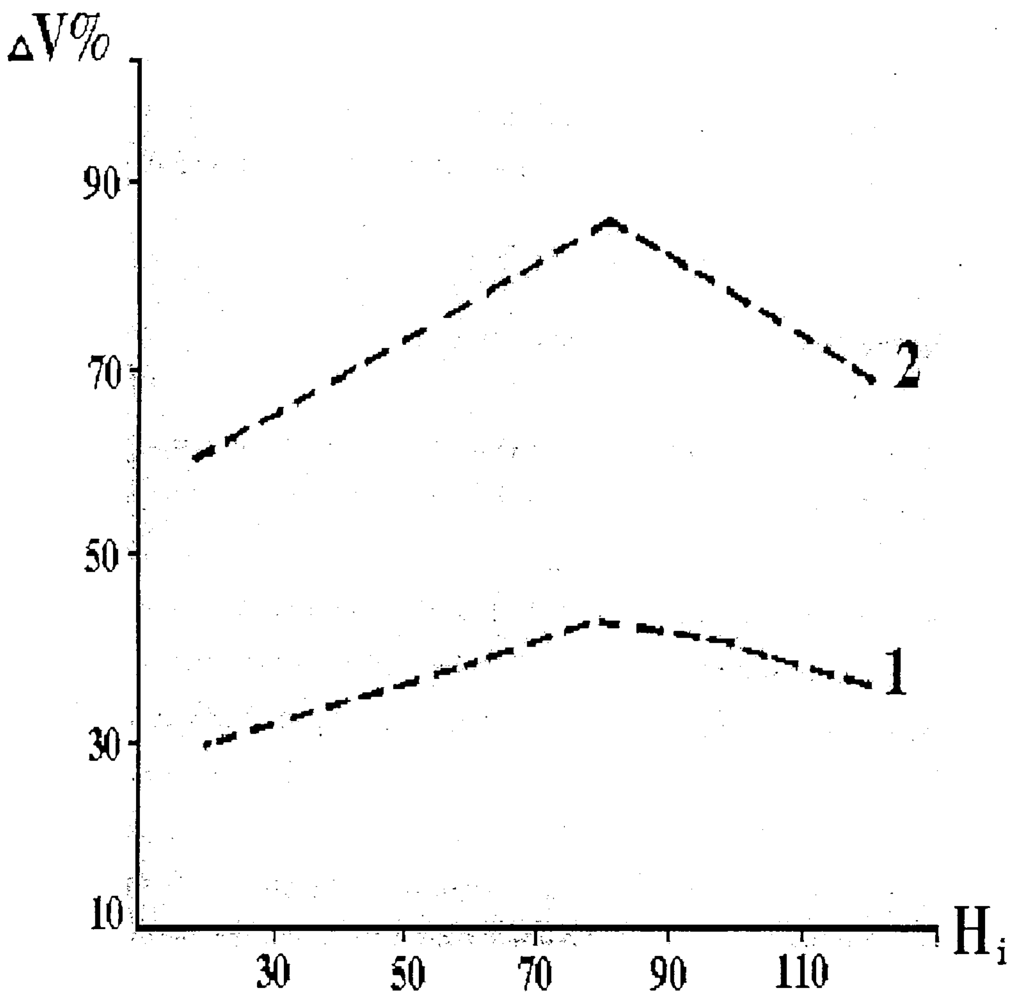

Fig.2.6. Dependency of ΔV on ice thickness at a moderate (1) and strong (2) adhesion for a standard convoy (1 nuclear icebreaker + 1 ship of the SA-15 type) (from Adamovich)

The adhesion is observed during the entire winter-spring period. According to Adamovich the maximum occurrence of the phenomenon under consideration in the Kara Sea was 22-23%, in the Barents Sea - 28%. Since the formation of the snow-ice "cushion" is governed by a complex interaction of the parameters in the system snow-ice cover-icebreaker's hull-surface water layer, a comparison of seasonal variations of the mean adhesion occurrence with seasonal variations of some indicators of hydro-meteorological and ice conditions has not revealed any specific dependences.

One of the phenomena accompanying adhesion is ice compacting. The factors contributing to the formation of the snow-ice "cushion" also include an enhanced amount of hummocking (more than 2-3 arbitrary units) and snow amount (Voyevoding, 1973; 1981; Voyevodin et al., 1981).

The average extent of the zones where adhesions are observed is not large as compared with the total extent of the route in ice and does not exceed 10% on different segments (from Adamovich).

2.4.3 "Ice river" and the zones of the drift boundary

The phenomena and ice formations related to dynamic processes in ice cover should also include a phenomenon of the "ice river" and drift boundary zones.

The "ice river" phenomenon is an intensive drift (with a speed up to 5 knots) of a narrow enough ice zone among relatively stable ice cover. The "ice river" is considered to belong to the category of dangerous ice phenomena, as under certain conditions it creates accident situations.

The existence of the drift boundary zones is governed by convergence or divergence of the ice cover drift. The drift boundary zones are most evident in winter (with a prevailing ice concentration of more than 9-10/10). They are characterized by increased amount of ice fracturing and hummocking, a higher probability of pressures.

These phenomena and formations are considered to be insufficently studied. That is why an assessment of their effect on shipping (the need for which is obvious) is possible only after special full-scale studies.

2.5 Special ice characteristics of navigation conditions

Studies of ice cover from ships of active ice navigation carried out in the last decade have revealed a need for investigating a number of special ice characteristics that have a significant influence on the progress of marine operations.

A feature of these characteristics is that they not only indicate a specific ice phenomenon (ice cover state) but also the character of its interaction with a moving ship. Thus, it is evident that the study of these characteristics and assessment of their effect on shipping is impossible without special shipborne observations.

2.5.1 The orientation type of a break-up in solid ice relative to a general course of icebreaker's motion

During the fall-winter period the type of the orientation of break-ups in solid ice relative to a general course of icebreaker's motion appears to be one of the most important special ice characteristics.

An experience of scientific-operational support to non-standard marine operations - experimental high-latitudinal voyages, early transit cruises along the NSR during the maximum growth of ice cover thickness have allowed Makarov and Frolov to determine three main types of the orientation of discontinuities in solid ice relative to a general course of icebreaker (Fig.2.7):

- zone of the "oriented" BSI: the prevailing orientation of the system of break-ups and the general course of icebreaker coincide or differ by not more than 30°. The progress of icebreaker in this zone is stable and is mainly along the break-ups and leads, overcoming some floe connections and irregularities of the edges of leads and fractures;
- zone of "non-oriented" BSI: the icebreaker's progress is along the system of break-ups, their orientation is small or the prevailing orientation of break-ups in solid ice differs

from the general icebreaker's course by not more than 30°. Icebreaker's progress in this zone combines sailing by break-ups and leads with the need to penetrate isthmus of compact ice (big floes and ice breccia). The velocity distribution in this zone is of a bi-modal character, the peaks of which correspond to the motion velocity in leads and break-ups and to the motion velocity in big floes.The progress in this zone is less stable than in the zone of "oriented" BSI requiring an increased attention of navigators to avoid ice damages;

- zone without BSI. The character of the ship's motion in this zone is governed by a combination of "traditional" ice cover characteristics (thickness, amount of hummocking, etc.). Mean motion velocities in this zone are significantly smaller (under other equal conditions) than in other zones.

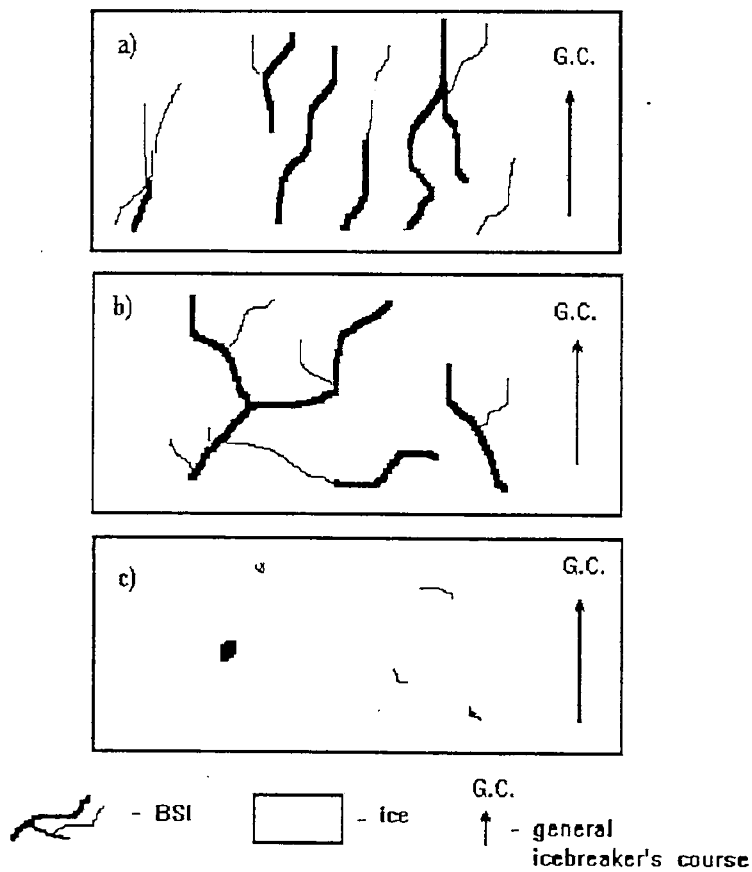

Fig.2.7. Types of BSI distribution relative to a general course of an icebreaker

1 - zone of "oriented" BSI

2 - zone of "non-oriented" BSI

3 - zone without BSI

The distribution character of the motion velocity in the zones identified is presented in Fig.2.8.

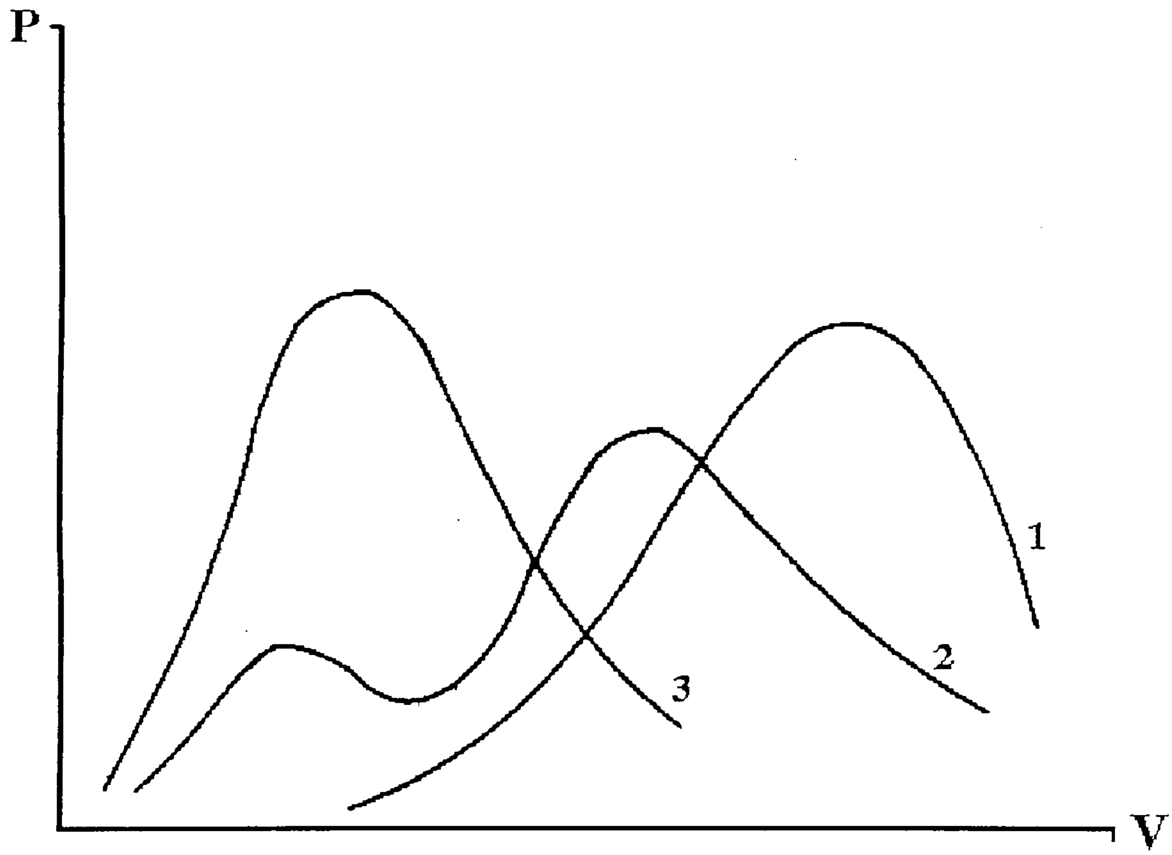

Fig.2.8. Distribution character (occurrence frequency) of the icebreaker motion velocity in the zones of different orientation of the BSI (from Makarov and Frolov)

1 - zone of "oriented" BSI

2 - zone of "non-oriented" BSI

3 - zone without BSI

The orientation type of BSI relative to the general course of icebreaker appears to be one of the main characteristics for the identification of uniform ice zones during the winter-spring navigation period.

2.5.2 Characteristics of the amount of hummocking

When navigating in the fast ice region, during trials of new icebreakers and ships at the test sites, additional data on the amount of hummocking allow resolving a number of applied problems (choice of an optimal variant for breaking the channel, location of the standard mile at field test sites, etc.). As a result of special shipborne observations, it is found that the following characteristics allow a more reliable assessment of the effect of hummocked formations on shipping:

- character of hummocked formations (chaotic, ridges);
- number of ridges per route unit;
- orientation of ridges relative to the general course of icebreaker.

Insufficient observation data, however, do not so far allow a quantitative assessment of the effect of these characteristics on the motion of ships in ice.

Let us note in conclusion that increased shipping along the NSR, specialized information on ice navigation conditions govern the need for further investigating special characteristics of navigation conditions.

2.6 Operating characteristics of icebreakers and ships of active ice navigation

2.6.1 Velocity of the ship's motion within a uniform ice zone, total time consumption, coefficient of the ice navigation difficulty

Studies of ice cover as a shipping medium, assessment of the economic effectiveness of cargo transportation and of respective hydrometeorological support require a quantitative indication of the scale of difficulties for ships navigating in ice. This indication should take into account a variety of combinations of ice cover characteristics and estimate the capability of a ship to overcome ice resistance without damaging the hull on the segments of different length. One of the most objective indications of the successful motion in ice is the velocity of the latter (Gordienko et al., 1967; Buzuyev et al., 1981).

When moving in ice the following types of velocities are considered:

- ice passport or "instantaneous" velocity (V_{ip}) - the velocity that a ship is capable of developing in standard ice conditions at different operation modes of the power plant. It is determined as a mean of the measurements made during the established ship motion;

- ice technical velocity (V_{it}) - the maximum possible (simultaneously maximum safe) velocity with which ship is capable of penetrating uniform ice on the segments of a sufficient length (more than 1 mile). For ships with strong hulls V_{it} is restricted (in the prescribed ice conditions) by the capacity of their power plant. For ships with a weak hull it is restricted by the strength of their hulls. Ice technical velocity is determined from the data of full-scale observations for each combination of ice cover characteristics. It is calculated as a quotient from the division of the route length in uniform ice by total time consumption for this period excluding delays en route not connected with ice penetration at the full capacity of ship's power plant. The ice is considered to be uniform if its characteristics change on the route segment chosen within the accuracy of conventional observations;

- ice operating net velocity (V_{ion}) - mean statistical velocity of ship's motion on the route segment with uniform ice. It is determined similar to the ice technical velocity, but is not related to a limit operation mode of the power plant. It is assumed that ship's power plant has an optimum operation mode providing for the safety and effectiveness of the ship's motion in various uniform ice zones. Thus, V_{ion} - a real operating velocity of the ship's motion from which all delays not related to ice and hydrometeorological conditions are excluded;

- operating gross ice velocity (V_{iog}) - mean ship velocity on the route segment obtained taking into account all types of delays.

The value of V_{ion} is an important characteristic of navigation conditions that allows a comparison of navigation conditions on a specific route in various navigation periods. An important advantage of these characteristics is that it is independent of the delays en route governed by the technical, organizational and other non-hydrometeorological factors. The use of only the V_{ion} data, however, does not allow a solution of many problems in planning of marine operations.

Evidence about the V_{ion} is used to determine another parameter of the ice navigation difficulty - total times for navigating a specific NSR segment for different types of ships and convoys (Σt). The value of Σt is determined for each stage of Arctic navigation on the main navigable routes. It is used in the plan of marine operations and for assessing economic effectiveness of cargo transportation and scientific-operational hydro-meteorological support to shipping.

For a more complete and objective comparative assessment of the difficulties connected with the motion of icebreakers and ships of different types in ice, another operating indicator of navigation conditions has been suggested - a coefficient of the navigation difficulty (Buzuyev and Gordienko, 1976). It is determined as a ratio of the ice operating net velocity of ship (convoy) on the segment with the known ice cover characteristics to its operating velocity in open water.

The studies showed (Buzuyev and Gordienko, 1976) that the use of K_d is advisable for investigating the navigation features at different navigation stages and determining the dates of a possible beginning and end of unescorted and other types of navigation of ships of different categories. The K_d indicator is used for dividing ice conditions into types, for a comparative analysis of the navigation difficulty along the specific routes, for a study of seasonal variations of the changes in navigation conditions on different routes.

2.6.2 Time consumption for the progress by ramming

Up to the present time the ice passage capability serves as one of the main parameters of the effectiveness of icebreaker's operation (Kashtelyan et al., 1968). Its values indicate a maximum thickness of level solid snow-free ice that is penetrated at a minimum velocity of a stable continuous motion (usually, $V_{min} \approx 1.5$ knots). Since such ideal conditions in nature are the exception, the indicated ice passage capability is called "ideal".

The operating ice passage capability serves as an indicator of the effective operation of icebreakers in real natural conditions when navigating in the ice with a wide range of combinations of ice cover characteristics. Its quantitative indication similar to the "ideal" ice passage capability should be a minimum operating ice velocity (V_{ion}) at which the motion in ice is continuous (without stops). The operating ice passage capability indicates effectiveness of operation of icebreakers not only in solid ice of different thickness, amount of hummocking, snow amount, etc., but also in compact drifting ice with a different combination of characteristics including pressures and other phenomena in ice cover. And the minimum V_{ion} in fast ice is (according to Buzuyev) about 1.5-2.0 knots, being about 4-5 knots in compact drifting ice.

When navigating under the conditions beyond the limits of the operating ice passage capability, a continuous character of ship's motion is combined with operation by ramming (thrusts).

When estimating the reliability and safety of ice shipping outside the operating ice passage capability, the time consumption for the operation by ramming (t_r) is determined. This quantitative indicator is determined as a percentage of the time lost for ramming in a uniform ice zone to the total time lost to penetrate a uniform ice zone under consideration.

Using the parameter t_r, the character of the icebreaker motion can be divided into four types:

- motion by occasional ramming ($t_r < 20\%$);
- motion by frequent ramming ($t_r = 20\text{-}50\%$);
- motion prevailingly by ramming ($t_r = 50\text{-}70\%$);
- motion by continuous ramming ($t_r > 70\%$).

As a result of processing special shipborne observation data, the most probable values of the parameter t_r and their variability are obtained for standard navigation conditions.

The importance of the given parameter when estimating the effectiveness of cargo transportation, risk and reliability of shipping in the Arctic seas is obvious.

2.6.3 Coefficient of the route meandering within a uniform ice zone

Much has been said above about the selective character of the motion of icebreaker. It means that the motion is along the way of the least resistance, that is, along the ice zones of lower concentration, smaller ice thickness and more level ice. An assessment of the possibility of a selective motion of icebreaker under certain ice conditions can be made by means of the coefficient of the route meandering (within a uniform ice zone) - K_m. Its value is determined as a ratio of the shortest distance between the initial and end points of the motion in the zone L_s. to the actual navigation extent in a uniform zone L_a:

$$K_m = \frac{L_s}{L_a} \tag{2.12}$$

The meandering coefficient is used as additional characteristics when assessing the time for travelling the route segment, a risk of ice damage and when addressing some applied objectives of ice shipping planning.

2.7 Ice-operating information for the organization and planning of shipping

Regime information about ice conditions and operating navigation characteristics of icebreakers and ships that refers to the routes and navigation variants represents ice-operating information on navigation conditions along the NSR. This information reflects mean values of characteristics and it is divided into groups (types) of disparate navigation difficulty.

2.7.1 Ice characteristics of navigation conditions

Ice-operating information indicates a statistical distribution of ice and operating characteristics of navigation conditions including some additional parameters, such as occurrence of the position of an optimal or the easiest navigation variant in ice, duration of different navigation types and a required icebreaking support, etc.

Ice characteristics of navigation conditions are represented by the length of the route in the main ice zones identified with regard to shipping. This means preservation of navigation type, preservation or insignificant changes in operating characteristics (character and velocity of the ship motion) within the ice zone identified. The main ice zones usually include:

a. during the summer navigation period:

- very open ice - zone with ice concentration not more than 30% (≤ 3/10);
- open ice - zone with ice concentration of 40-60% (4-6/10);
- ice massif - zone where concentration of ice more than 30 cm thick (beginning with first-year thin) is 70% and more (≥ 7/10);
- ice massif core - zone where ice more than 120 cm thick (beginning with first-year thick) occupies more than 70% and more (≥ 7/10) and where young ice (H<30 cm) and open water comprise not more than 10%(≤ 1/10);
- ice massif periphery - part of the ice massif except for the massif core;
- fast ice - immobile ice cover.

b. during the fall-winter navigation period:

- polynyas and zone of young ice (ZYI) - zone where young and thinner ice (H< 30 cm) including open water zone comprise more than 50% (>5/10);
- ice massif - zone where ice beginning with first-year thin ice (H>30 cm) is 50% and more (≥ 5/10);
- core and periphery of the ice massif - identified similarly to the summer navigation period;
- fast ice - immobile ice cover.

As additional ice indicators of navigation conditions, the lengths of the route in zones of specific ice cover characteristics that significantly affect a certain type of navigation or of ship can be considered. These characteristics and their effect on shipping are analyzed in detail in section 2.2.

2.7.2 Operating navigation characteristics and their use as indicators of ice conditions and for selecting an optimal navigation variant

The operating characteristics of navigation conditions (motion velocity, time consumption, coefficient of navigation difficulty) for specific types of icebreakers and ships are used in several forms. First of all, as criteria for choosing an optimal variant and navigation type in terms of their safety and economic effectiveness. Secondly, as parameters for dividing ice conditions into types, allowing one, using common methods, to divide into types all diverse ice cover characteristics on the navigation route in various NSR regions for any season of the year. And, finally, as quantitative indicators of the ice navigation difficulty to assess its distribution under mean and typical ice conditions along the routes and on the entire NSR.

A large data set of full-scale data on operating characteristics of the motion of icebreakers and ships in real ice conditions (in special AARI expeditions) has allowed an assessment of the influence of some ice cover characteristics on the difficulty (success) of navigation. This resulted in the construction of an empirical-statistical method and the model for a quantitative assessment of the navigation difficulty in ice (the "QAD" model). The tests of the "QAD" model under conditions of operational support to real voyages in the western Arctic for 5-7 years has allowed an adjustment of the model with a calculation error of operating characteristics for icebreakers and ships being not more than 10%. Also, statistical data on operating parameters of actual voyages along the segments of the western Arctic all-year-round for 5-7 years were obtained.

A subsequent application of the "QAD" model to systematized full-scale observation data of the ice cover distribution (composite ice charts constructed on the basis of data of airborne ice reconnaissance, satellites and other sources) collected over more than 40 years of regular ice observations on the NSR (for the summer-fall period with a 10 day interval and for the winter-spring period with a monthly interval) has allowed an identification of an optimal navigation variant in real ice situation all-year-round. Also, standard-reference information on the distribution of ice cover characteristics and calculated operating parameters for various classes of ships were obtained.

For the determination of an optimal navigation variant one uses criteria of safety and economic effectiveness of ice navigation. They can be expressed through operating parameters. In particular, safety of navigation is governed by a minimum permissible velocity of a continuous motion of ship or icebreaker in ice and economic effectiveness - by a minimum time consumption for navigation along the route under consideration (the NSR segment) between the departure and destination points. Taking into account differences in operating parameters and, respectively, in the indicated criteria for ships of different types, one can also expect significant differences in the location of an optimal navigation variant. In practice, however, this does not take place due to the use of the concept of icebreaking support and obligatory icebreaking routing of ships on the NSR segments with heavy ice conditions.

Strictly speaking, using these (or similar) criteria, an optimal navigation variant can be chosen for any type of icebreaker, ship or a convoy of ships, the motion of which is described by the "QAD" model. However, taking into account that the success of most NSR transport operations is governed by the technical capabilities of the most powerful modern icebreakers (nuclear icebreakers) of the "Arktika" type (power - 75 000 hp) and minimum errors in the determination of their operating characteristics by the "QAD" model, the operating indicators of the "Arktika" served as main criteria for choosing an optimal route on the NSR. In particular, navigation safety is achieved provided that the minimum calculated velocity of a continuous motion of the "Arktika" is not less than 1.10 of its passport velocity in open water (that is $V_{min} > 1.7$ knots) and navigation
effectiveness is achieved by observing the minimum of the calculated time consumption for navigation between the departure and destination points.

2.7.3 Generalized ice-navigation indicators of navigation conditions

The design of new icebreakers and transportation vessels, organization and planning of shipping along the NSR require to address the following goals:

- a comprehensive climatic assessment of ice navigation conditions taking into account their effect on shipping;

- differentiation (division into types) of ice conditions by the navigation difficulty with an assessment of their occurrence frequency;
- forecasting of ice navigation conditions on different segments and along the whole NSR for some navigation periods.

A solution to these problems is possible using operating and ice-operating parameters that indicate a total effect of diverse ice cover characteristics on the success of navigation.

Most often the differentiation of ice navigation conditions by three types is used - easy, medium and heavy. Usually the following operating indicators are used as the parameters for dividing ice conditions into types:

- total calculated time consumption for a self-contained navigation of the nuclear icebreaker of the "Arktika" type in specific ice zones ($\Sigma\ t_{ice}$) or a total increase in the calculated time consumption of the nuclear icebreaker of the "Arktika" type due to ice navigation ($\Sigma\ t_{ice}$) for the NSR segment or a specific navigation route;
- critical values of the coefficient of ice navigation difficulty (K_d) of nuclear icebreaker of the "Arktika" type governing a possibility (safety) of specific navigation types in ice ($K_d = V_{io\ o}/V_{io\ i}$).

For easy type of ice conditions $K_d \leq 3.0$ which corresponds to a possibility of mass escorting of the ULA class ships and sister ships of UL, L1 classes. For a "medium" type $K_d \leq 4.0$ the routing of single and pairs of ships of the ULA class is possible. For a "heavy" type of ice conditions $K_d \leq 10.0$ only self-contained navigation of icebreaker is possible.

Types of ice navigation conditions (T_{nc}) with corresponding ice and operating characteristics have a 10 day interval for the summer-fall navigation period and a monthly interval for the winter-spring period. On the basis of systematic ice observation data for more than 40 years Tnc are obtained for an optimal navigation variant along the traditional NSR segments (the division scheme of the NSR taking into account calls to ports). A 10 day type of ice navigation conditions is considered to be a basic ice-operating parameter. A set of 10 day T_{nc} governs a mean monthly type of ice navigation conditions.

The climatic estimates of ice conditions and operating characteristics for various ships and convoys are made for identified types of navigation conditions. They are widely used in the activities of the design and planning institutions of Russia, connected with the organization and feasibility studies of shipping along the NSR (Arikainen, 1990).

In recent years work to create methods for forecasting types of ice navigation conditions and other ice-navigation shipping indicators on the NSR with different periods in advance has been initiated (see Project I.6.1, section 5). In particular, the methods for forecasting 10 day T_{nc} for some western NSR segments during summer navigation with a month in advance have been developed. This is in agreement with the objectives of tactical planning of the fleet operation on the NSR.

The objectives of preliminary planning of the fleet activities, as well as the techniques of long-range forecasting of ice navigation conditions have required obtaining of more generalized ice-navigation parameters both in space (the Arctic region, the NSR segment) and in time (navigation and its periods). Considering various generalized indicators it is clear that the most informative of them is a parameter that indicates the distribution of 10 day or mean monthly T_{nc}. And the navigation type (Tn) appears to be the characteristics meeting these requirements :

$$T_n = f(\Sigma\ T_{nc})$$

The navigation type can be represented by five possible gradations - easy, medium with a tendency to easy, medium, medium with a tendency to heavy, heavy - depending on a set of mean monthly or 10 day T_{nc}.

At present a principal possibility of forecasting this ice-navigation parameter 4-6 months in advance has been proved. The forecasting method for T_n, however, has been developed only for winter navigation and only for such NSR segments where regular voyages during this period of the year are made.

2.8 Conclusion

The existing sets of raw and processed data on ice conditions on the navigation route (see Project I.4.1, section 11) indicate that this is only a beginning of systematized data for the objectives of transit shipping along the NSR. However, at present a basis of the methods for presenting the information on ice navigation conditions in the form of ice and operating characteristics, as well as ice-navigation indicators of different generalization applicable for the organization and planning of shipping, has been developed.

The possibility of forecasting these parameters suggests the possible creation of a general system of hydrometeorological services for a successive planning of transit shipping or specific marine operations on the NSR. Naturally, such system should include not only specialized ice information, but also hydrometeorological and ice information of traditional kind, the so called information of a general use.

In our opinion the need for creating such system for large-scale operation such as transit shipping along the NSR is obvious. Obviously, such work will require considerable efforts and appropriate financial support. This work may take several years. The first and extremely important stage should be development of a detailed concept of such a system. This part of the work may be fulfilled in the framework of the second stage (May 1994-April 1995) of INSROP.

3 DESCRIPTION OF THE EMPIRICAL-STATISTICAL METHOD FOR A QUANTITATIVE ASSESSMENT OF THE DIFFICULTY OF ICE NAVIGATION (THE "QAD" MODEL)

3.1 A background for the development of the method and the model of a quantitative assessment of the difficulty of ice navigation

The provision of hydrometeorological support to the organization, planning and operational management of shipping along the NSR have required an objective assessment of the effect of real ice conditions on navigation of icebreakers and ships in the Arctic.

The existing approaches on the basis of the theoretical methods for assessing ice resistance to the ship's motion, simulation of the motion process in the ice tank and full-scale ship trials in idealized ice conditions could not resolve the problem (Kashtelyan et al., 1986; Ryvlin and Kheisin, 1980).

Collection of full-scale data on navigation of ships in different ice conditions and their procession allowed obtaining empirical-statistical dependencies of the influence of real ice conditions on ship's motion. This approach served as a basis for specialized ice information for the organization, planning and management of shipping along the NSR.

The main reasons for developing the method were formed in three directions.

A. A comprehensive study of ice cover as a shipping medium and the use of icebreaker as a peculiar tool of its study made it possible:

- to express the effect of diverse ice conditions by means of operating parameters of icebreaker's (ship) motion;
- to make a classification of ice cover as a shipping medium from the standpoint of the character of ship's motion and different interaction of the ship's hull and ice;
- to identify ice cover characteristics producing the main effect on the ship's motion.

B. For many years special ice cover observations from board icebreaker (ship) during specific transport operations were carried out. This allowed determining the differences in the distribution of ice cover characteristics directly en route from their total spatial distribution over the navigation region which is determined from the data of ice airborne reconnaissance and satellites. The indicated differences are governed by a selective motion of ship in ice, as well as by different scales of generalized ice characteristics during air - and shipborne observations (Buzuyev, 1975; Buzuyev and Fedyakov, 1981).

C. A large number of full-scale observations of operating characteristics of icebreakers and ships (motion velocity, the power plant capacity used, character of the ship's hull/ice interaction, etc.)during their ice trials on the test site and operation in real ice conditions have allowed one:

- to find out the differences between the passport (technical) and operating motion characteristics of icebreakers and ships under specific ice conditions;
- to obtain the empirical-statistical dependencies between the operating and passport (technical) motion characteristics for specific types of icebreakers and ships in various iceconditions;
- to determine empirical-statistical dependencies of operating motion characteristics of icebreakers and ships on specific ice cover characteristics on the sailing route.

Numerous special observations of ice cover and operating characteristics of the ship's motion, a careful analysis of observation results, theoretical generalizations closely connected with an earlier found law of ice resistance to the motion of ship (Kashtelyan et al., 1968) have enabled a significant development of an empirical-statistical direction in studying ice cover as a shipping medium.

The ice cover classification created by Buzuyev and Ryvlin (1969) in terms of shipping has identified ice cover characteristics that produce the most noticeable effect on the ship's motion in specific sea ice formation (Table 3.1). For the ice thickness range presenting a certain difficulty for the ship's motion (usually ice more than 30 cm thick) and classified by

Gordienko et al. (1967) as "ice thickness gradations requiring icebreaking support", it is found that the largest effect on ship's motion is produced by ice concentration and thickness, as well as amount of hummocking, fracturing, snow height depth, degree of destruction and ice pressures. A review of the effect of these ice cover characteristics is presented in Part II of the Report.

Thus, empirical-statistical dependencies of the effect of some ice cover characteristics and their combinations on the motion of icebreakers and ships in ice were determined. This has created a real basis for their theoretical generalization in the form of the method for a quantitative assessment of the ice navigation difficulty.

Table 3.1. Classification of ice navigation conditions (Buzuyev and Ryvlin, 1969)

Ice conditions	Ice forms by the Nomencl.	Ship motion character	Main ship hull/ice interaction processes	Ice parameters, mainly affecting the resistance
Solid ice	Fast ice, big and vast floes of drifting ice	Mainly uniform	Breaking of a continuous ice cover	Thickness, amount of hummocking, degree of destruction, amount of snow
Small floe, medium floe	Medium floe, small floe	Non-uniform	Breaking and pushing aside the floes	Zone length, thickness, concentration, amount of hummocking, degree of destruction, pressure
Ice cake	Ice cake (also in the channel after the icebreaker)	Uniform	Pushing aside the ice	Concentration, fast ice width, friction coefficient, pressure

3.2 A general description of the method and model for a quantitative assessment of the difficulty of ice navigation

In the early 80s an empirical-statistical method for a quantitative assessment of the difficulty of ice navigation ("QAD" method) has been created under the supervision of Buzuyev. The method summarized the results of multiyear studies at the Laboratory for Ice Navigation Studies of the AARI.

Arbitrarily the "QAD" method can be presented in the form of two components.

The first part of the method - a transition from the total distribution of ice cover characteristics in the navigation regions recorded on the airborne ice reconnaissance charts and so on, to the distribution of ice cover characteristics directly on the navigation route.

Section 2.2 of the Report considers the main features of the distribution of ice cover characteristics on the navigation route depending on their presentation on traditional ice charts.

Primarily, this is ice thickness recorded in some range that refers to ice age gradations (Nomenclature, 1974), or determined on the basis of the data of polar stations nearest to the motion route (see Fig.2.2).

Also important appear to be ratios of ice cover concentration on the route of the motion and over the navigation region that differ considerably for various periods of the year (see Table 2.1).

Similar empirical ratios are obtained for the amount of ice hummocking (see Table 2.3).

As to the amount of fracturing of ice cover (Handbook, 1981) and corresponding ice forms (Nomenclature, 1974), these characteristics are considered to be among the major ones in the classification of ice navigation conditions (see Table 3.1). The "QAD" method takes into account the dimensions of different ice forms on the route of the ship's motion. They depend on the stage of ice development and the season of the year (see Table 2.4).

The snow cover depth on the ice on the navigation route, similar to ice thickness, has a specific distribution type depending on the ice surface character and mean snow depth (see Fig.2.4).

The second part of the method - an assessment of the effect of ice cover characteristics interacting with ship on the success of the voyage expressed through the ship's motion characteristics. The velocity of ship in a uniform ice zone is considered to be the main motion characteristics.

The ice zone is considered to be uniform if all ice cover characteristics change within the accuracy limits of standard observations (Bushuyev and Loshilov, 1967). The uniform ice zones are as a rule, delineated as independent ones on the airborne ice reconnaissance chart.

The "QAD" method uses two types of ice velocities:

- ice technical velocity (V_{it}) - the velocity at which a ship is capable of travelling in uniform ice zones of sufficient extent (not less than 1 mile) with the maximum power of the ship's power plant (or close to maximum if there are restrictions concerning the strength of the ship's hull);

- ice operating net velocity (V_{ion}) - the mean statistical velocity of the progress of a ship or convoy in specific uniform ice zones when the operation mode of the ship's power plant is optimum. This is the real mean velocity of the progress of ships in specific ice zones.

For its determination all delays not related to ice and hydrometeorological conditions are excluded.

From the aforementioned determinations for respective uniform ice zones and specific ship types $V_{ion} \leq V_{it}$. And the maximum of the differences corresponds to favourable navigation conditions because when moving in open water navigators usually use only 25-30%, and in very open and young ice - 50-70% of the total capacity of the ship's power plant.

Taking into account the use of two velocity types (V_{it} and V_{ion}) the second part of the "QAD" method is divided into independent blocks:

a. Determination of the ice technical velocity of icebreakers and ships of a different type on the basis of empirical-statistical ratios obtained for a wide range of ice conditions:

$$V_{it} = f\ (H, C, R, D...) \tag{3.1}$$

where: H - ice thickness,

C - ice concentration,

R - amount of ice hummocking,

D - degree of ice destruction.

The ice technical velocity is used as a reference parameter allowing finding the effect of specific ice cover characteristics on the navigation difficulty and comparative estimates for icebreakers and ships of different types.

b. Transition from the ice technical velocity (V_{it}) of icebreakers and ships of a specific type in the uniform ice zone to their ice operating net velocity (V_{ion}) in a corresponding ice zone. It is based on the obtained empirical-statistical ratios of a type:

$$V_{ion} = f\ (V_{it}) \tag{3.2}$$

Let us then consider in greater detail the main aspects of the assessment of the ice cover effect on the ship's motion velocity.The most reliable data representative by volume are collected for the ice technical velocities (V_{it}) of a self-contained motion of icebreakers of different types in solid ice (fast ice, gigantic and vast ice floes) and ice cakes (mainly along the channel made earlier) of the concentration of 100% (10/10). In these conditions the requirement to the uniform test conditions is fulfilled best of all.

The technical velocity of icebreakers in solid ice ($V_{it\ s/i}$) and ice cakes ($V_{it\ i/c}$) with a concentration of 10/10 is approximated by the dependencies:

$$V_{it\ s/i} = V_{it\ o} - \Delta V_{s/i} \tag{3.3}$$

$$V_{it\ i/c} = V_{it\ o} - \Delta V_{i/c} \tag{3.4}$$

where: $V_{it\ o}$ - technical velocity of icebreaker in open water;

$\Delta V_{s/i}$ - velocity losses during a self-contained voyage in solid ice;

$\Delta V_{i/c}$ - velocity losses during a self-contained voyage in ice cakes.

In turn, the velocity losses in ice may in a general form be represented by the dependencies:

$$\Delta V_{s/i} = f(H_i, H_{lim}, V_{it\ o}) \tag{3.5}$$

$$\Delta V_{i/c} = f(H_i, B, L, N, V_{it\ o}) \tag{3.6}$$

where: H_i - actual ice thickness (from the observations, computations, etc.);

H_{lim} - thickness limit of level solid ice penetrated by ship (ice passage capability);

N - capacity of the power plant of icebreaker;

B - width of icebreaker;

L - length of icebreaker.

To calculate the motion velocity in the ice of any horizontal dimensions (l) a dependency is used:

$$V_{it} = V_{it\,o} - \left(1 - \frac{1}{\exp^{\frac{l^*}{L}}}\right)\Delta V_{s/i} - \frac{1}{\exp^{\frac{l^*}{L}}}\Delta V_{i/c} \qquad (3.7)$$

where: l^* - horizontal dimensions of ice formations (ice forms) on the pathway of the ship (m),
L - icebreaker length (m).

It is obvious that the dependencies (3.3) and (3.4) represent particular cases of the formula (3.7) at $l \rightarrow \infty$ (solid ice) and $l \rightarrow 0$ (ice cake). Thus, there is a possibility of estimating motion velocities of icebreakers for any combinations of thickness and forms of ice of 100% concentration (10/10).

The next important stage of the "QAD" model is determination of the mean ice technical velocity of icebreaker in a uniform ice zone. A uniform ice zone is, as a rule, ice cover of different age gradations with different proportions of partial concentration. This makes reliable full-scale observations of the motion velocity of icebreakers of various types over the entire range of the changes in concentration and age gradations (thickness) to be practically impossible for obtaining reliable empirical dependencies.

Developing the idea of a partial effect of ice of different age categories on the ship's motion (Sergeyev, 1978) the following principle of the methods has been formulated to take these characteristics into account. The entire navigation route at any combination of the ice age categories in a uniform ice zone is differentiated into effective segments with an arbitrary concentration of 100% (10/10) and 0% (open water) for each ice age category (Buzuyev and Fedyakov, 1983). The motion velocities in open water and in the ice of 100% concentration of a certain thickness are determined by the formula (3.7). Hence, the task is to determine a "relative" extent of the route that icebreaker passes in the ice of each age gradation ($S_{ice\,i}$) within a uniform ice zone. Open water is considered arbitrarily as an independent gradation for which $H_{ice} = 0$.

It is obvious:

$$\sum_{i=1}^{n} S_{ice_i} = 1 \qquad (3.8)$$

where n - a number of age gradations in a uniform ice zone.

A "relative" length of the way in the ice of a specific age gradation ($S_{ice\,i}$) is determined by the ratio:

$$S_{ice_i} = \frac{V_{it\,10_i}(V_{it\,o} - V_{it_i})}{V_{it_i}(V_{it\,o} - V_{it\,10_i})} \qquad (3.9)$$

where $V_{it\,10i}$ - a technical velocity of icebreaker in the ice of a specific age gradation and 10/10 concentration,

$V_{it\,i}$ - same, in the ice of a specific age gradation and of a prescribed concentration.

Knowing a "relative" part of the route that the icebreaker will pass in the ice of each age gradation ($S_{ice\,i}$) and the values of V_{it} corresponding to the ice of a prescribed thickness and open water (at ice concentration of 10/10), one can calculate mean ice technical velocity in a uniform ice zone:

$$V_{it} = \frac{1}{\sum_{i=1}^{n} \frac{S_{ice_i}}{V_{it_i}}} \qquad (3.10)$$

The results of the calculations made by the ratio (3.10) for various combinations of the age categories and concentration of ice cover are in satisfactory agreement with the actual data.

It should be noted that the idea of interpreting diverse combinations of ice cover characteristics as some assumed ice navigation conditions is used quite often (Sergeyev, 1976; Sergeyev and Khromov, 1980). Such approach, for example, allows presenting snow depth and amount of hummocking as some increase and the degree of ice destruction as some decrease in mean ice thickness. These dependencies used in the "QAD" method have an empirical-statistical basis.

Up to the present the most serious difficulties are related to estimating the distribution of horizontal dimensions of floes (ice forms) and compacting on the navigation route due to the difficulty of their full-scale observations.

An analysis of the observation data on floe dimensions on the navigation route has shown that their value in all cases turns out to be less than standard gradations of ice forms indicated in the Nomenclature (1974). The values of the most probable (equivalent) dimensions of ice formations on the navigation route for the summer period are given in Table 2.4. For other periods of the year empirical correction coefficients (see Part II, section 2.6 of the present Report) are obtained.

It seems that one of the most complicated and at the same time important questions of a quantitative estimate of the ice cover effect on ship's motion is to take into account compacting, since quite often the success and sometimes the safety of ice navigation depend on it. When estimating the pressure effect one can make use of the results of a statistical (Voyevodin, 1978) or a physical-statistical (Timokhov) approach. The "QAD" method takes into account compacting in its climatic form for the Arctic region. The pressure intensity is assumed to be constant and equal to 1 arbitrary unit since the total probability of compacting within the intensity range of 0-1 up to 1-2 arbitrary units is about 80% in the Arctic region (Voyevodin, 1978; Buzuyev and Fedyakov, 1979). There is a possibility of taking into account pressures and other intensity. The relative extent of the route in the ice at compacting is assumed to be constant for each age category at a total ice concentration in a uniform ice zone of not less than 90% (9/10).

Finally, after calculating the technical velocity of the motion of an icebreaker of a certain type on the basis of the empirical dependencies (see formula 3.2) her operating velocity in ice for a self-contained voyage (V_{ion}) and for escorting standard convoys ($V_{ion\ c}$) is calculated. The obtained values serve as a basis to determine total time losses for a specific marine operation in certain ice conditions (Buzuyev and Fedyakov, 1983).

The formalization of the "QAD" method by means of the present-day computer means (IBM, etc.) has allowed constructing a model for a quantitative assessment of the difficulty of ice navigation ("QAD").

An empirical-statistical model "QAD" has been developed for a self-contained voyage of icebreakers of the "Arktika" type (55 MW), the "Yermak" (30 MW), the "Moskva" (19 MW), standard convoys: indicated types of icebreakers plus the M/V ULA (of the "Amguema" type), or the M/V UL (of the "Samotlor" type), as well as for a self-contained voyage of the M/V SA-15. There is a possibility to adjust the "QAD" model to other existing and perspective types of icebreakers and ships of active ice navigation.

The error of the calculated parameters (motion velocity, time losses) is not more than 10% for a self-contained motion of icebreaker and not more than 20% for a standard convoy (icebreaker plus one ship).

3.3. An example of calculations using the "QAD" model

As an example of calculating operating characteristics by the "QAD" model, the actual ice conditions for an optimal navigation route on the NSR segment Bely island - Kara Gate strait in June of 1978 are given below. There are also presented corresponding calculated speeds and time of a self-contained motion of an icebreaker of the "Arktika" type, as well as of standard convoys including the nuclear icebreaker "Arktika" plus M/V ULA (of the "Amguema" type) and the "Arktika" plus the M/V UL (of the "Samotlor" type).

The lengths of homogeneous ice zones and corresponding ice characteristics taken from a composite ice chart are given in Table 3.2.

Table 3.2. Lengths of homogeneous ice zones and corresponding ice characteristics on the segment of the NSR Bely island - Kara Gate Strait in June of 1979

Zone No.	Zone extent ml	Number of ice gradation	Ice concent.	Ice thickness cm	Ice size m	Destruction degree	Amount of ridging
1	15.0	0	open water				
2	265.0	2	9.0 1.0	190.0 10.0	175.30.	0.5	2.5
3	25.0	1	8.0	190.0	175.	1.0	2.5
4	60.0	0	open water				
5	45.0	1	10.0	140.0	fast ice	1.0	0.5

Table 3.3 presents calculated speeds and time of the motion of an icebreaker and standard convoys for each homogeneous ice zone and also for the entire segment of the route as a whole. Calculated operating characteristics are given both for the case of no ice compression on the segment and when navigating at the compression of 1 arbitrary unit.

Table 3.3. Calculated operating characteristics for a self- contained motion of an icebreaker and standard convoys

Zone No.	"Arktika" icebreaker, self-contained				"Arktika" + UL				"Arktika" + ULA			
	No pressure		With pressure		No pressure		With pressure		No pressure		With pressure	
	Veloc V_{ion} kh	Time h	Veloc V_{ion}, kh	Time h	Veloc V_{ion} kh	Time h	Veloc V_{ion} kh	Time h	Veloc V_{ion} kh	Time h	Veloc V_{ion} kh	Time h
1	17.8	0.8	17.8	0.8	13.3	1.1	13.3	1.1	12.8	1.2	12.8	1.2
2	8.8	30.0	7.3	36.1	6.5	40.6	5.4	49.2	7.1	37.2	5.6	47.0
3	11.8	2.1	11.8	2.1	7.6	3.3	7.6	3.3	8.6	2.9	8.6	2.9
4	17.8	3.4	17.8	3.4	13.3	4.5	13.3	4.5	12.8	4.7	12.8	4.7
5	7.8	5.8	7.8	5.8	5.5	8.2	5.5	8.2	6.1	7.4	6.1	7.4

3.4 Areas of the "QAD" model application

The "QAD" model has been developed for navigation conditions of icebreakers and ships in the Arctic region, in particular, in the NSR seas. It has been, however, successfully used for the support of marine operations in the Antarctic.

The "QAD" model exploits ice information of a general use that shows distribution of ice cover characteristics (concentration, thickness, amount of hummocking, degree of destruction, ice compacting) on the whole over the sea or the navigation region on traditional composite ice situation charts. The latter are prepared on the basis of ice cover observations from satellites, aircraft of ice airborne reconnaissance, data of polar stations and ships (an operational composite ice chart). Similar composite charts can be made on the basis of the forecasted distribution of the specific characteristics of ice cover (a prognostic composite ice chart).

In addition, the model makes use of the tactical-technical parameters of icebreakers and vessels (capacity of the power plant, displacement, particulars of the ship's hull, passport speed and ice passage capability).

As a result, the empirical-statistical model "QAD" allows obtaining the calculated operating characteristics of the motion of a specific vessel or a convoy of vessels in ice (motion velocity, time losses, parameters of the navigation difficulty in specific ice zones). These characteristics objectively reflect the effect of various ice conditions on the possibility and effectiveness of the motion of a specific type of ship or convoy of ships in ice.

It should be remembered that one of the main aspects of the research direction under consideration became the use of ship (icebreaker) as an instrument for studying the ice cover as a shipping medium. That is why the construction of the method and model for calculation of quantitative operating parameters of the ship's motion at any combination of ice cover characteristics considerably extended the possibilities of research and applied studies for ice shipping. In the physical-statistical context the "QAD" model has allowed the studies of the ice conditions and the navigation difficulty for any possible navigation variants on the segments and on the whole along the NSR in all seasons of the year without making the voyages. An application of the model allows the climatic estimates of the ice navigation conditions by the existing and perspective routes on the basis of traditional ice information on the NSR seas available for about 30-40 years. This is quite important for the perspective shipping planning.

The possibility of presenting a large number of ice cover characteristics by means of several operating indicators has allowed the use of the "QAD" model for dividing ice conditions into types. At the present time such approach is widely used in the studies of ice regime and some characteristics of ice cover of the Arctic seas.

In addition the possibility of obtaining the objective operating indicators by means of the "QAD" model has served as a basis to obtain specialized (operational and prognostic) ice data of traditional types. And long series of the calculated operating parameters have allowed the creation of independent methods for specialized ice forecasting for shipping along the NSR.

Of the applied tasks it is necessary to mention a possibility of an objective choice of an optimal navigation variant and a quantitative assessment of the ice navigation difficulty depending on the composition of a real convoy.

During the last years the "QAD" model has undergone testing providing support to specific marine operations along the Northern Sea Route. This allowed its successful use for providing support to navigation in the Arctic in recent years.

4 DATABASE ON ICE DAMAGES OF ICE-STRENGTHENED SHIPS AND ICEBREAKERS

4.1 The construction concept of the database on ice damages

The analysis of ice damages has been given a lot of consideration in domestic and foreign publications (1-6). The final result of the activities in this field are probabilistic parameters of hull damages for some ship types or for some classes of ice- strengthened ships or icebreakers (1,5). In the opinion of the authors of the present Report all works listed have without exception some disadvantages, the most significant being the following ones:

- no work contains quantitative estimates of the influence of ice conditions, the duration of the stay of ship in such ice situation, the ship's speed on the quantity and quality of damages. Also significant appears to be the influence of the type of icebreaker, the composition of the convoy, the caravan's speed on the parameters of the damages;

- the studies mentioned above present only the data processing results but not the method of obtaining these results. The statistical parameters are obtained only for several types of ships and are not to be updated after obtaining new information on damages.

On the other hand, both these disadvantages have an objective origin: the researchers of ice damages possessed only the documents on current repair and did not have the information about ice conditions of the operation of ships.Up to the present time no tool has been developed that allows one to update the information and to formalize the process of obtaining the statistical parameters. The latter circumstance is important with the appearance of new ship types and exploration of the new route for the export of hydrocarbons from the Russian North. There is an opinion among navigators about the difference of ice conditions in the western and eastern NSR regions and about the differences in the ice navigation methods especially when following icebreaker in these two regions. However, such opinion has not yet been confirmed or rejected by quantitative estimates.

All above-mentioned reasons have led to a suggestion to develop a tool which would allow calculating the statistical correlation estimates between the different factors influencing the effectiveness of shipping in the Arctic. A specialized database "Ice Damages of Ships" (IDS-Data Base) appears to be such a tool. Conceptually the database consists of two connected parts: the data on ice damages of the hulls of the ice-strengthened ships and icebreakers and the data on the conditions of receiving the ice damages. The structure of this information is described in more detail in the next sections of this chapter.

4.2 Methods for the establishment of the database on ice damages

The establishment of the database on ice damages requires to take into account some peculiarities of the information both on ice damages and on the situation of receiving the ice damages. These peculiarities are as follows:

- a limited number of transport vessels (not more than 10) and icebreakers (5-6 types) navigate in the Arctic. The information on the ice damages should be prescribed on the so-called area of damages. A damage area for ships and icebreakers is the outside plating of the hull with the attached framing and other structures. The prescription of the area of damages is a time-consuming procedure with a large information volume. Taking into account the limited number of ship types and, hence, the information on the damage area types, the information on the outside plating structure should be prescribed only for the various types of ice-strengthened ships and icebreakers;

- the ice damages received during ice navigation can be divided into classes. For every kind of damage the parameters can be found out that quantitatively characterize the damage degree. The database is oriented to the hull ice damages which constitute 87% of all ice damages from our data, but it can be expanded both for the description and the recording of the rudder-propeller equipment damages that constitute the remaining 13% of the ice damages;

- all ice damages of the ship's hull can be subdivided into two large categories: accumulated damages whose parameters gradually increase during the operation (for example, the area and the value of the remaining deformation of corrugating) and one-time damages that are received in a known place at a known time (for example, the hole received during the impact with a certain hummock at a known time and place). Thus, for the first category of damages which covers an absolute majority of damages it is impossible to determine exactly the parameters of damages and parameters of ice conditions. However, the regions of ship navigation, time and duration of navigation when the damages were received are known. By the time and the navigation regions one can reconstruct on the basis of ice reconnaissance data the ice situation during which the damages were accumulated.

Before one describes the data base structure it is necessary to present a classification of damages.

4.3 Classification of ice damages

The following classification of ice damages is accepted in the database:

1 - corrugating (Fig.4.1) - a regular remaining plastic deformation of the outside plating sheets between framing. It is characterized by the value of the remaining deflection W;

2 - dent (Fig.4.2) - a two-dimensional plastic remaining deformation on the outside plating between framing. It is characterized by the value of the remaining deflection W;

3 - stem outward bending - deviation of the damaged stem line from the design shape (Fig.4.3). W - value of the maximum remaining deflection;

4 - buckling of frame webs (Fig.4.4);

5 - tripping of frame (Fig.4.5);

6 - cracks of frame webs (Fig.4.6);

7 - bilge keel crushing - absence of the bilge keel at some length;

8 - damage (deformation) of the bilge keel which is characterized by the value of the remaining deformation of the bilge keel - W;

9 - estrangement of framing from the outside plating - breaking of the welding connection between framing and plating (Fig.4.7).

10 - hole - breaking of the plating impermeability in some area of the outside plating, the total hole area - W;

11 - deformation of plate elements attached to the outside plating (decks, semidecks, etc.). W - value of the plate element deformation (Fig.4.8);

12 - through cracks of the outside plating. The damage parameter is W - length of crack.

The number of the damage type in this list corresponds to the numerical code of the damage type.

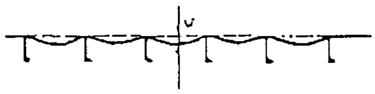

Figure 4.1. Corrugation of the outside plating.
W - value of the remaining deformation

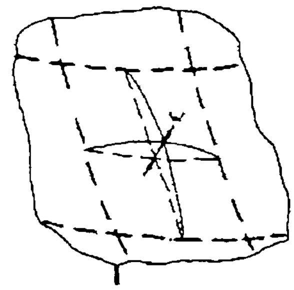

Figure 4.2. Dent
W - value of the remaining deformation

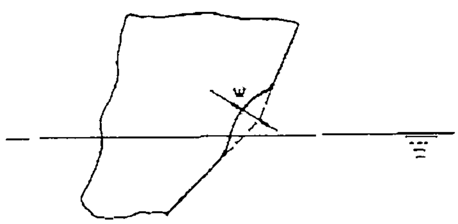

Figure 4.3. Stem remaining deformation
W - value of the remaining deformation

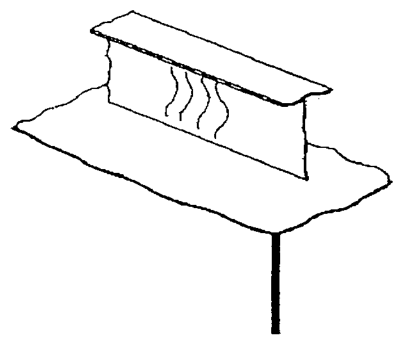

Figure 4.4. Example of frame web buckling

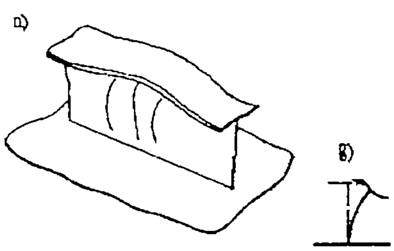

Figure 4.5. Tripping of the frame
a) view, b) cross section

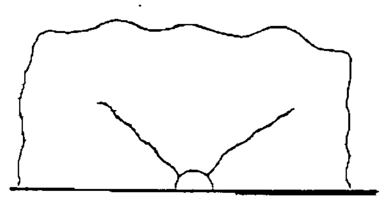

Figure 4.6. Example of crack in frame web

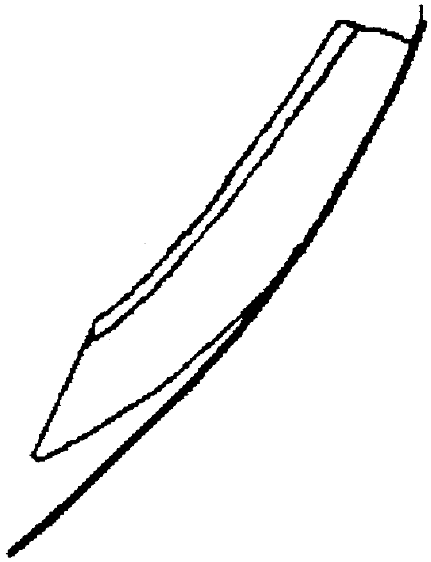

Fig. 4.7. Estrangement of framing

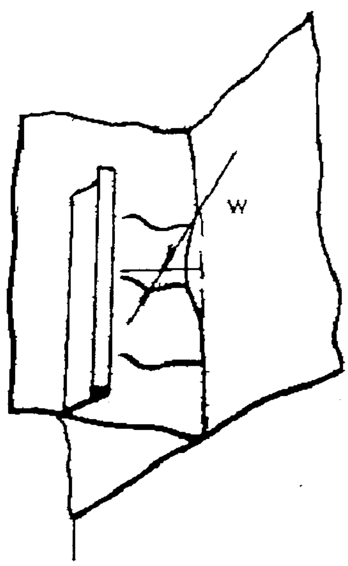

Fig. 4.8. Deformation of plate elements

4.4 Data structure on ice damages and the conditions of receiving them

Data are divided into three groups. The first one is the information about geometrical and structural topology of the outside plating presented as an outside plating plan for ships of one type. This information group is independent. The next two groups are connected with each other - this is the information proper about the damages from the dock or diver inspection statements and the information about the situations of receiving the damages from the logs of the ships or icebreakers.

4.4.1 Data structure on the outside plating plan

Data on the outside plating plan (OPP) is prescribed by a number of the information sets, each of them describing a number of the lines in the coordinate system XOY, where the axis OX passes through the main plane, the axis OY - through the sternmost point of the OPP (Fig.4.9).

Data record structure of the OPP-information:

A. Name of the leading ship of the series.
B. Outside countour of the OPP is defined as a line set passing through the points (X_i, Y_i).
C. Quadrangles in the contour that prescribe the sheets of plating and their thickness. The quadrangle is prescribed by the four pairs of coordinates (X_{l1}, Y_{l1}, X_{l2}, Y_{l2}, X_{l3}, Y_{l3}, X_{l4}, Y_{l4}).
D. Main framing straight lines corresponding to the beams of the main direction are prescribed by the two pairs of coordinates (X_{b1}, Y_{b1}, X_{b2}, Y_{b2}). A cross section of the frame is prescribed by the section code - the text line which contains the sign of the section type and the number of the section by the range of sizes or by the description of sizes of the section if the section is not by the range of sizes.
E. Web framing is determined by the lines with coordinates (X_{w1}, Y_{w1}, X_{w2}, Y_{w2}). A cross section of the web frames is defined as in D.

F. Plate structures attached to the outside plating (decks, semidecks, internal bottom plating, floors, bottom stringers) are determined by the vector (X_{p1}, Y_{p1}, X_{p2}, Y_{p2}) and by the sheet thickness of the structure under consideration.

For every element from items A-F a limit element number is found.

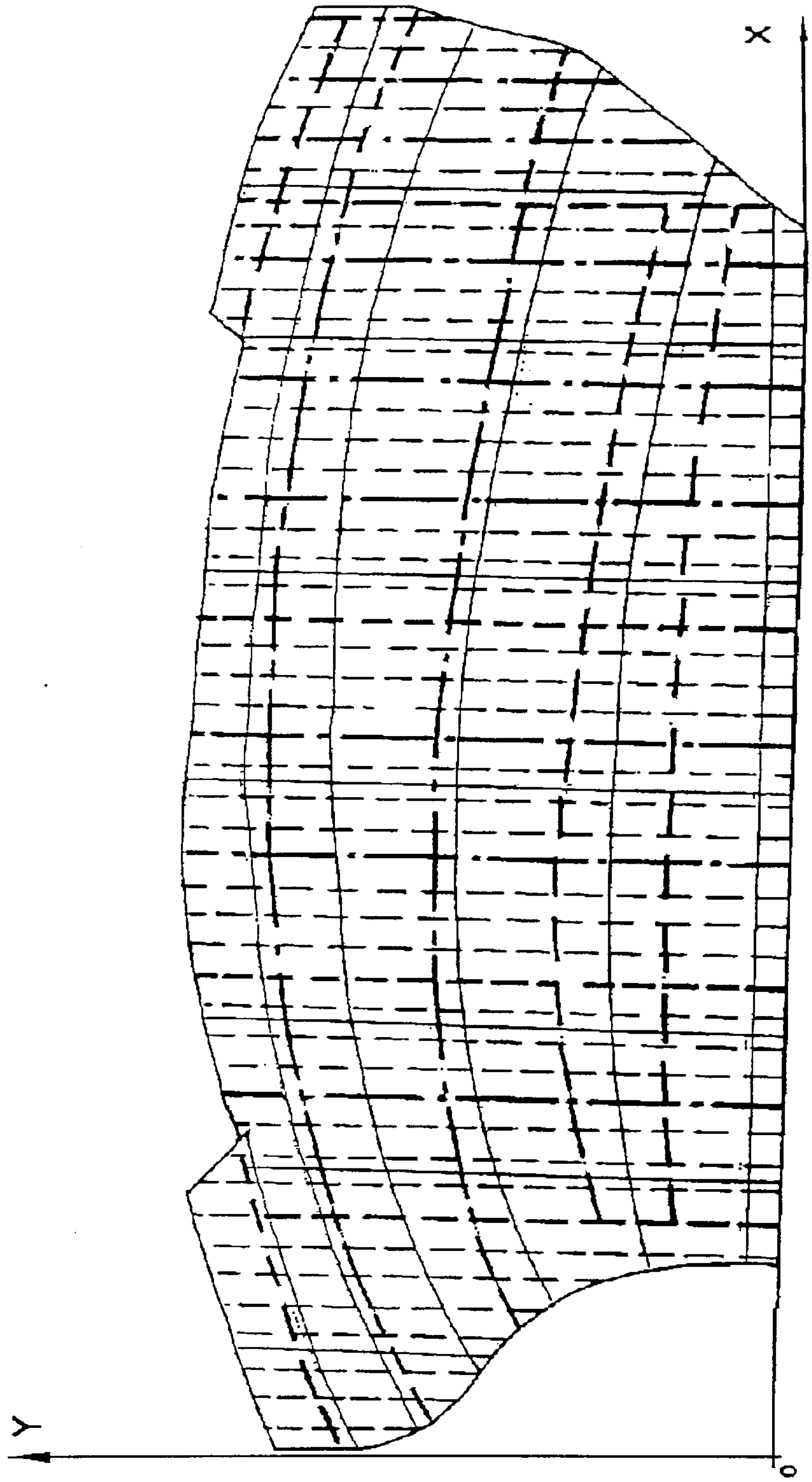

Figure 4.9. Outside plating plan and its coordinate system

------- - main framing
======= - web framing
- - - - - plate elements attached to the outside plating

4.4.2 Data structure on ice damages

A record of ice damages refers to one fact of the inspection of ship in the dock, by the divers or the crew. The data structure is as follows:

- ship name;
- ship type name;
- inspection date;
- date of the previous inspection;
- number of damages;
- every damage is described by the coordinates of the quadrangle zone of the damages (X_1, Y_1, X_2, Y_2, X_3, Y_3, X_4, Y_4), by the damage type (see 4.3) and by the value of the damage W (Fig.4.10).

4.4.3 Data structure on the conditions of receiving ice damages

A record of the situations of receiving the ice damages corresponds to the record on the damage description and can be of two types for the accumulated or one-time damages:

- for the accumulated damages the parts of ship navigation are prescribed between the inspections, the duration and time of navigating at this part are prescribed;
- for one-time damages the geographical coordinates of the place of receiving the damage and a text description of ice conditions and circumstance of receiving the damage are entered into the database.

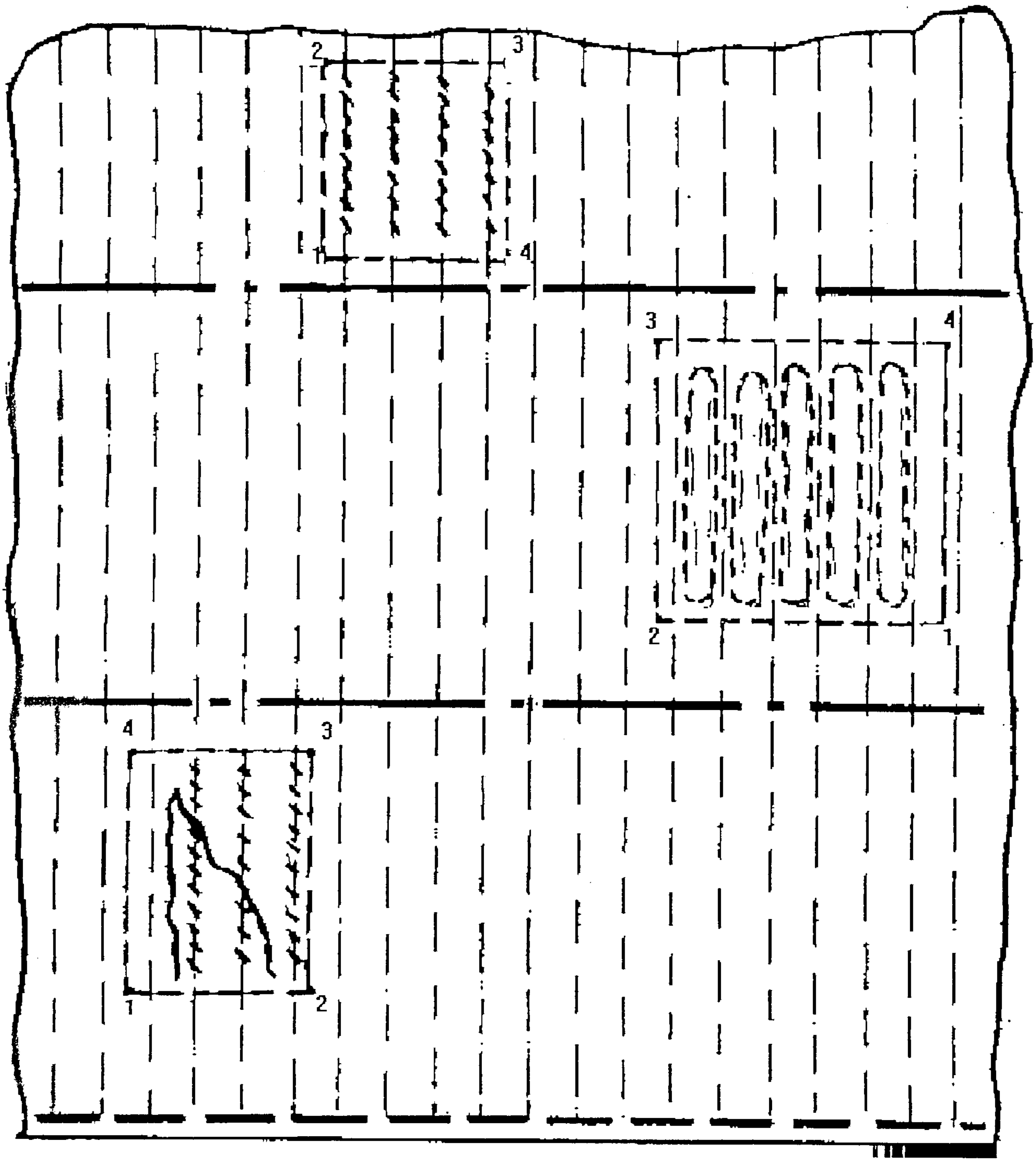

Figure 4.10. Definition of the damage zone by the coordinates X and Y

4.5 Management structure of the database on ice damages

The database management system (DBMS) provides the realization of all necessary functions for data processing. There are the following functions of the main menu:

- help;
- view of the database on the OPP;
- view of the database on damages;
- data input and editing;
- additional options;
- data processing.

"Help" function provides necessary comments and explanations for the user of the DBMS.

"View of the database on the OPP" is for the information control on the OPP and it is realized. with the help of graphic software that allows one to draw the OPP on the screen or the plotter, to increase any OPP-window on the screen, to obtain the information about the framing and outside plating.

"View of the database on damages" envisages the transition to the second level menu which consists of the following functions:

- view of all records;
- view of the records by a sign.

The "view of all information" allows one to display the OPP with the damage areas being marked by different colours with the indication of the damage parameter. Every colour corresponds to a specific type of damage. The second record frame presents the information about the conditions of receiving ice damages in the text format.

The "view of the information by a sign" allows one to select all the records for the given ship, for the given type, for the given region or for any combination of the signs listed.

The function "data input and editing" allows one in the dialog mode to input information on damages, erase records and correct the information in the records both on the damages themselves and on the conditions of receiving them.

The "additional options" of the main menu allows for the following operations :

- output of the marked records to hard information media;
- merging of some records into a work file (sorting) by the chosen signs (for example, for ships of one type, for one ship, for one navigation region, for a given navigation period, etc.)

The "data processing" - one of the main functions of the main menu.It allows the statistical processing of the formed or prescribed work file to calculate two-dimensional damage histograms at the damage area. The histograms can be on the damages of certain types, on the damage parameters, or on a given combination of damages. The second possibility of this menu branch makes this data base different from the statistical studies of the ice damage problem carried out up to the present since it allows one to obtain the correlation dependencies of the characteristics of ice damages on the geographical and ice navigation conditions of the ships by means of the information on the conditions of receiving the damages.

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PART II

COLLECTION AND ANALYSIS OF STATISTICAL DATA ON HULL ICE DAMAGES OF TRANSPORTSHPS ON NSR

INTRODUCTION

Generalization and analysis of data on hull ice damages during the operation of ships on arctic routes show that the conditions of getting damages, damage character and distribution of damages over the underwater portion of hull have much in common for the Russian and foreign arctic fleet. As ice conditions on routes of the domestic and American-Canadian Arctic are similar, the existing differences in character and sizes of damages of hull structures are principally due to the working regimes of various classes of ships in ice and distinguishing features of the water area, in particular to the convoying of ships at a short or close tow (behind the icebreaker) as well as to the shallowness of routes of the Central and Eastern sections of the Northern Sea Route. It should be noted that heavy damages caused by the getting of a ship foul of another while using the above convoying methods should not be attributed to ice damages because they are not directly affected by the ice/hull interaction and more influenced by the choice of the tactics of convoying and navigational experience of a ship's operator. For the same reason, damages associated with-bottom touching the ground or striking a rock damages should not be considered.

5 CENERAL ANALYSIS OF DATA ON SHIP HULL DAMAGES OF RUSSIAN ARCTIC FLEET ON THE NSR

On the whole, there has been a stable tendency in the Russian arctic fleet for the last 20-30 years towards an increase in accident rates for ships linked with their more intensive use and the expansion of areas and longer time of operation in ice. So the average relative accident rate level at the beginning of 80-ies exceeded 2-2.5 times that at the beginning of 70-ies.

As the experience of operation of transport fleet in the Arctic shows ships suffer the greater part of hull ice damages (70-80%) while following the icebreaker in the channel (including convoying at a short or close tow). During independent sailing and compressions not more than 10-12% ice damages occur. The same relationship is valid also for the distribution of the amount of ice damages over separate parts of the hull along the length of the ship - 60-80% of ice damages are concentrated in the forward third of the ship and only 10-20% fall on the middle. Only on ULA ships, where working conditions approach those of icebreakers, is the area of heaviest damages somewhat shifted and covers midship body.

The forms values and location over the hull of ice damages are shown in Figs 5.1-5.7 and table 6.1.

On the average the portion of damages (bulges, corrugations, dents) accompanied by leakage varies in different years within 25-40% of the total number of hull ice damages. Ships of L1 and lower categories have a number of frame damages including holes along the board and bilge, dimensions of the damages of structural elements (for example, maximum deflections) 2-3 times exceeding those for ships of the highest ice categories.

Heavily deteriorated vessels (older than 15 years) suffered ice damages practically on every voyage in arctic ice (mainly the ships of L1 class), Fig.5.2.

On ships of the highest ice categories holes occur rather seldom and, as a rule, are associated with navigator errors in the close towing of ships by icebreakers (damages of forecastle.

plating near chocks and stem) or during the motion under especially severe ice conditions (characteristic for the Eastern area of the Northern Sea Route). Distribution of damages over the main grillage is to a considerable extent also connected with the movement order of ships in a convoy. So, bottom grillages of ships directly following the icebreaker especially at a "short" stay and close tow are subject to the effect of higher ice loadings from the impact of ice floes thrown out of the icebreaker screws. Apparently this circumstance accounts for high susceptibility to damage (70% of all hull damages) of bottom grillages of "Amguema" type (ULA) ships often assisted through heavy ice isthmuses by icebreakers. On longer ships of UL category, in particular on "Samotlor" type ships, the areas most susceptible to damages are as a rule side grillages in the bow part and bilge accounting for 70-80% of ice hull damages (Fig.5.1); surface area of plating to be replaced on these ships reaches 100 m per ship and more.

As a rule the ice damages of arctic ships occur in a bow third and in the middle part of the hull being located near the forepeak and bilge strakes.

The overwhelming portion of ice damages of floors (up to 90%) is of restricted character i.e. they are local dents - local damages of separate elements of framing (separate stiffening ribs brackets, web framing plates). On ships of the highest ice categories (UL, ULA) the loss of lifting capability of grillage as a whole is not observed. Cracks in outer plating on ships of these categories are of secondary character and they are observed only in the zone of deep dents (except cracks near hand holes of air-bubbling manifold on ships of "Norilsk" type).

Despite the continuous improvement of regulatory documents (Register Rules) and tactics of the escorting of ships in ice the relative level and extent of ice damages keep increasing year after year. More severe conditions of operating ships on all routes of the Arctic basin resulted not only in an increase of hull damage rates of old worn out ships, but also in a considerable increase of the number of heavy hull ice damages to modern ships built according to the Register Rules at shipyards of leading foreign companies (Valmet, Wartsila, Rauma-Repola ets.) for highest ice categories UL, ULA.

Distribution of ice damages to hulls in the classes (ice categories) of the vessels reflects composition of the fleets used in the Arctic navigation. However the frequent damages were recorded within the most numerous group of vessels involved in the Arctic traffic: vessels of ice category UL and L1 the ice strengthenings of which were inadequate for intensive operation in the Arctic, in particular, in its Eastern sector.

According to data of last years also the ships with particularly strong hulls are often damaged: ice category ULA ships and icebreakers account for 25 to 30% of the total number of ice damages, this being associated with their use in severe ice conditions.

It should be noted that for one-type ships operating in the Western and Eastern Arctic, along with common features there are differences in the location of numerous, ice damage areas and especially considerable differences exist in the dimension of such damages.

The analysis of the character of ice damages and qualitative composition of the arctic cargo ship groups most susceptible to damages shows that principal causes of ice hull damages are as follows:

- utilization of ships with an ice class not sufficient for certain areas and seasons;
- considerable age wear out of structural hull members in the zone being under the effect of ice loadings;
- insufficient building structural strength in more severe conditions of the operation of ships in ice;
- errors of navigators while making maneuvering.

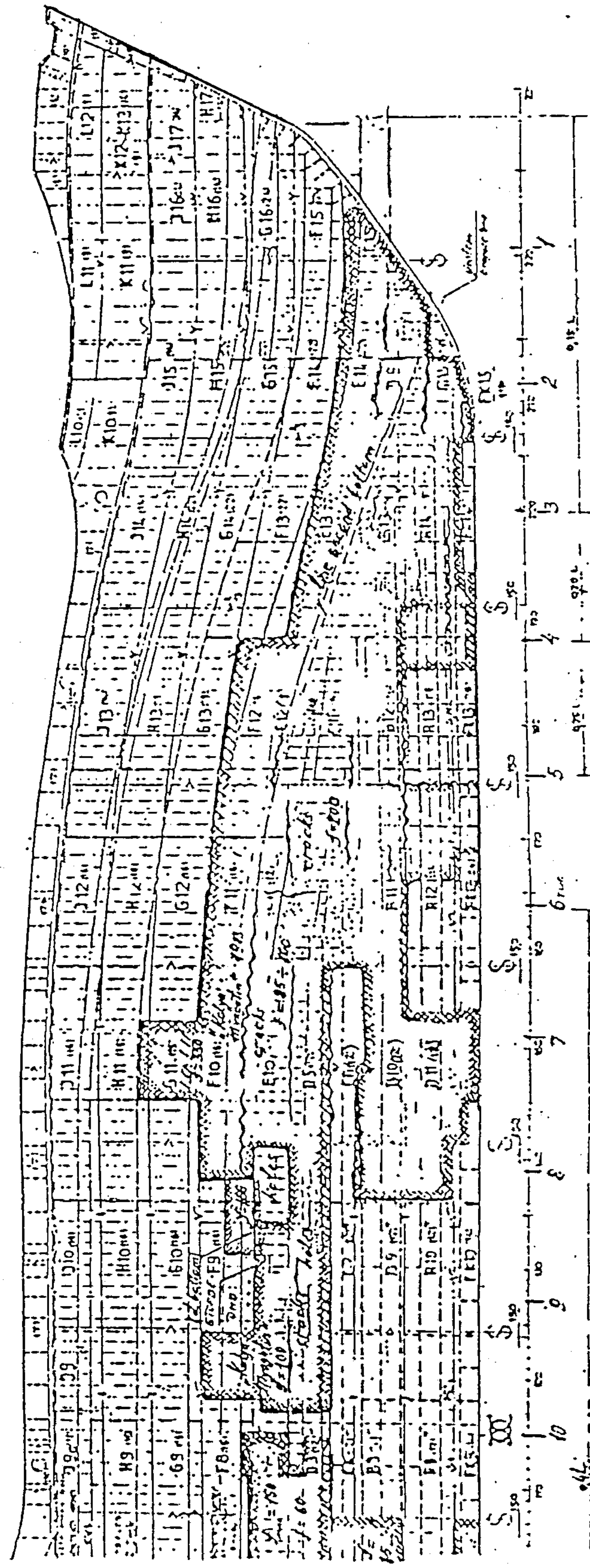
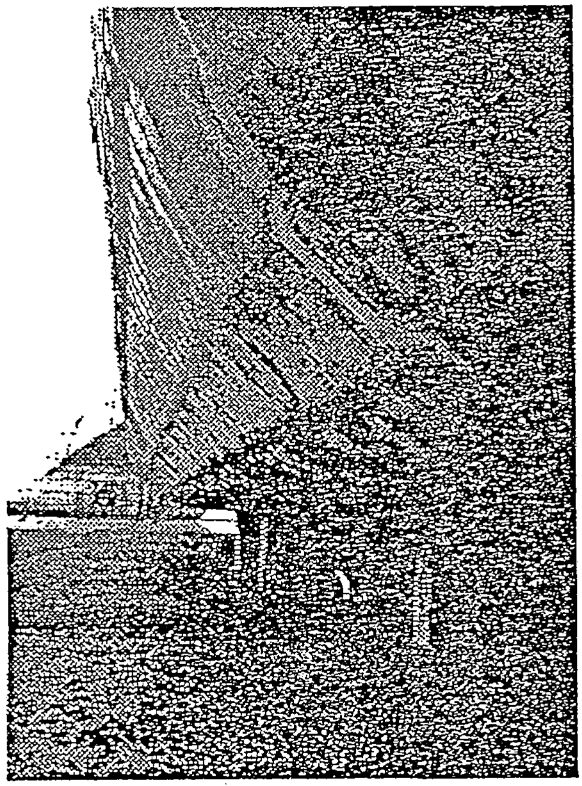
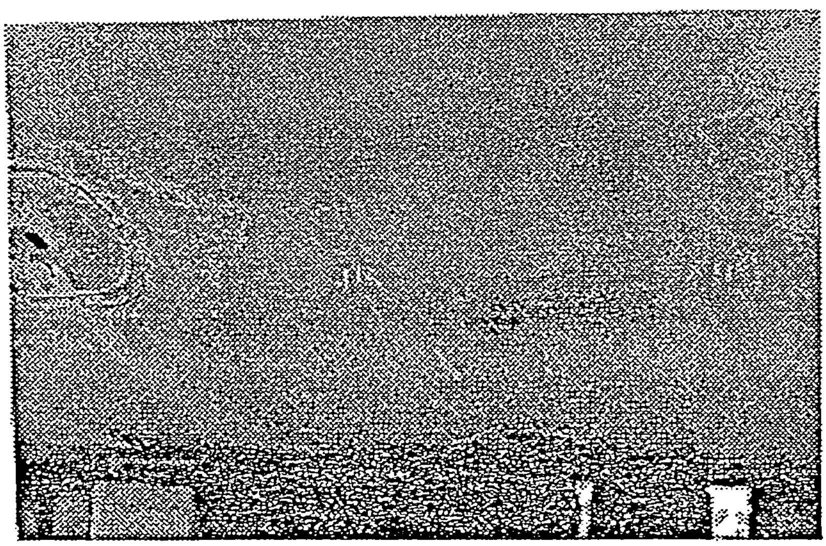


Fig. 5.2. Distribution of zones with heaviest ice hull damages of ships of the L1 ice category "Pioner" type



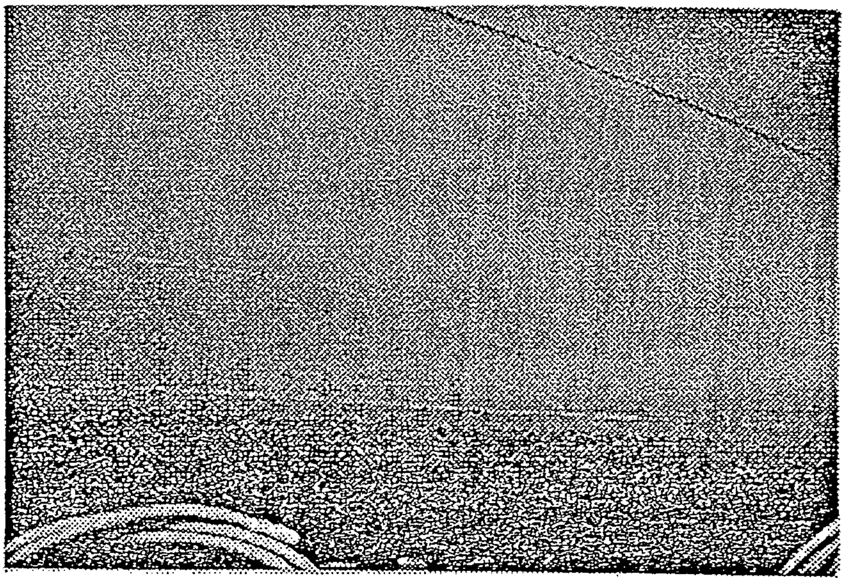
b)



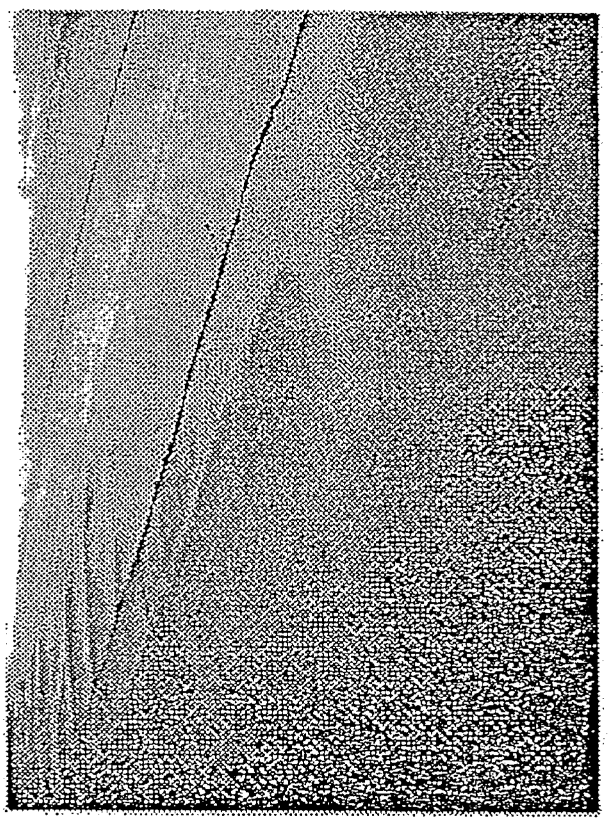
a)

Fig.5.3. Permanent sets in the form of bulges in area of bulge

a, b - bulge and bottom strakes



b)



a)

Fig.5.4. Corrugation of side shell plating

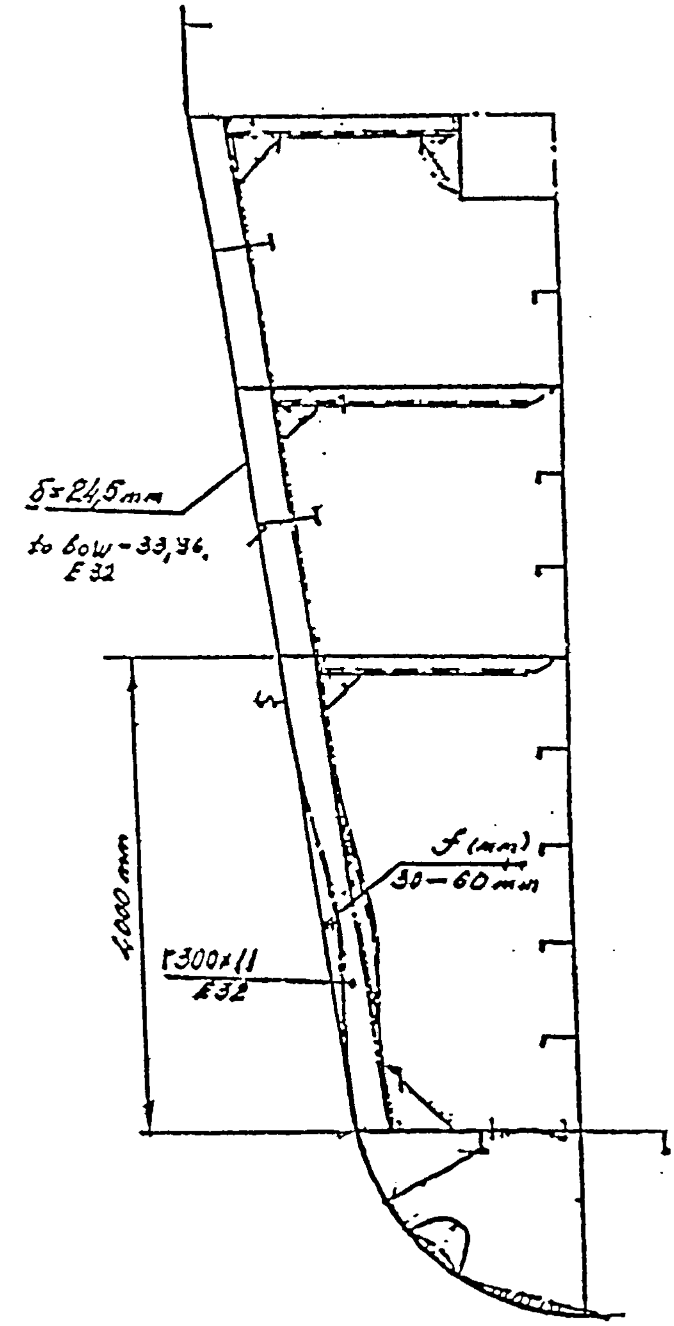


Fig. 5.5. Ice damages to the frames in the midbody
on arctic ships of "Norilsk" type
(Easten part of NSR)

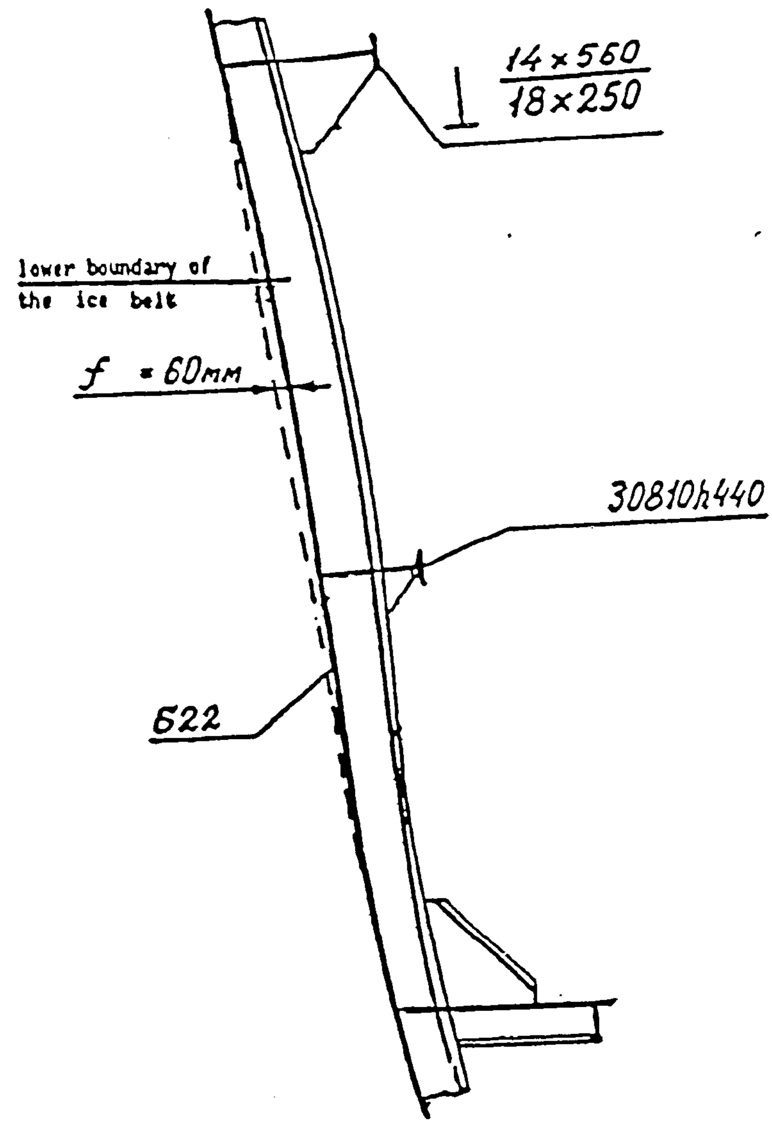


Fig. 5.6. Frame ice damages (permanent dent) of the side on m/s " Vitus Bering", ULA

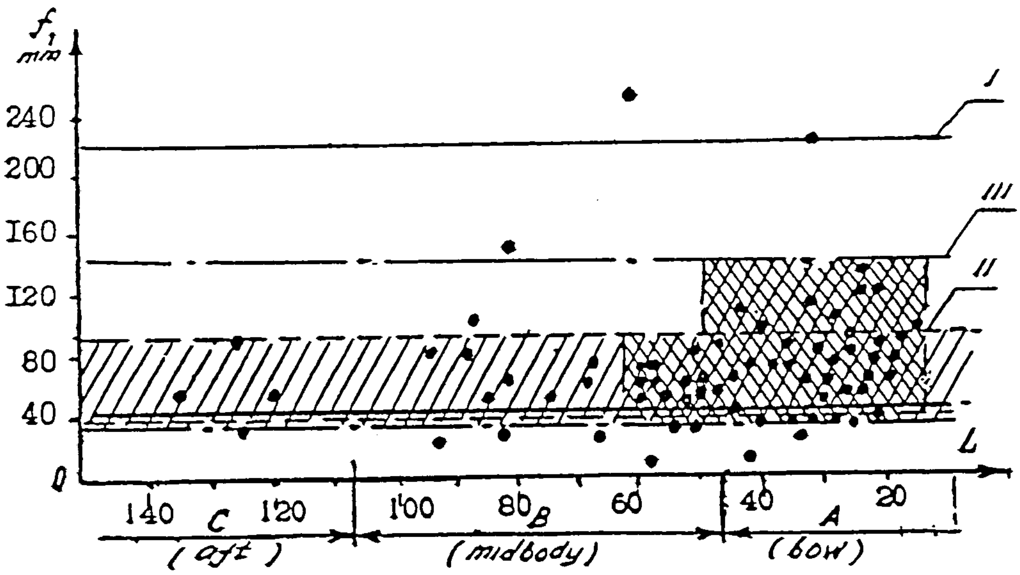


Fig. 5.7 Distribution of permanent deflections of frames along ships of " Amguema " type (ULA).
I - side, II - bilge, III - bottom

6 RANGE OF THE CHANGE OF THE VALUES OF STRUCTURAL ICE DAMAGES. FREQUENCY OF ICE DAMAGES (DEFLECTIONS) IN DIFFERENT AREAS OF THE HULL

It should be that the values of structural ice damages depend on the areas of operation of ships in the Arctic.

As stated above the extent of ice damages of hull structures differ considerably for ships operating in Eastern and Western regions of the Russian Arctic. The most serious ice damages were registered on ships working on eastern tracks of the Northern Sea Route where ice conditions are more severe than in the West. So, for ships of "Norilsk" type which were operating in the East of this Route, there are extensive ice damages within ice belt in midbody and bow portion of ship. At the same time ships of a similar type operating in the Western arctic area suffered only insignificant ice damages of bilge and bottom shell plating strakes.

After arctic navigation in ice the maximum permanent deflections of the framing on domestic arctic vessels were not more than 200 mm, the bulges reached 70 to 80 mm.

In general, similar ice damages are observed on the new generation independent (SA-15 type) ice-going vessels (ULA) of the new generation close in dimensions to the "Samotlor" type tankers.

However, attention is attracted by an extremely large amount of ice damages to the new vessels designed for all-the-year-round operation in the Western Arctic based on the draft requirements of the Register, 1981.

The extent of ice damages that occurred in the East of the Northern Sea Route is considerably higher than that in the West - for ships of "Norilsk" type, for example, the damaged area reaches on the average 100-300 m^2 per one ship, maxisus permanent sets reached 200 mm for framing while in the West this value is 50-60 m^2 and permanent set for framing reached 40-50 mm, for plates -20-25 mm.

Practically all the ships of SA-15 type which regularly made voyages in the Eastern region of the Northern Sea Route -"Bratsk", "Igarka", "Monchegorsk", "Okha", "Nikel", "Nizhneyansk", "Kola" a.o. - suffered numerous heavy damages. After navigations in the East, in the process of expensive repairs, hundreds of square meters of the underwater plating and framing have been replaced mainly in almost inaccessible regions of bilge and second bottom, while operating in the Western Part of Arctic only insignificant damages of shell plating took place.

Ships of the arctic navigation, especially modern ones, sustain fairly well the loadings arising as a result of the ice pressure. The portion of structural damages caused by the ice pressure does not exceed 5-6% of the total number of damages. Ice pressure front is of serious danger principally for old ships with considerable age wear of members (such as category L1 ships of "Pioner" and "Volgoles" type). Hull damages of these ships caused by the ice pressure are excessively large and even may result in their loss (timber carrier "Vitimles", 1964, m/s "Kolya Myagotin", "Nina Sagaidak", 1983, the East Siberian Sea). It should be noted that ice strengthenings of L1 category do not provide safety of the ship while working in ice in the Eastern Region of the Northern Sea Route.

Data on the distribution of the frequency and values of damages over the length of transport arctic cargo ships are shown in Figs.5.1-5.7, where for each of the investigated damages of shell plating the value and place of the largest permanent deflection are indicated.

In conclusion it should be stated that analysis carried out on the basis of information about the permanent set of structural elements of arctic cargo ships has shown that:

- one of the causes of ice damages is also unfounded deviation from the requirement imposed for hull structures by the Register Rules. These deviations are encountered in almost all designs and frequently lead to mass hull ice damages (as for example, took place on ship of "Norilsk" type);
- principal structural causes of the ice damage of framing is the insufficient stability of its plate elements (webs, brackets, diaphragms etc.) abutting upon the shell plating in the zone of action of ice loading, because it is necessary for these elements

to take certain constructive measures including the installation of additional stiffeners and an increase in plate thickness;

- as a rule, the most damageable hull portions on all Arctic vessels are forepeak area, bilge strakes and abutting bottom strakes in the fore and middle parts of the vessel. High damage rate of the bottom strakes is attributed both to the commonly used way of escorting ships (in close tow) and to the shallows occurring along the whole length of the Northern Sea Route.
- maximum permanent deflections (after ice damages) do not exceed 200 mm, Tabl.6.1.
- to improve the reliability of the hull of cargo ships operating in the Eastern Part of the Northern Sea Route it is necessary to introduce special requirements into Russian Register Rules including additional highest ice class of the cargo ships ULA-Super.

Table 6.1. Maximum of permanent dents of arctic ships (classes UL,ULA)

f_{max}, mm	Strakes	After body	Midbody	Forebody
Dents	side	-	100	200
	bilge	55	100	200
	bottom	35	100	200
Bulge	side	50-60	35	-
	bilge	40	50	40
	bottom	55	45	60

According to the plan of works on this project (Part II) the investigations will be performed in 1994-1995.

At the concluding stage of work a comparative assessment of the probability of the occurrence of dangerous ice damages of transport ships of different ice classes working in ice conditions of the Northern Sea Route will be carried out. Results of work will be used for the assessment of risk of the occurrence of heavy ice hull damages, spoilage of cargo during the passage of ships of foreign shipowners along the NSR as well as for the improvement of the Rules of construction and classification of ships regarding ice strengthening.

APPENDIX A

Project review

NKK

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Total 4 pages

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REF : I.5.5 Review comment.

Dear Dr. Simonsen

The attached is my review comment for I.5.5. I apology the late response. It took a lot of time, but honestly the content is almost vacant and I was disappointed. Probably cross check between projects will be necessary to extract the useful report from Russian side. I did not mention any topological error or grammatical error, it may be better to take English review by the native speaker before distribution.

Best regards,

亀崎一彦

Kazhiko Kamesaki

Review comment on I.5.5 Planning and risk assessment

Reviewer
Kazuhiko KAMESAKI
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Review comment

1. Nomenclature lists should be attached at first pages. Some nomenclatures appeared without any definition in this report.For example, Kd,Vio ice, f of Tn=fTicn in 1.5 page 14.

2. Paragraph title is too long and does not represents the contents properly. For example, 1.4 "Standard - reference information on ice conditions and operating characteristics of the ships and standard convoys for the optimal navigation variant along the segments and on the whole along the NSR ". Simplify paragraph title and clearly define what you want to address in a paragraph.

3. Many duplications appeared in part 1 and 2. For example ,Ice category definition is duplicate between 1.3 and 2.7.1. Also 1.5 and 2.7 have the same title and contents are almost discussed in same depth. It gives very diffuse and lengthy impression. I feel that part 2 should focus on the ice environmental data applied for QAD modeling.

4. Ice terminology should be defined in appendix. Most words coincident with WMO Sea-ice nomenclature, however it is better to define again to avoid misunderstanding in case. For example, the practical difference and usage between ice massif and vast floe in the report is vague.

5. Segments and/or districts along the standard navigation route should be defined using map. I understood that the NSR segments are divided as follows from 1.2. Are they true ? , the segment definition is very important and the general characteristic for ice condition on each segment shall be described.
   - Western ice edge - Dikson Island
   - Dikson island - the Cheluskin Cape
   - the Cheluskin Cape - the Tiksi Bay
   - the Tiksi Bay - the Kolyma river
   - the Kolyma river - the Shekagsky Cape
   - the Shekagsky Cape - the Bering strait

   Ice data in part 2 should be discussed in accordance with the segments. For example, clarify that Table 2.1, Table 2.3, Fig.2.4 are applicable for all segments. Table 2.2 should be provided for all segments along NSR and the difference between west and east NSR should be clarified. In 2.3 " Ice formation ", try to describe the ice formation feature in each segment and clearly show the characteristics in terms of area.

6. Try to use the illustrative figure to help the understanding. For example, 2.5.1 BSI discussion, if you attach the illustrative figure, it is quite understandable.

7. Try to show or put raw data measured data to verify figures or tables. We cannot imagine that how correct figures are.

8. Equation (3.7) in page 51, alphabetical *l* and numeric 1 is not distinguishable. Use distinguishable alphabetical or handling l instead of l, also hard to understand to derive (3.3) or (3.4) putting l as 0 or infinite. Check equation again.

9. I understand that "QAD" is already developed. If correct, should show a sample calculation results. It is vague what is input term and what is output, clarify these ambiguity showing sample dataset.

10. Page 27 is illegible.

11. Subscript letter is too small. For example, $V_{io\ ice}$, T_{n}.

12. As for ice damage, regulation for Russian shipping registration shall be summarized and the correlation between the regulation for hull strength and damage data shall be discussed.

13. Design ice pressure shall be estimated from plasticity analysis or formula for the rule defining hull skin plate excluding safety factor, providing that ice damages are simply caused by plastic deformation. Thus, ice pressure distribution including the statistics analysis can be investigated.

14. Ice damage data for L1 class is not interested. Ice damage data for ULA, UL class is of the most significant one and worth to be analyzed.

15. Ice damage data distribution along the segments for the NSR shall be clarified by showing data, everybody can understand that the east NSR will be more harsh than the west and result more damages. Discuss the quantitative difference.

16. Ice damage data for propeller and rudder shall be incorporated for damage data base.

17. Define Convoy formation in detail, such as distance between icebreaker and following cargo vessels, et. I think that ice damage data occurred in convoy operation is different phenomena. Try to separate ice damage data from convoy operation and analyze cause and trend.

Suggestion for 1994 study
Too much portions were allocated for general discussion. The few data was attached and no sample calculation was demonstrated in this annual report. I suggest the followings to avoid the lengthy description and make the report more quantitative and useful;

- focus on the QAD model and its necessary data set
- limiting ships to UL,ULA class represented by Arctica class , SA-15, m/v Domitriy Donskoy type

Our final goal is to estimate a trafficability of existing ship and newly design ship for the NSR. For example , if one plans a shipping from one port to another port along the NSR deploying a ULA ice breaking cargo vessel with 40,000 ton full load displacement and 30,000 hp engine that exceeding SA-15 capability, this project results will give some quantitative answer in terms of ;

- expecting navigation periods in each season and segment
- expecting hull damages and deviation from current regulation
- expecting associated environmental pollution and other risks to be taken into consideration.

To perform this study, off course , we need dataset originated from ship own capability and dataset originated from environmental condition as you mentioned. QAD is reasonable from this view point, however as I mentioned, concrete dataset both for environment and ship own performance is almost vacant in this report. I hope in next year to demonstrate the QAD calculation results limiting the navigation segment or the type of ship.

COMMENTS ON THE REVIEW OF DR.KAZUHIKO KAMESAKI FOR PROJECT I.5.5 "PLANNING AND RISK ASSESSMENT"

The authors have carefully considered the comments and proposals of the Reviewer and are very grateful for the attention and specific comments on the work accomplished.

The authors agree with much of the comments and have taken them into account when preparing the final report.

In particular:

- list of arbitrary designations and abbreviations is made;
- titles of sections 1.4 and 1.5 are changed;
- editorial changes are made in sections 1.4 and 1.5;
- comments to tables 2.1 and 2.3 are given;
- chapter 3 is supplemented by section 3.3 "Example of calculations using a "QAD" model", which presents the results of calculating operational characteristics by actual data on ice navigation conditions;
- section 2.5.1 is supplemented by Fig.2.7, which makes clear the statements in the text;
- misprints and technical errors, made in draft report are eliminated.

Comment No.5 concerns zonation of the NSR region with corresponding characteristics of ice conditions.

Zonation of the NSR region by ice conditions and navigation difficulty is a goal of Project I.1.2.

A description of ice conditions on the navigation route on each delineated NSR segment was not included into the objectives of Project I.5.5. Such description, as well as presentation of regime features of total ice cover distribution in each zone of the NSR region at first were objectives of Project I.2.1.

Comment No.7 on the presentation of raw data to verify tables and figures. We do not consider it advisable not least due to a vast amount of such data.

Comment No.12. We agree that this issue is very important. However within the framework of this work there was no task to establish relationships between the sizes of ice damages and requirements of the Rules to ice strengthenings which can be seen from the title of work "Collection and analysis of statistical data on hull ice damages of transport ships on NSR".

Accordingly the task to be achieved concerned the assessment of actual operational hull state of ships from the point of view of safety . Nevertheless in our study we touched upon the subject of the correlation between Rules and ice damages having indicated among the reasons of the occurrence of ice damages also unjustified deviations from Rules requirements to ice strengthenings (page 77) in the design and construction of ships.

At the same time, as it was noted in the work (p. 75,77), it is far from being the only cause of ship's hull damages in ice. So, for example, ice damages on tankers of "'Samotlor"type (UL) and "Norilsk " type ships (ULA) where most significant deviations from the Rules requirements concerned the forebody , ice damages were found practically over the whole underwater hull portion even in the areas meeting in full the Rules requirements.

Problems of relations between structural strength, specification requirements to ice strengthenings and sizes of ice damages go beyond the scope of this work (Project I.5.5) because here aspects of design and construction of ships are investigated and also the assessment is made of structural strength of particular ships.

The analysis and subsequent more accurate definition of the Russian Register requirements taking into account data on ship's ice damages may be performed by the institute provided it is considered advisable to incorporate this work into the program of INSROP.

Comment No. 13. Assessment of ice loadings by permanent deflection of the shell plating and hull framing is one of the most interesting research subjects integrating all the three problems of structural mechanics: that of external forces, of internal forces and of admissible stresses (states).

The institute has been dealing with these problems for many years evaluating actual ice loadings affecting the hull by permanent deflection of shell plating on the basis of collection, generalization and analysis of data on the ships' hull ice damages and also using theoretical and experimental investigations of elastoplastic deflection of ships' structures. As already noted, only the first problem, i.e. collection and analysis of statistical data on ice damages, was considered within the framework of INSROP Project I.5.5.

Second problem-determination of loading by permanent deflections - is a rather complicated theoretical problem of structural mechanics of ships. The preconditions and methods of solution of this problem are considered differently even by specialists in this field. In particular, it concerns the account of the frequency of loadings and the effect of the accumulation of strain. Therefore this part of the problem goes beyond the work we completed and should be regarded as a separate task which may also be fulfilled at the next stage within the scope of INSROP.

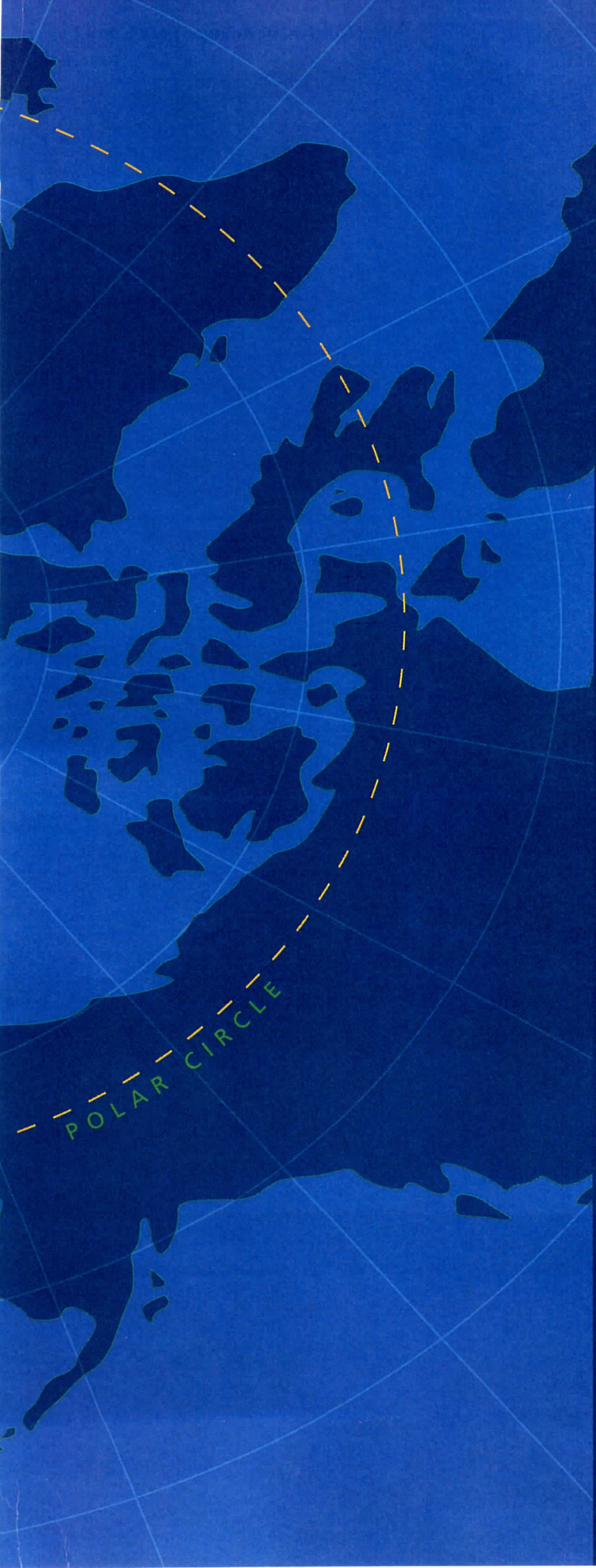
Comment No. 14. The opinion of the inexpediency of the analysis of L1 category ice-strengthened ships is erroneous and apparently is the consequence of insufficient knowledge of the experience and particular features of operation of Russian cargo ships in the Arctic. Throughout a number of decades transport ships of this category carried out and continue to carry out transportation of considerable volumes of cargo along the NSR. The experience gained of the operation and repair of hulls of these ships after arctic navigations should by all means be taken into account while making analysis of ice damages of arctic ships of which those of class L1 form a part.

Comment No. 15. Information about different levels of the hull ice damages of ships operating in the West and East of the NSR is given in part II of the report. There are also quantitative characteristics of these differences (by depths of permanent deflections and damaged shell plating area) shown by way of example of the operational experience of the most numerous modern ships of "Norilsk " (SA-15) type, p. 76,77 of the report.

Comment No. 16. In accordance with the task formulated in part II of the report only the analysis of ships hull ice damages was carried out. Consideration of damages of the screwrudder systems was not envisaged in this study.

Comment No. 17. As mentioned in the report, forebody bottoms of ships "closely" escorted by an icebreaker through ice isthmuses are subject to additional loadings due to the impact of ice floes from under propellers of the icebreaker. However the identification of these damages seems not to be possible because the forebody part of the hull is most frequently subjected to all kinds of ice damages and dock inspections are made as a rule after the completion of ice navigation.

As to the proposals for 1994 and future studies, we are grateful to the Reviewer for his wishes and will try to take them into account in our future work.



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 stockholding 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.