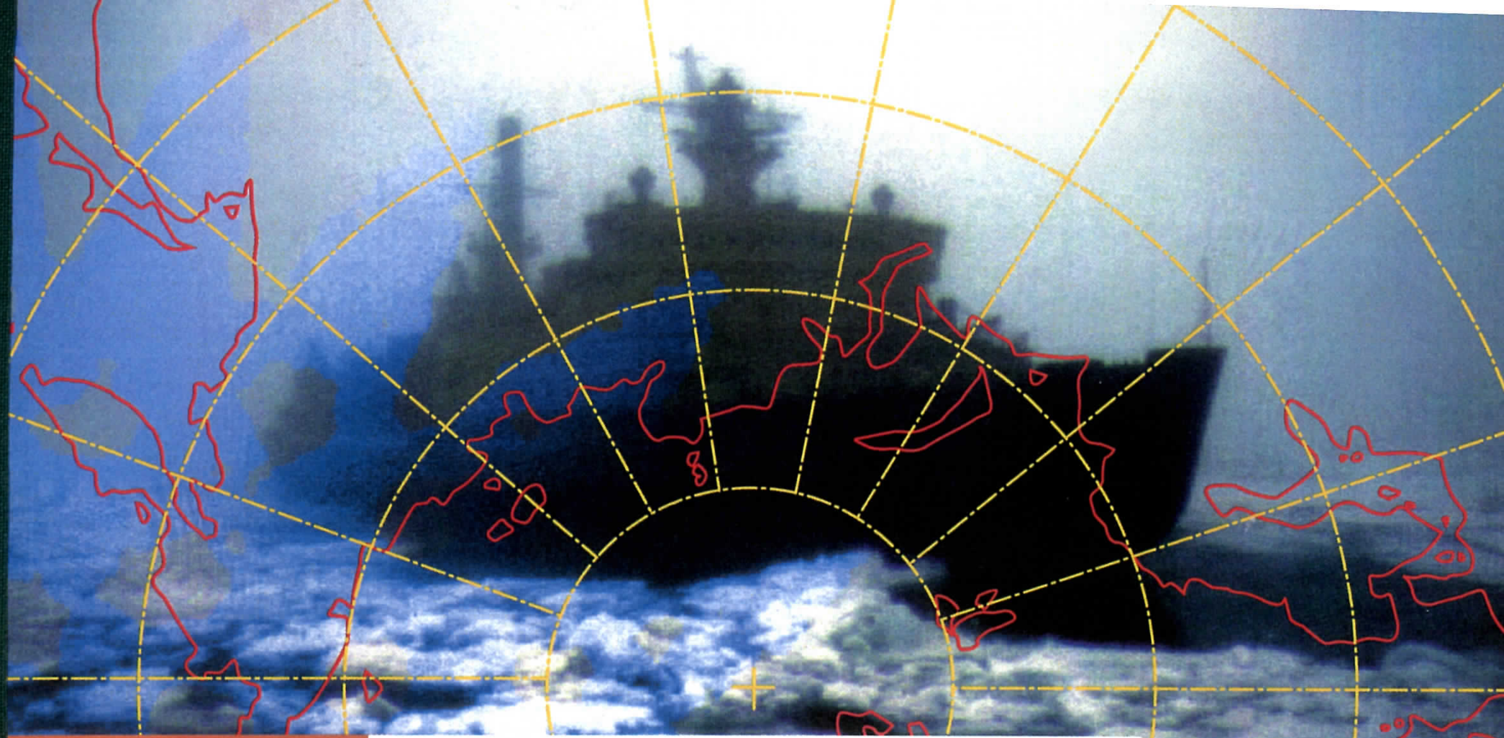

INSROP WORKING PAPER NO. 107 - 1998

The NSR Simulation Study Work Package 5:

Collection of SA-15 Operations Data

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INSROP International Northern Sea Route Programme

Central Marine Research & Design Institute, Russia

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Box B:	The Simulation Study of the NSR Commercial Shipping
Work Package 5:	Collection of SA-15 Operations Data
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Title:	**Collection of SA-15 Operations Data**
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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.

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ABSTRACT

Results are presented of the analysis of data on the experience of operation on the Northern Sea Route (NSR) of multipurpose icebreaking cargo ships of the *SA-15* type, class ULA, with a deadweight of 15 000 t. Materials are processed on the full scale trials of the propulsion in ice and ice impact strength of these ships. Data about the ice damages of their hulls are collected and analyzed. Consideration was given to the results of the sailing independently and that under the icebreaker assistance during different periods of navigation in relation to the area of operation in the Arctic. En-route reports of captains about conditions and tactics of the navigation along the NSR were summarized. On the basis of processing of the obtained data, speeds of the movement of ships under consideration were determined depending on ice conditions; evaluation was made of the efficiency of the icebreaker escorting and of the compliance of the ships' ice performance with operational conditions in the Russian Arctic. Recommendations were given on the improvement of the hull structure of ships of the *SA-15* type taking into account statistic data on the ice damageability.

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INTRODUCTION

The present work performed in the context of WP5 of INSROP Project 2 on the collection and systematization of data on the operational experience in the Arctic of modern large icebreaking cargo ships of the *SA-15* type aims at the verification of results of the mathematical modeling of the merchant shipping on the NSR envisaged by the investigations within WP6 and WP8.

In the course of the fulfilment of work, consideration was given to different aspects of the operation of the *SA-15* type ships in the Russian Arctic including the study of the effect of various ice conditions on the efficiency of the operation of these ships (as to area and season as well as to the tactics of sailing – independently and under the icebreaker support). Full-scale ice trials of ships to be put in operation, data on scientific observations during expedition voyages and on the en-route reports of captains of the Murmansk and Far East Shipping Companies (MSCO and FESCO) were principal sources of information. Data on the ice damageability gathered during dock inspection and hull repairs of ships of this type were also examined.

As a result of the processing of statistical materials on the propulsion in ice and ice impact strength, average values of speeds of the movement of ships of the *SA-15* type depending on conditions and modes of navigation in ice were obtained and the compliance of ice performance of these ships, including the ice class, with the conditions of the all the year round operation on the NSR evaluated.

1. Purpose, main characteristics and particular features of hull construction of the *SA-15* type ships

Large multipurpose icebreaking cargo ships of the *SA-15* type were built for the Soviet Union at Finnish shipyards *Wärtsilä* and *Valmet* (prototype m/s *Norilsk*). Purpose of these ships is the transportation of a wide range of cargoes to the equipped ports of the Arctic throughout the year. They are also adapted to carry out unloading onto the fast ice and have a roll-on roll-off deck with an angled lowered ramp.

When ordering the *SA-15* type ships, attention was paid to provide high ice resistance qualities. The feasibility study has shown that these ships should be built for the ULA class of the USSR Register. Power of the propulsion machinery, propulsion system, principal dimensions, their ratios and the hull shape should provide for virtually independent navigation during the summer period and the effective operation in winter ice conditions under the assistance of powerful icebreakers [1]. Taking into account the fact that ships of the *SA-15* type will be used in the winter snow covered ice at a low air temperature, they are equipped with the air bubbling system (ABS) and their hulls are covered with the low friction *Inerta-160* painting [2, 3].

Principal particulars of the *SA-15* type ship are presented in Table 1.1. The general arrangement plan of the ship is shown in Fig.1.1.

The ship's power plant comprises two medium speed main engines with a *Valmet-Renk* ASM2x187.5F single stage double reduction gear. The maximum continuous power of each engine is 7720 kW (10500 h.p.) at a rotational speed of 560 rev/min. There are two *Voith* fluid couplings and two *Renk* plate friction couplings fixed between the main engine and the reduction gear.

A *KaMeWa* controllable pitch propeller (CPP) specially designed for ice conditions and used for the first time in the domestic practice is installed on the ship. The four blade propeller has a diameter of 5.6 m, hub/propeller radius ratio of 0.42, and a rotational speed of 120 rev/min.

Table 1.1

Principal particulars of icebreaking cargo ships of the *SA-15* type

Characteristics	Value
Type of ship	Multipurpose
Number of units in the series [1]	19
Year of construction	1982-1987
Ice class	ULA
Length, m	
• overall	174
• between perpendiculars	159.6
Breadth, m	24.5
Depth, m	15.2
Draft, m	
• loaded	10.5
• arctic	9
• specified	8.5
Displacement, t	
• loadline	31200
• arctic	25900
• specified	24100
Deadweight, t	
• loadline	20000
• arctic	14700
• specified	12900
Cargo-carrying capacity, t	
• loadline	15700
• arctic	10345
• specified	8555
Register tonnage, reg.t	
• gross	16500
• net	11000
Number of holds / tweendecks	5 / 5
Container capacity, units	532 × 20′ or 240 × 40′
Number and lifting capacity of cranes, units × t	3 × 20 and 1 × double 40
Type of propulsion plant	Medium speed engine
Main engine	*Wärtsilä-Sulzer* 14ZV 40/48
Number and power of main engines, kW	
• maximum	2 × 7700
• service	2 × 6930
Engine room location	Intermediate
Number and type of propellers	1 × CPP
Icebreaking capability at 2 kn speed, m	1.0
Open water speed (at a maximum load), kn	18.1
Endurance, miles	12000
Number of crew, persons	39

[1] List of ships of the series with the indication of shipowners is given in the Annex, Table A.1

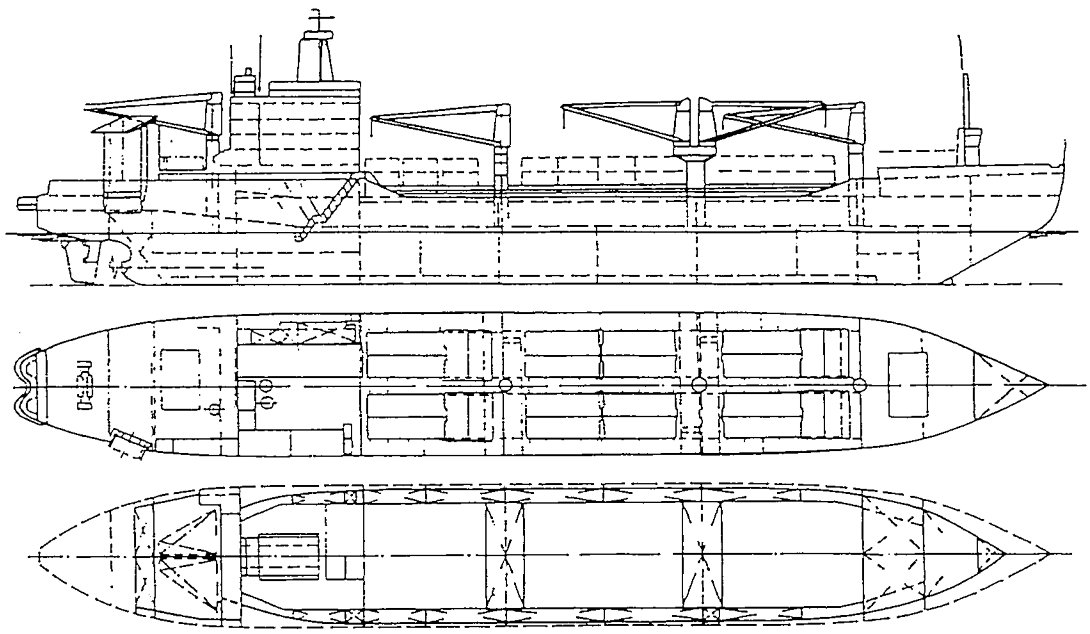

Fig.1.1. General arrangement plan of ship of the *SA-15* type

During navigation in open water the power is transferred to the propeller through friction couplings. Under the ice conditions, to protect the main engines against dynamic overload due to propeller-ice interaction the power is transferred through fluid couplings. Power losses depend on the fluid coupling slip. According to the information of the *Renk* company the slip varies within 2 - 8 % and this was later confirmed by trials.

The ship's power plant is equipped with an *engine – CPP* remote automatic control system which provides:

- propeller pitch control at a constant rotational speed of the main engines under conditions of the navigation in ice covered waters,
- propeller pitch control with the simultaneous alteration of the rotational speed of the main engines under conditions of the navigation in open water.

The hull structure of ships of the *SA-15* type is characterized by the following particular features. The hull has a mixed framing system (Fig.1.2). The ship's side from the tweendeck to bilge is made up according to the transverse system with web frames placed at intervals of 4 - 5 spacings (3.2 - 4 m). Above the tweendeck, the side including the sheer strake is made up according to the longitudinal framing system excluding the forepeak and afterpeak areas extending by about 0.05 of the length **L** of ship if counted both from bow and stern.

The main board spacing is 800 mm. Over the whole side the intermediate frames (each 400 mm) are installed extending from the bilge to tweendeck. Frame ends are fastened by brackets with tweendeck and bottom structures (Figs.1.2 and 1.3). The deck and the bottom have a longitudinal framing system except ends.

The bottom at ends on stretches extending by 0.25 **L** from the fore and after perpendiculars is built up according to the transversal system. Distance between floors is 800 mm and between bottom longitudinal ribs – 620 mm.

Steel of the grade E32 with a yield limit of 315 MPa was used as a material of the main hull. Double bottom structures are made out of the conventional carbon steel with a yield limit of 235 MPa.

Particular feature of the forepeak structure is the use, instead of web frames, of permeable diaphragms, 12 mm thick (Figs.1.4 and 1.5). In the double sides adjacent to cargo holds, instead of some web frames, vertical permeable diaphragms are installed.

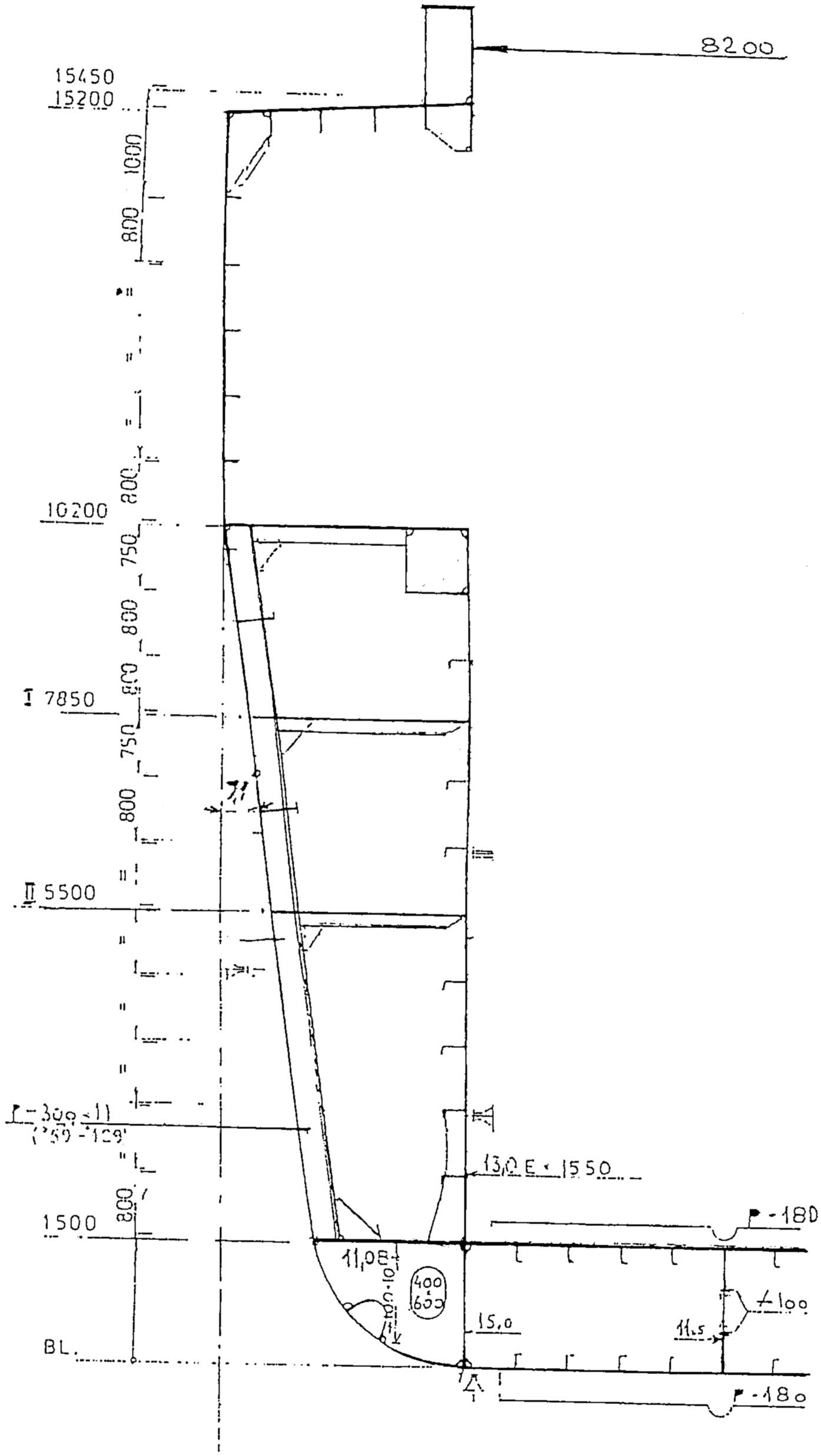

Fig. 1.2. Middle frame

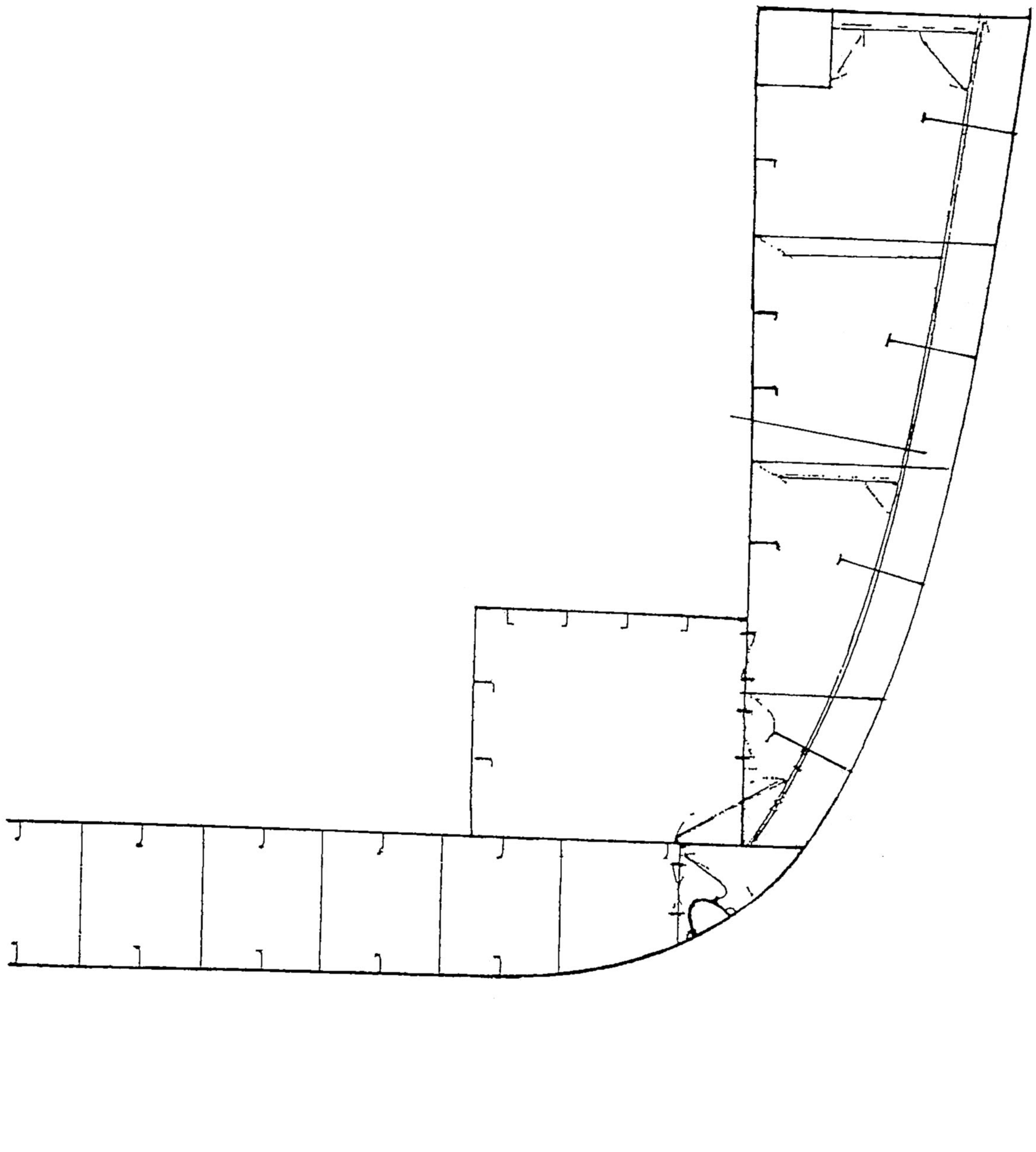

Fig. 1.3. Section through fr. $134_{1/2}$ - $150_{1/2}$

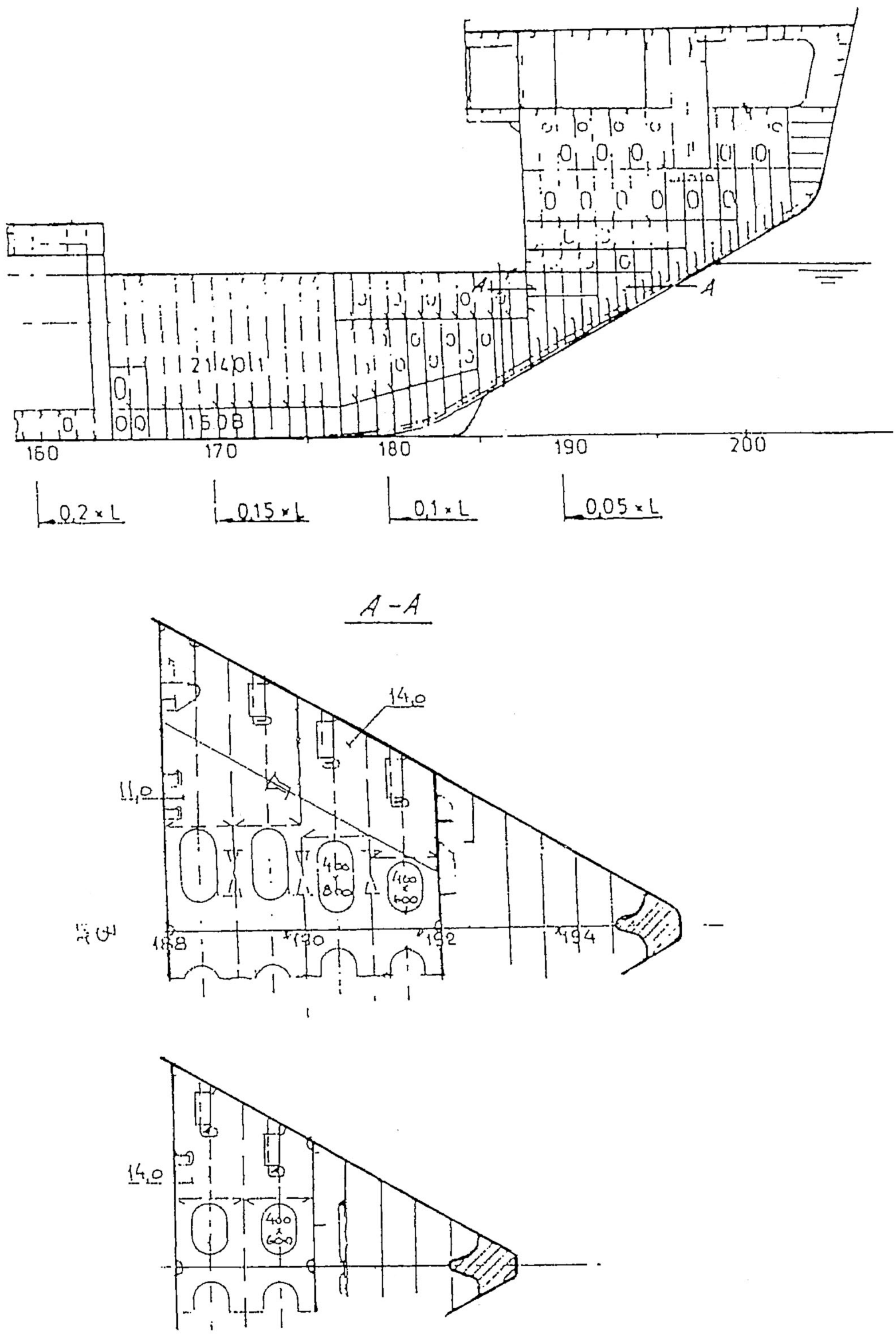

Fig. 1.4. Forepeak structure

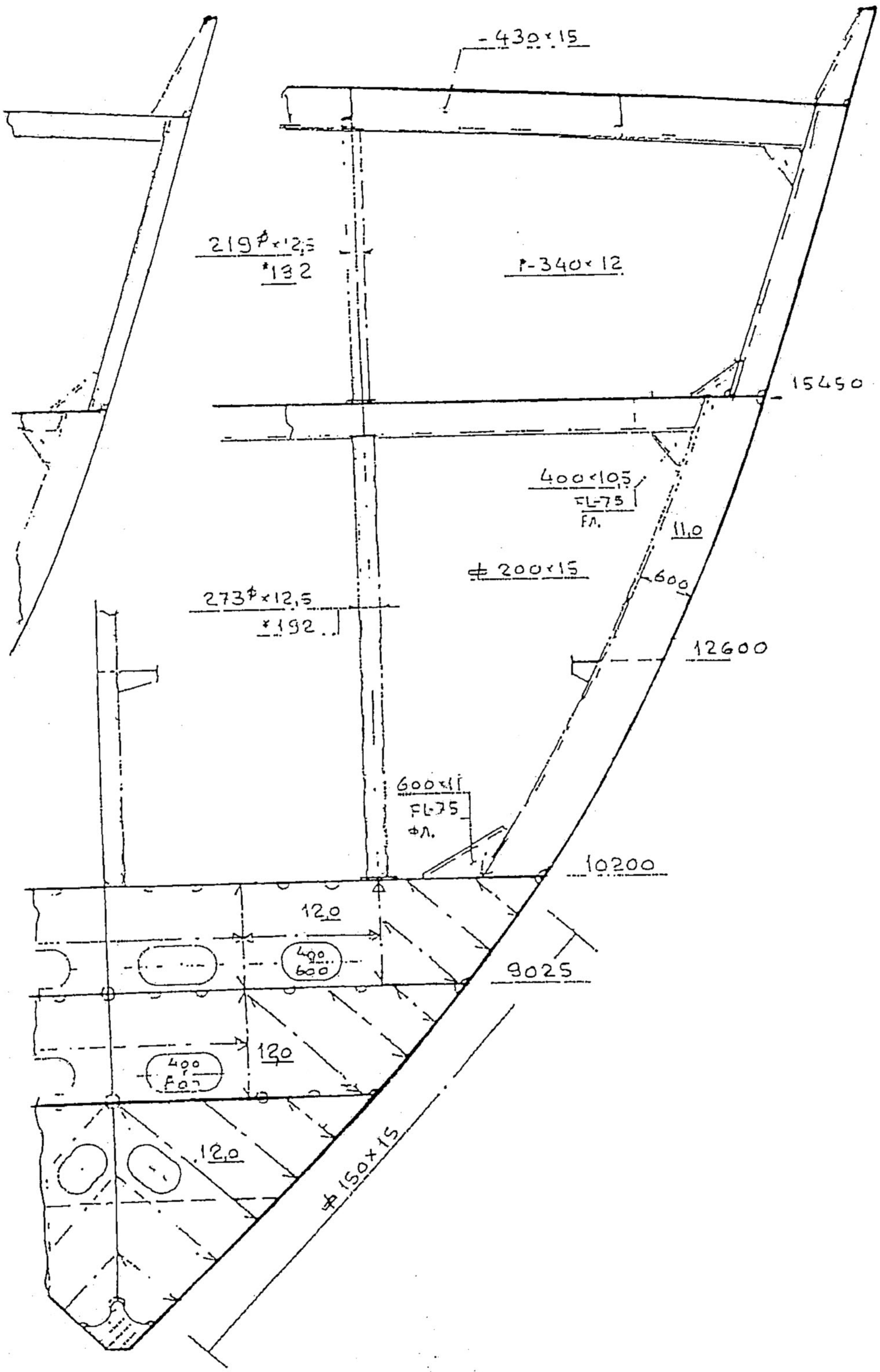

Fig. 1.5. Section through fr. 192

2. Regime full-scale tests of the ice performance of ships of the *SA-15* type

2.1. Results of tests of the propulsion in the level compact ice

During the navigation of 1983 the third ship of the m/s *Igarka* series was tested. The main purpose of these tests was to check the fulfilment of the *Wärtsilä* commitment and to determine actual ice qualities of the *SA-15* type ships. In accordance with the specification data the ship had to overcome compact level ice 100 cm thick and covered with snow 20 cm deep at the speed of continuous motion equal to 1 knot and the main engines power equal to 90 % of the maximum continuous power. When thickness of ice is 80 cm, depth of snow cover is 20 cm, the ship's speed should be 3 kn the power being the same.

The tests of m/s *Igarka* under various running conditions of the propulsion were carried out in the level fast ice 70 - 140 cm thick [4, 5]. Passability in the compact ice and in a channel broken in the fast ice was evaluated. The tests were conducted in the fast ice of the Yenisei Gulf at the beginning of May with no signs of the ice decay. Ambient air temperature varied from 0 to –10° C.

The obtained relationship between the speed and power in the compact level ice 70 - 80 cm thick and snow cover 5 - 10 cm deep is presented in Fig.2.1. Fig.2.2 shows attainable speeds of the continuous motion of m/s *Igarka* in the fast ice of variable thickness with a snow depth of 10 - 15 cm and at the power rate of the main engines equal to 90 % of the maximum continuous power. The minimum speed of a steady ship motion was equal to 0.5 kn in the level fast ice with a thickness of 130 cm and snow cover about 20 cm deep. Under the same conditions the speed of the ship moving astern was about 1 knot. For a comparison, the points corresponding to the specification data are also plotted. As one can see, results of the full-scale trials confirmed the guarantee of the supplier for the expected icebreaking capability of the *SA-15* type ships.

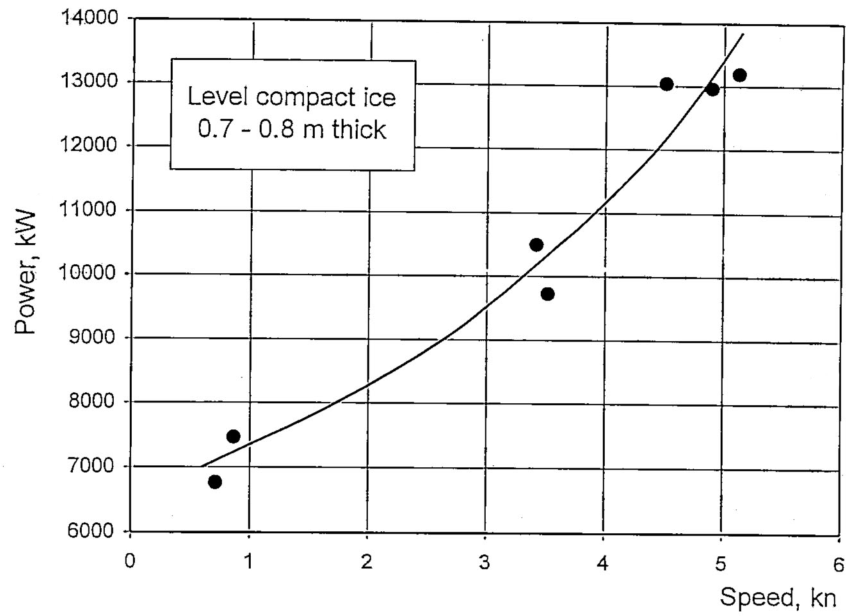

Fig.2.1. Relationship between speed and main engines power of m/s *Igarka*

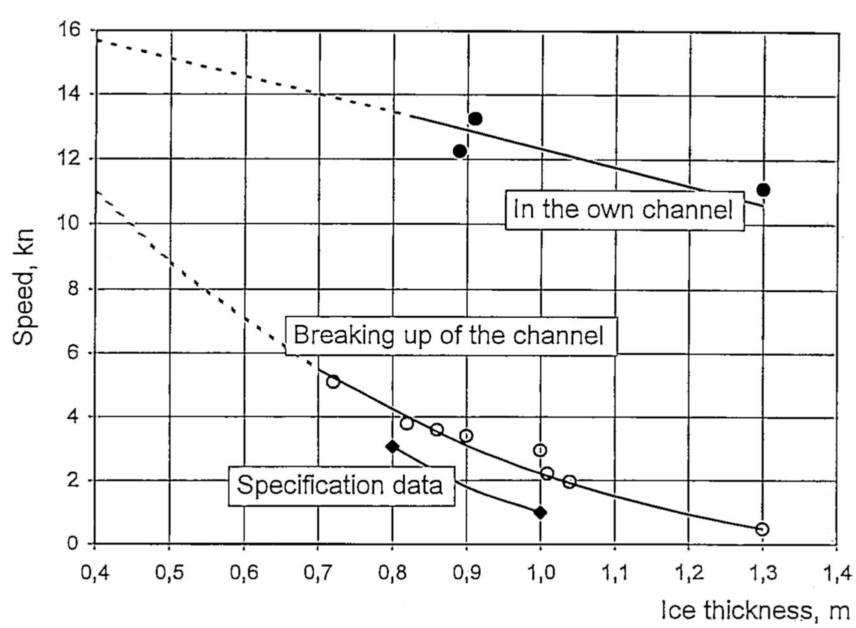

Fig.2.2. Propulsion of m/s *Igarka* in the level compact ice (snow cover 10 ÷ 15 cm deep)

Apart from the passability in the compact ice, Fig.2.2 shows speeds of m/s *Igarka* reached in her own channel broken up in the fast ice with a thicknesses of approximately 90 and 130 cm. The obtained relationships correspond to the ship's motion without the use of the air bubbling system. During the passages of ship with the ABS switched on (one compressor out of two units was in operation) the ship's speed in the channel increased on the average by 0.7 kn. In the compact ice with insignificant snow cover no noticeable effect of the ABS was observed. At the same time, when ice thickness is close to a limiting value for m/s *Igarka*, the ABS reduces the power needed for starting the ship from rest by approximately 30 %. Moreover, the stability of ship motion is ensured at a minimum speed as low as 0.2 - 0.3 kn.

The ship's manoeuvrability in ice was also studied. Results of reversing and inertia tests of m/s *Igarka* are presented in Tables 2.1 and 2.2. The ship was tested in her own channel newly broken in the compact fast ice with a thickness of approximately 90 cm and in an old refreshed channel made in the same ice. Concentration of the ice cake in the new channel was 8/10 - 9/10 while in the old one it was 10/10. Reversing tests were carried out without the use of ABS for the following three manoeuvres:

- full speed ahead (FSA)-full speed astern (FSAst),
- half speed ahead (HSA)-FSAst,
- slow speed ahead (SSA)-FSAst.

Table 2.1

Results of reversing tests of m/s *Igarka* in a channel broken in the fast ice 90 cm thick

Running condition	State of the channel	Initial speed, kn	Stopping time, s	Stopping distance	
				m	lengths of the ship
FSA-FSAst	Fresh	12.3	205	685	4.2
HSA-FSAst	Fresh	9.2	162	430	2.6
SSA-FSAst	Fresh	8.0	128	270	1.6
HSA-FSAst	Old refreshed	7.8	110	240	1.5
SSA-FSAst	Old refreshed	4.6	68	95	0.6

Table 2.2

Results of inertia tests of m/s *Igarka* in a channel broken in the fast ice 90 cm thick

Running condition	State of the channel	ABS	Initial speed, kn	Stopping time, s	Stopping distance	
					m	lengths of the ship
FSA-FSAst	Old refreshed	On	9.8	323	760	4.6
HSA-FSAst	Old refreshed	On	8.0	318	575	3.5
SSA-FSAst	Old refreshed	On	6.2	250	315	1.9
SSA-FSAst	Old refreshed	Off	5.5	183	240	1.5
SSA-FSAst	Fresh	Off	8.2	417	705	4.3

Inertia tests were carried out in the same ice conditions for the following modes of operation: FSA – Stop, HSA – Stop, SSA – Stop. The last operation was performed both in the fresh and in the old channel. At the same time, influence of the air bubbling system on the propulsion and inertia characteristics of the ship was tested. Stopping distance and path of the ship's movement were determined by the *Data Bridge* navigation system, speed was controlled by a Doppler log and log-sight, stopping time being determined by a stop-watch. Acceleration distance of the ship from "Stop" position to FSA in the own fresh channel is four ship's lengths.

From the comparison of data of Tables 2.1 and 2.2 one can see that under the same ice conditions and at equal acceleration rates, the ship's stopping distance at FSAst reversing is 2 - 2.5 times as short as that when the handle of the remote automatic control system is switched to the "Stop" position. It should be noted that in the same conditions and at equal acceleration rates in the channel, the *Moskva* [1] type icebreaker had a stopping distance 1.7 times shorter than that of m/s *Igarka.* This can be attributed to a considerably larger inertial mass of the cargo ship, the displacement of which is twice as high as that of the icebreaker.

Turning ability in ice of m/s *Igarka* was evaluated by a diameter of the turning circle. The turning was performed in a first-year ice field approximately 50 cm thick with a hummocking of 1/5 - 2/5 according to the 5-point scale. The rudder was shifted by 35° to the port at full speed. The mean diameter of the turning circle was approximately 1400 m, or 8.6 lengths of the ship. Turning time was 2700 s.

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[1] Principal characteristics of the icebreaker are shown in the Annex, Table A.2

When comparing the obtained manoeuvring capabilities of m/s *Igarka* in ice and open water one can notice that the turning circle diameter in open water is approximately half of that in the compact ice. When manoeuvring from full speed ahead to "Stop", stopping distances in brash ice of old and new channels are shorter than that in open water by approximately a factor of 2 and 1.5, respectively. It took 370 s to achieve full speed of the ship in open water from "Stop" position, while the acceleration distance was equal to 14 lengths of the ship.

As a whole, results of the full-scale trials of the icebreaking capability and manoeuvring capacity of m/s *Igarka* confirmed the anticipated ice qualities of new icebreaking cargo ships of the *SA-15* type.

2.2. Tests of the ice impact hull strength

Full-scale tests of the ice impact strength of the *SA-15* type ships were an integral part of traditional works on the analysis of the compliance of new ships with the actual conditions of their operation in the Arctic.

The main purpose of tests was the verification of the compliance of hull ice strengthenings (design ice loads) with ice conditions on the NSR. Besides, scientific problems were also defined: investigation of the salient features of the hull/ice interaction, assessment of the strained state of hull structures under different ice conditions, study of the ice load distribution pattern over the surface of the underwater portion of the forebody, more accurate determination of sizes of the hull/ice contact zones at the impact against ice of different thickness and concentration.

Main results of the ice strength trials of m/s *Igarka* and m/s *Kapitan Danilkin* are given below.

2.2.1. Results of the hull strain-gauging of m/s *Igarka*

Trials of the motorship were carried out in 1983 – in May by CNIIMF and by *Wärtsilä* and in July-August, when strain-gauging of the ship's forebody during the working voyage Murmansk-Pevek-Bering Strait was made, by AARI.

Trials were being carried out near the Franz Josef Land. Measurements were made with the use of the equipment installed aboard by *Wärtsilä*. General mounting of the instrumentation system (installation of sensors and laying out) was conducted by the builder in the process of construction of the ship to be tested.

Trials were made in the mode of short range specialized measurements of the stressed state of hull structures. Sensors were placed on hull by "spots" – by groups in the forebody within the waterline, Fig.2.3.

Prior to the beginning of trials the ship was loaded for a working voyage to the Western Europe. Forward draft of 9.4 m (stern draft – 10.4 m) ensured contact with ice of the bow group of sensors. During the trials the operational sensors were concentrated between frames 164 and 168 (Fig.2.4).

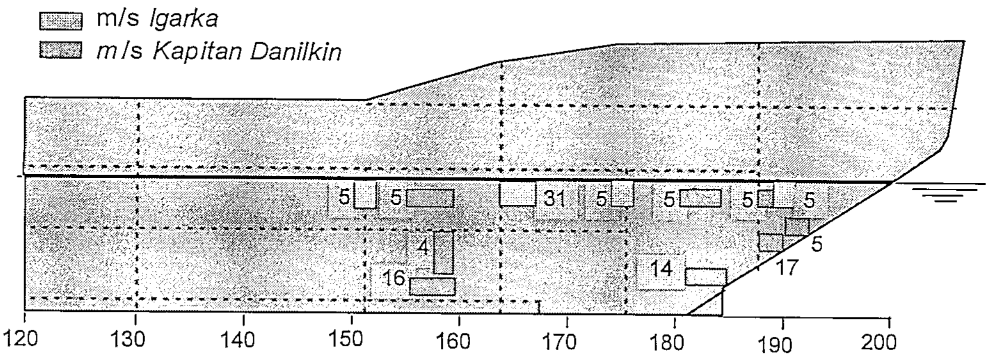

Fig.2.3. Zones of the location of sensors in the forebody of m/s *Igarka,* m/s *Kapitan Danilkin* and number of sensors in each zone

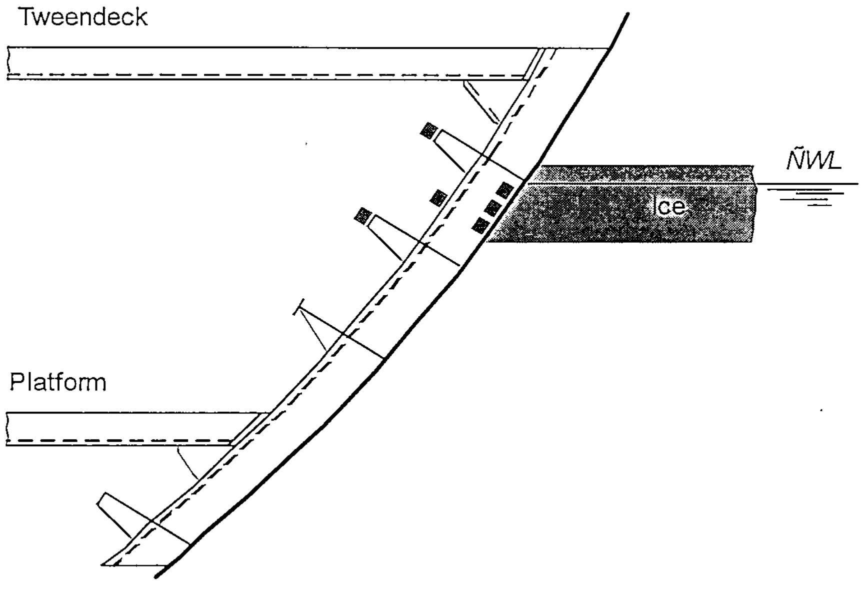

Fig.2.4. Arrangement of sensors on m/s *Igarka* in the area of frames 164 - 167

Measurements of the ice impact strength of hull of m/s *Igarka* were made in the mode of independent sailing through a relatively level (or slightly hummocking – numbers 1/5 - 2/5) natural small floe ice and ice cake with a thickness from 60 - 70 cm to 90 - 100 cm and during the movement in its own channel through compact ice fields up to 1 m thick (snow depth was 10 - 30 cm, air temperature over the test area –2°C). Speed of movement changed from 1 to 3 m/s, ice sample compression strength did not exceed 2.1 MPa.

During the movement through compact ice with a thickness close to a limiting one for m/s *Igarka* (70 - 90 cm) the instruments recorded only 7 impacts of hull against ice despite the fact that the ship moving for a long time through the hummocking ice was breaking through hummocked stretches by ramming.

On the basis of the analysis of readings of the recorders one came to the conclusion that at impacts against ice floes during the trials the length of a ship's hull/ice contact zone had been approximately equal to one frame spacing (400 mm) and the width (height) varied within 0.3 - 0.4 m. Average (design) contact pressure corresponding to the above sizes of the contact zone varied from 1.5 to 3 MPa (impacts 1 and 7, Table 2.3). The table shows sizes of the contact zone and corresponding contact forces for each recorded impact.

Table 2.3

Contact zone sizes and ice loading

No. of impact	Sizes of contact zone, m		Intensity of loading, MPa	Overall forces, MN
	Height	Length		
1	0.42	0.40	1.54	0.26
2	0.40	0.40	2.90	0.46
3	0.34	0.40	2.43	0.33
4	0.36	0.40	2.92	0.42
5	0.37	0.40	2.90	0.43
6	0.36	0.40	2.20	0.32
7	0.30	0.40	3.00	0.36

The highest stresses in structural elements after processing of the results were as follows:

- 195 MPa – in the middle of the side plate,
- 258 MPa – at the free edge of the side frame in the middle between stringers.

Overall stress level in the structural elements of the side grillage recorded during the trials is not high and 1.5 - 3 times lower than the indicated highest values.

In Pevek, for the evaluation of strength of the forebody shell plating, specialists of AARI have installed sensors in the forepeak. Strain sensors were installed on the framing in deep-tank No.1. According to the adopted domestic procedure, sensors were arranged by groups: 2 - 3 horizontal lines and a vertical one. Total number of the forepeak plating sensors was 6. Arrangement of sensors is shown in Figs.2.5 and 2.6. Tests were carried out on the short-term basis.

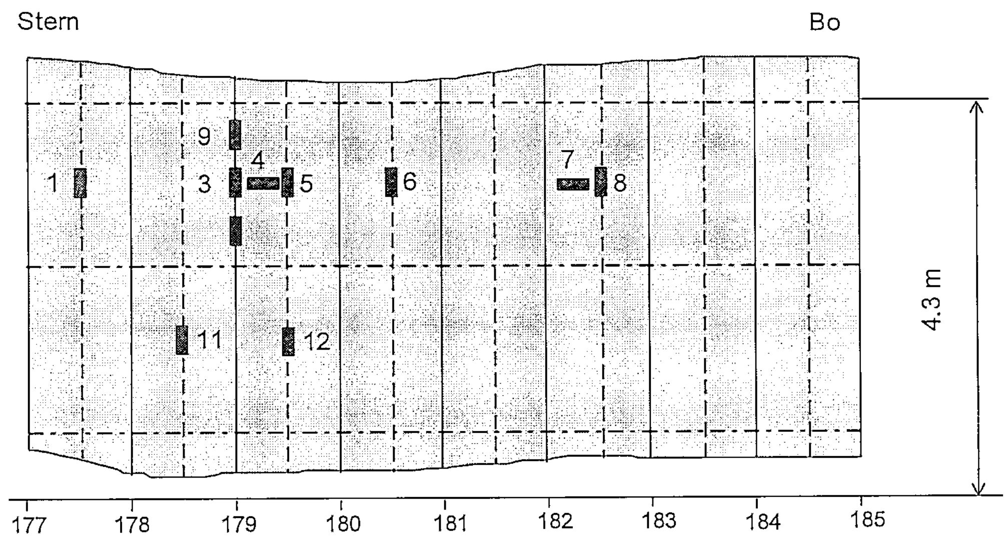

Fig.2.5. Portside arrangement of sensors

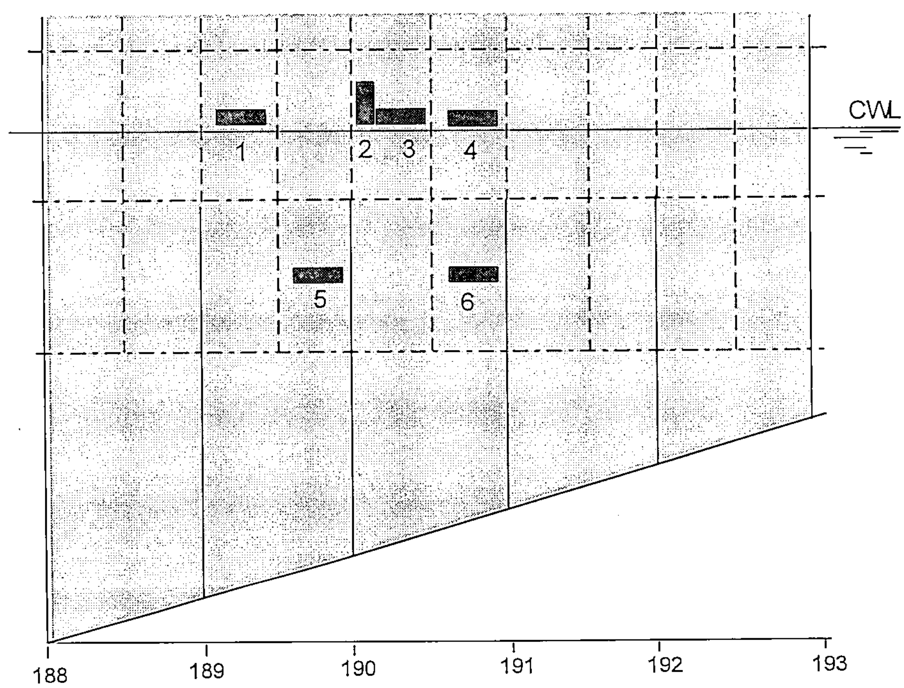

Fig.2.6. Forepeak arrangement of sensors

During the independent navigation the movement proceeded in the loose ice with a concentration of 4/10 ÷ 5/10, 60 ÷ 80 cm thick, in ice breccia-up to 150 cm; when following the icebreaker in the channel the concentration was 6/10 ÷ 7/10 and ice breccia more than 200 cm thick.

Maximum stresses in the forepeak plating equal to 74 MPa were recorded during the independent movement at a speed of about 14 knots through loose ice 120 ÷ 150 cm thick in ice breccia and it was 23 % of the yield limit of the plating material. When moving in the channel behind the icebreaker the level of the measured stresses was lower. Due to the insufficient body of information and short duration of tests it is not possible to make certain kind of statistic processing. Results of the strain-gauging of the forepeak plating are presented in Table 2.4.

Table 2.4

Stresses in the forepeak plating, MPa

Speed, kn	Ice thickness, cm	Number of sensor			
		2	4	5	6
Independent movement					
13	100 ÷ 120	16	17	-	-
		23	11.5	-	-
		-	-	-	69
		-	-	43.5	27
10	100 ÷ 120	16	51	-	-
		19.5	26	-	-
		29	-	25.5	-
14	120 ÷ 150	-	-	74	48
		-	26	27.5	21
13	80 ÷ 100	-	-	46	21
		-	29	15.5	-
13	80 ÷ 100	21	40	12.5	12
10	80 ÷ 100	13	-	27.5	15
10	90 ÷ 100	42	31.5	25.5	-
10	90 ÷ 100	-	-	43.5	21
13	90 ÷ 100	-	17	27.5	-
Movement in the channel following the icebreaker					
7	200	13	37.5	-	-
5.5	200	-	-	27.5	-
7	200	-	-	33.5	15

On the basis of the results of hull strain-gauging of m/s *Igarka* the following conclusions may be drawn:

1. Despite the movement at a high speed (up to 14 knots) through ice of considerable thickness (1.2 - 1.5 m) the level of measured stresses is rather low. Among the reasons of this discrepancy one may mention a combination of ice loads, random in character both by value and location of their application, and also a very limited number of measurements (sizes of the hull area investigated are small, just as small is the number of sensors, duration of measurements is short etc.) as well as movement through the summer decayed ice.
2. The arrangement of sensors was such that it did not permit gathering possibly largest body of information on loads in plane of the waterline (ice field). It would be more profitable to arrange sensors in line in plane of the action of ice loads (somewhat below the waterline plane) at intervals of 2 - 3 spacings.
3. Sizes of the zone of the hull/ice contact at impacts with moderate speeds of 3 - 4 m/s are small. Height of the zone is close to the calculated values determined by the Rules of the Marine Register of Shipping (MRS) [6].

2.2.2. Results of the trials of m/s *Igarka* and m/s *Kapitan Danilkin* by means of the automatic system of measurements

The experience of short-term trials, in particular of those of m/s *Igarka,* has shown that the restriction in time for which a ship is put out of action, as a rule, does not permit to carry out trials in full and this factor substantially reduces the authenticity of the results obtained.

Therefore in the process of the warranty repair in Finland an automatic system of measurement of the stressed state of structures was installed aboard m/s *Igarka* permitting to collect and statistically process the information supplied from sensors in the automatic mode during commercial voyages without putting the ship out of operation.

Repeated trials of m/s *Igarka* after the reequipment of the measuring unit with an automated system and partial rebuilding of disabled sensors were also carried out during the summer navigation (July) 1984 near the Franz Josef Land under the ice conditions close to those of trials of 1983 (in the first-year ice at a state of decay[1] 1 - 2 with a thickness from 0.6 - 0.7 m to 1.4 - 1.6 m with the inclusions of old ice 1.2 - 2.2 m thick at the stage of melting). Near the area of trials the compression strength of ice about 1.5 m thick was approximately 1.5 - 1.8 MPa. Average level of the measured stresses, just as during the first trials in 1983, turned out to be not high, maximum values in shell plates reaching 237 MPa, in the framing – 264 MPa.

The trials proved the reliability of work of the automated system and in the process of these trials the major part of the program was fulfilled corresponding ice conditions being observed. The installed equipment enabled constructing bar charts not only of stress levels in strength members, but also of efficient zones of the hull/ice contact for ice loads exceeding 1 MPa.

On the basis of the experience of measurements and the analysis of the stressed state of hull of m/s *Igarka* a new program of ice strength trials of the last ship of the second (partly improved) series of these ships (*SA-15 Super*) – *Kapitan Danilkin* – was prepared. On ships of this series, according to the recommendations of CNIIMF, side plating and bilge strake thickness was increased and also framing over the flat bottom section in forebody and forepeak additionally strengthened. Besides, certain changes were introduced into the pattern of the location of sensors.

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[1] In accordance with the 10-point scale

So, considerable number of sensors was concentrated in the bilge area to record stress and ice pressure on the plating in this hull section being a zone of mass ice damages of ships of this type (Fig.2.3). Ice pressure sensors were introduced into the measuring system.

During the trials, a set of the recording equipment was used permitting to take down the results on tapes and diskettes, to observe oscillograms on the displays getting necessary prints at any arbitrary moment. Installation of sensors and laying out of cables was carried out directly in the course of the construction of ship at the shipyard. Side by side with the construction shipyard the Ship's Laboratory of the Technical Research Centre of Finland (*VTT*) also participated in investigations having produced an automated complex of the recording equipment including a special ice pressure transducer.

While developing the programme of trials of the ice impact hull strength the method of the comprehensive investigation of hull/ice interaction was used as a basis, this method including the following:

- determination of the stressed state of the hull area to be investigated by the strain-gauging of plating and framing;
- determination of the total ice force affecting the hull area in question by the measurement of tangential stresses in webs of the framing holding this area near support sections;
- measurements, along with the strain-gauging, of maximum local ice loads (pressures) on the plating of the area in question at typical points by means of the ice pressure sensors specially developed by Finnish experts of the *VTT*;
- calculated determination of actual ice loads by the method of finite elements on the basis of the results of strain-gauging.

The first stage of full-scale trials of the ice impact strength of m/s *Kapitan Danilkin* (including "ramming" upon an ice floe 4 - 5 m thick) was performed jointly by CNIIMF and *Wärtsilä* at the end of November 1987 to the north-west of the Spitsbergen Archipelago. During the trials the automated system installed aboard was switched over for the work in the mode of short-term trials.

General characteristic of meteorologic and ice conditions in the tested area:

- meteorological conditions
  - air temperature – 24 ... – 30°C,
  - water temperature – 1.1 ... – 1.6°C,
  - wind speed 8 ... 16 m/s,
  - polar night, snow-storm, visibility extremely restricted;
- ice conditions
  - drifting ice with a concentration of 9/10 ÷ 10/10,
  - residual second-year ice with a concentration of 5/10 ÷ 6/10, 1.5 - 2.5 m deep with separate inclusions of multi-year ice 2.5 - 5 m deep; small floes and ice cake, hummocking of 1/5 - 2/5, snow cover depth over level sections – 30 - 40 cm,
  - grey ice of a concentration of 3/10 - 4/10, grey-white ice, floes, loose ice, snow coverage – up to 10 cm.

Speeds of movement and ramming varied within 2.0 - 7.5 knots. At speeds up to 6 knots the stress in plating did not exceed 30 % of the yield strength of steel. During the completing stage of trials at speeds of about 9 knots the yield limit of the forebody (forepeak) plating was identified being specified by the shipping company as a criterion for the completion of this stage of trials.

During the subsequent period of the operation of ship in the Arctic, measurements were made in the automatic mode. Some results of trials are presented in Figs.2.7, 2.8 and 2.9. As one can see from figures, the hull/ice contact zone area is of primary influence upon the intensity of ice loads. Slight effect of the speed on the contact zone sizes attests that the predominant role in the formation of this zone belongs to the structure and strength of the ice cover.

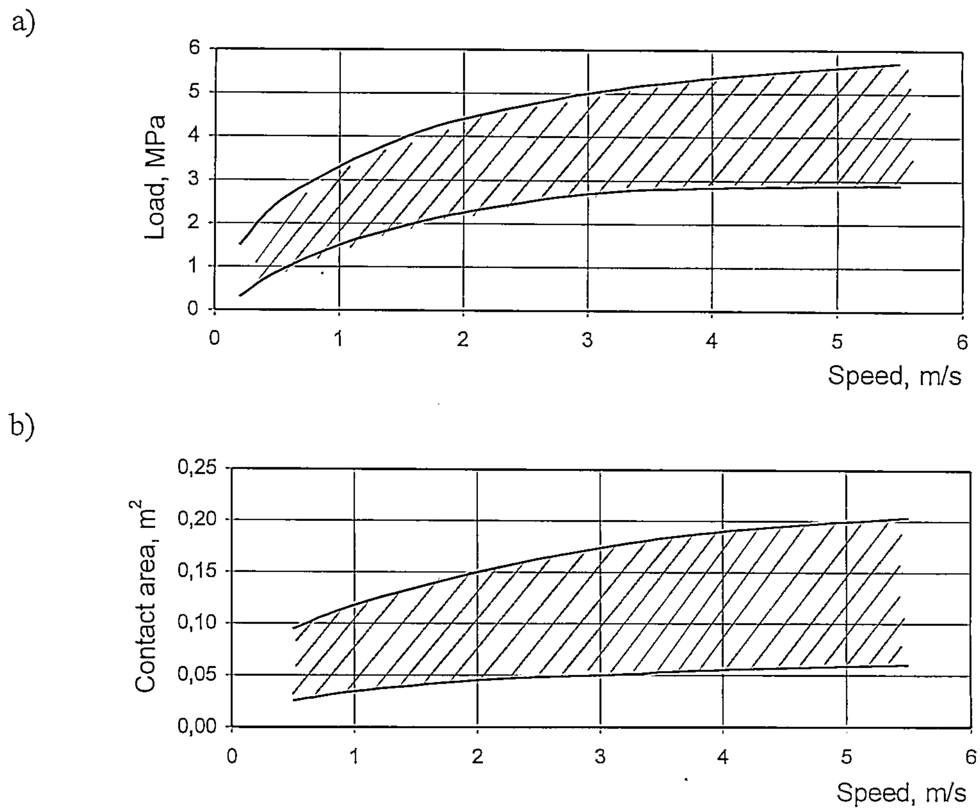


Fig.2.7. Influence of the ship's speed upon the intensity of ice loads (a) and sizes of the hull/ice contact zone (b)

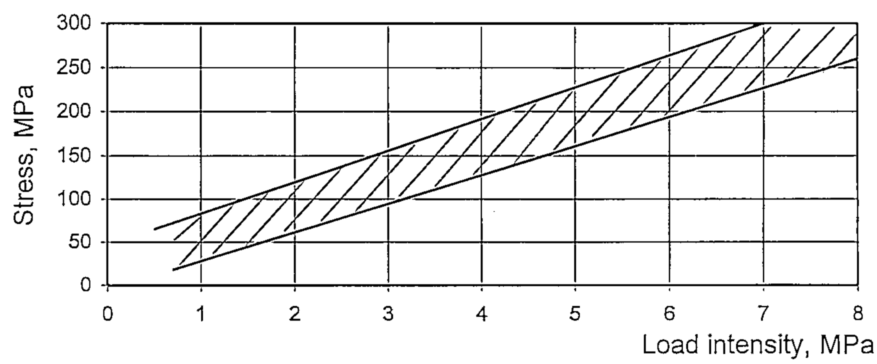


Fig.2.8. Relationship between the stressed state of the shell plating and the intensity of ice loads

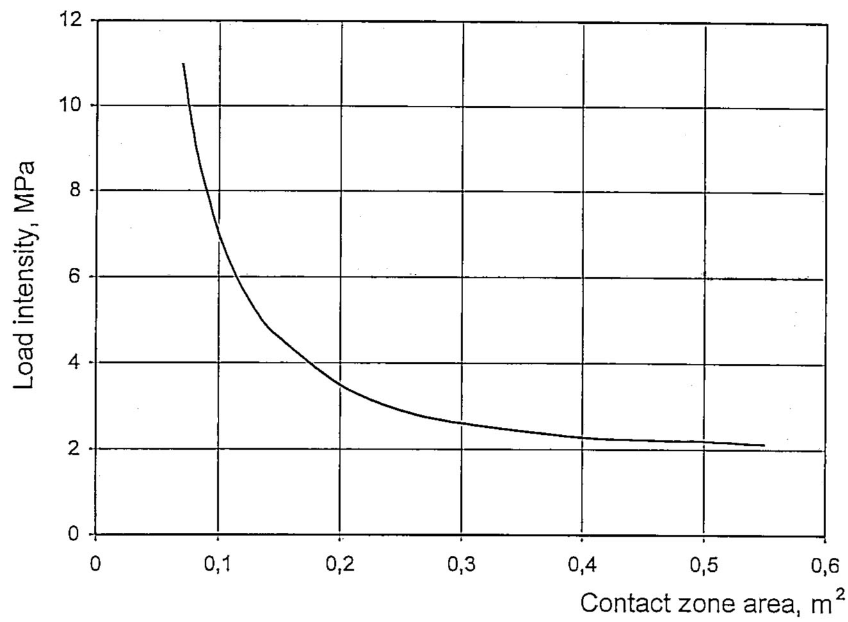


Fig.2.9. Relationship between the intensity of ice loads and the hull/ice contact zone sizes at a speed of 3 - 4 m/s

In the course of trials of m/s *Kapitan Danilkin* quite a number of conclusions was drawn, important from the viewpoint of the hull design and operational practice, and namely:

1. Design ice loads upon the boot topping in the fore and aft determined according to the MRS Rules satisfactorily comply with the level of actual loads characteristic of the western area of the Arctic.
2. Actual ice loads within the bilge strake are close to those upon the boot topping; especially it is true for ship's ends where such loads reach not less than 100 % of loads upon the ice strake, corresponding values in the middle part of the bilge strake being 50 - 60 %.
3. Real range of the variation of heights of the hull/ice contact zones was determined: when ice is from 0.7 - 1 m to 2 - 3 m thick the contact zone height varies within 0.2 - 0.6 m. These values though being smaller than those determined according to the MRS Rules, are still in the satisfactory compliance with calculated figures. The trials have proved the validity of the form of the variation in time of the contact zone ice pressure specified in the Rules.

4. Levels of the maximum values of local short-duration ice pressures (peaks of pressures) over restricted hull areas expected on the NSR have been determined: during the ice trials of m/s *Kapitan Danilkin* in the Arctic, pressures of 9 - 11 MPa were observed; if these ships operated in the heavy ice by ramming, some individual peaks of forebody ice pressures may reach 25 - 30 MPa.
5. Experimental dependencies of the intensity of ice loads at the impact against the thick ice on the contact zone area and ship's speed were obtained as well as the relation between the intensity of ice loads and the stress level in the forebody plating established.
6. Structure and strength of ice floes are of the decisive effect upon sizes of the ice/hull contact zone.

Results of the full-scale trials were used to improve hull structures of ships of the *SA-15 Super* type, work out joint recommendations on the assignment of admissible ice loads for the underwater hull areas below the ice strake as well as to develop requirements for the ice strength of arctic ships to be constructed and to introduce corrections into the chapter "Hull ice strengthening" of the MRS Rules.

3. ANALYSIS OF ICE DAMAGES OF SHIPS OF THE *SA-15* TYPE

3.1. Ice damages of hull structures

Hull ice damages of ships of this type were detected already in 1982 and 1983, i.e. during the first years of their operation in the Arctic (Fig.3.1).

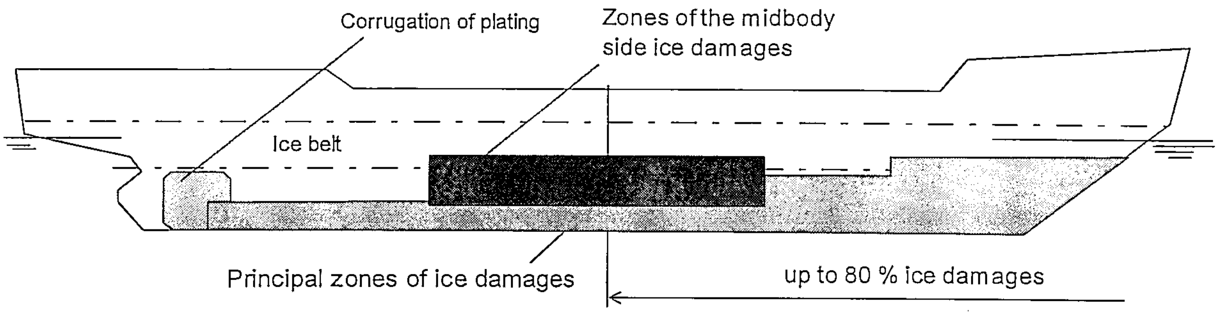


Fig.3.1. Distribution of permanent ice deflections over the underwater hull of ships of the *SA-15* type

Of 5 ships of the *SA-15* type operating during this navigation period in the Eastern Arctic, 4 ships – m/ss *Arkhangelsk*, *Monchegorsk*, *Nizhneyansk* and *Igarka* – suffered considerable ice damages.

One of the first ships of this type which suffered ice damages was m/s *Arkhangelsk* when it was operating in September 1983 under heavy ice conditions of the Eastern Arctic, supposedly as a result of the "throw-off" from hummock onto the grounded ice. The damaged area was located within the ice belt (Fr.195 - 199) immediately abutting upon the stem. As a result of the impact a dent was formed extended along the stem this dent having a size of 4500 × 2000 mm with a maximum deflection of 200 mm (Fig.3.2). Along the stem, in the zone of the weld, there was a crack approximately 1500 mm long with the edge shift extending onto the stem. In the area of the dent the loss of stability of the platform plating and frame webs was detected. Until the elimination of the damage the ice category of this ship was lowered and the cement box installed.

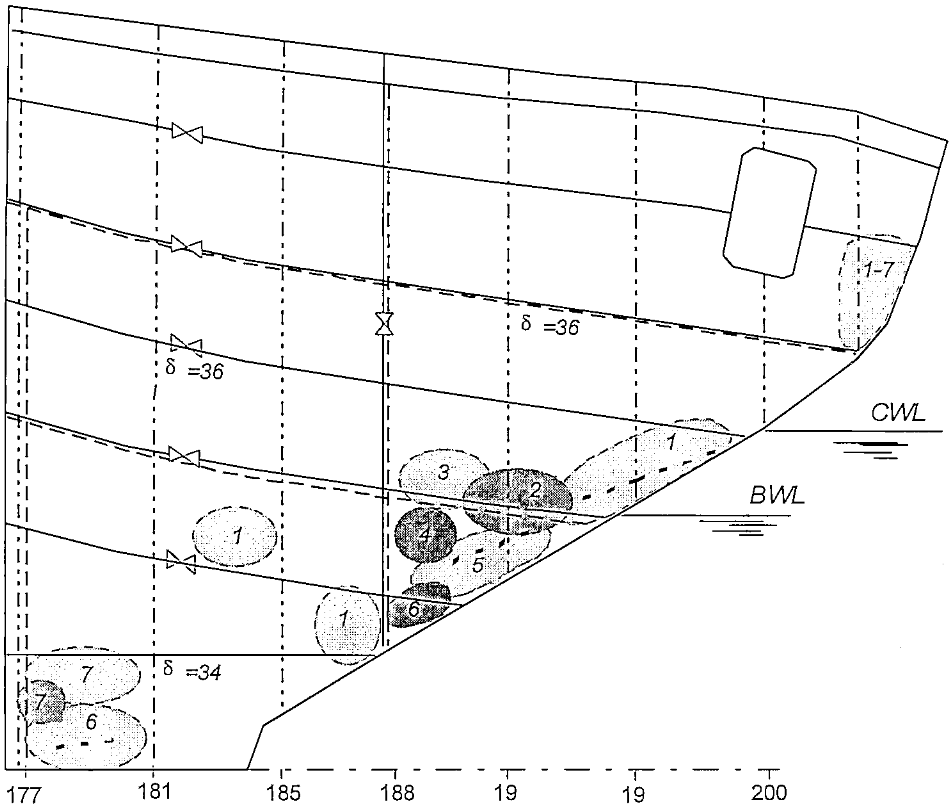


Fig.3.2. Ice damages (dents and cracks) in the forepeak plating of ships: 1 – m/s *Arkhangelsk*, 2 – m/s *Monchegorsk*, 3 – m/s *Anatoly Kolesnichenko*, 4 – m/s *Igarka*, 5 – m/s *Bratsk*, 6 – m/s *Anadyr*, 7 – m/s *Nikel*

Extensive hull ice damages notwithstanding the short period of operation (1.5 years) were caused to m/s *Monchegorsk* during its work in ice of the Eastern Region. As a result of the dock inspection during the period of the guaranteed repair in Finland the damages revealed turned out to be so serious that the replacement of shell plates with framing in several places of hull (underwater portion) was required. Worst damages were recorded at the bottom in the forebody, along the bilge belt and below the ice belt in the after end.

While inspecting the underwater hull portion of m/s *Monchegorsk* in dock (in Turku) the following damages were detected:

1. There were separate bulges and dents in the forebody below the ice belt. Most deformed surface in the zone of the fore part of the bilge (fr.155 - 168) had to be cut off together with framing for replacement. Separate bulges were also revealed within the ice belt at the waterline.

2. Bilgeways within the air-bubbling manifold were bent inside the air-bubbling tube (where there is no framing) approximately from the midship to the after end (Figs.3.1 and 3.3).
3. In the aft underwater hull portion below the ice belt there is the extensive crimping and there are bulges 12 ÷ 14 mm thick of the shell plating. Practically all the plating near the propeller shaft stern bossing from fr. 50 towords the afterbody is corrugated (Fig.3.1). Deep bulges and dents can be observed. Maximum dent $\mathbf{f_{max}}$ deflection in the area of fr. 30 – 34 is 113 mm.
4. In the area of dents the plating frame webs have permanent bulges.

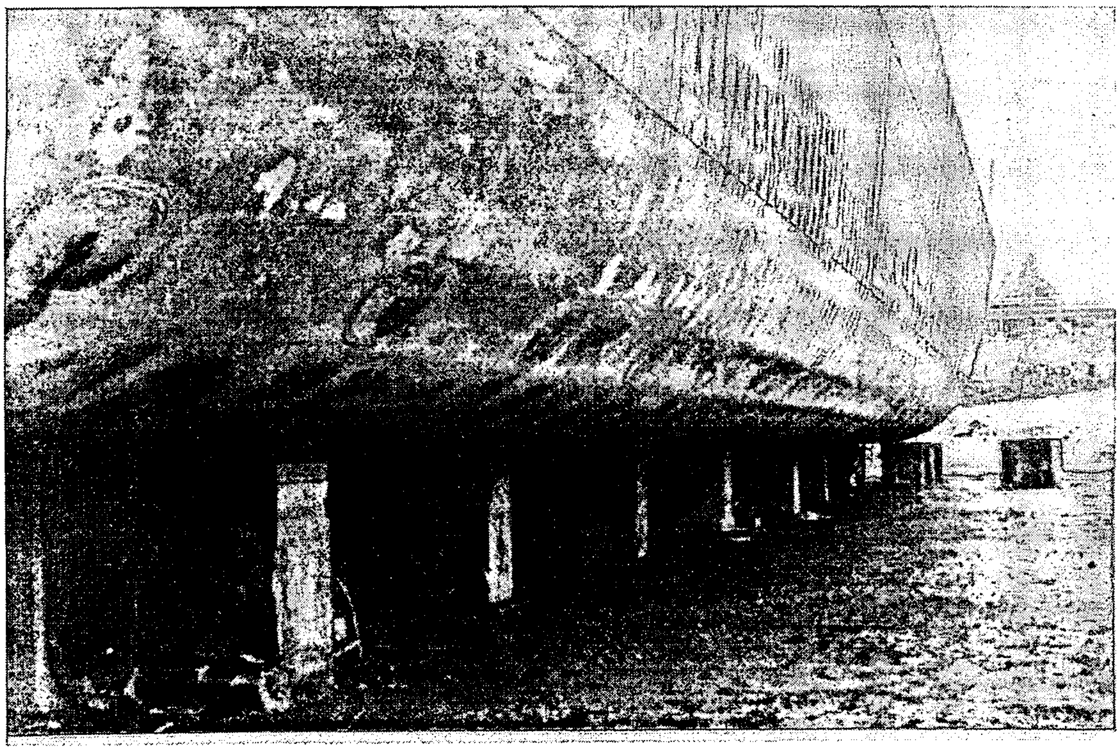


Fig.3.3. Ice damages of the midbody

On the whole, similar damages were found during the dock inspection of m/s *Nizhneyansk*. Especially damaged is the plating below the ice belt in the aft near the stern bossing and bilge portions - air-bubbling manifold and adjacent plates. At the beginning of October 1983 in the Chuckchee Sea m/s *Nizhneyansk* while getting foul of the leading icebreaker suffered following damages: a hole measuring 300 × 500 mm under the upper deck in the area of fr. 186 - 191, and a dent 2000 mm long with a deflection of 100 - 150 mm in the upper part of the deep-tank No.1.

Shell plating of the forecastle (with a thickness of 11 mm) in the area adjacent to the hole, fr. 188 - 173, has crimping. Plate crimping in this area is observed on all ships of the series. In the area of fr. 150 - 165 shell plates 18 mm thick (above the ice belt) strengthened by the longitudinal framing have individual bulges found in this area also on m/s *Norilsk*.

Most detailed information is available on the dock inspection of m/s *Igarka* which also worked in the Eastern Region during the 1983 navigation. A deep dent in the ice belt of m/s *Igarka* appeared at the ballast waterline level (at the stem) in the area of fr. 190 - 193 that is approximately in the same area as on m/s *Arkhangelsk*. While operating in heavy ice under pressure a stern "ice knife" was crushed.

Shell plating damages above the ice belt are mainly concentrated in the area situated astern from the collision bulkhead between fr. 160 and fr. 190. Damages are bulges and crimping under the forecastle deck (fr. 175 - 185) and also under the main deck.

Below the ice belt, crimping and bulges cover large areas of the bilge strake (in the area of the air-bubbling manifold and below), bottom strakes in the area of fr.151 - 175 as well as those situated astern from fr. 123 including the area of the stern bossing and bottom plating from fr. 19 to fr. 40. These damages are of a multiple character and of considerable extent. During the dock inspection of m/s *Igarka* in May 1984 (Turku) more than 60 bulges and dents 20 - 70 mm deep and measuring 600 × 800 - 1000 mm were detected. The largest number of shell damages (70 %) fall on the bilge strake from fr. 39 to fr. 120 (Fig.3.4).

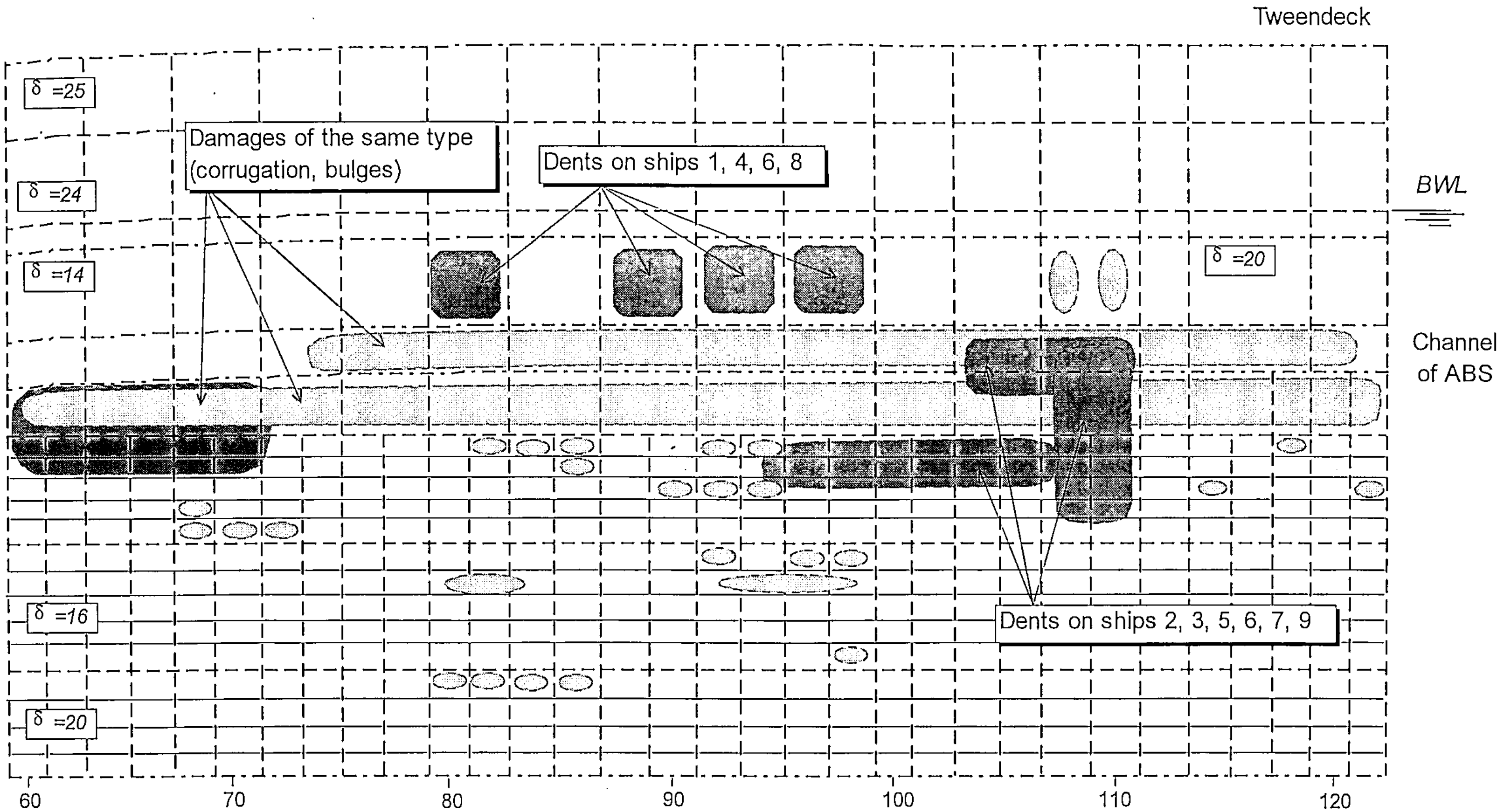


Fig.3.4. Ice damages in the midbody:

1 – m/s *Arkhangelsk*, 2 – m/s *Bratsk*, 3 – m/s *Kandalaksha*, 4 – m/s *Kola*, 5 – m/s *Kemerovo*, 6 – m/s *Monchegorsk*, 7 – m/s *Nizhneyansk*, 8 – m/s *Nikel*, 9 – m/s *Tiksi*

Bulges near the passage along the bilge of the air-bubbling manifold are 20 - 50 mm deep and their sizes are within 550 × 410 mm. Approximately 30 % of damages fall on bottom regions of the shell plating in ends.

On all ships of the *Norilsk* type in the area of dents there is a local loss of stability (bulges) of bulkhead plates, platforms and frame webs abutting on the shell plating.

If we compare the area of the extent of ice damages with the distribution of shell plating thicknesses one can find out that major damages are observed in the middle and after parts of the ship at places where the shell plating thickness is only 13 - 14 mm the frame spacing along the bottom and the bilge below the ice belt (in particular, near the stern bossing) being equal to 800 mm.

In the course of the operation of the ships of this type in the Arctic during subsequent years there were no noticeable changes in the general pattern of hull ice damages. For this period the drawbacks of standards (MRS Rules) turned out to be even more pronounced as far as midship ice loadings are concerned, in particular for the bottom. Considerable amount of damages in this area was inevitably recorded after voyages during the early period of navigation in seas of the eastern region of the NSR in 1986 - 1988.

During the navigation season of 1986 in the East Siberian Sea, heavy ice damages were caused to the hull of m/s *Monchegorsk* engaged since 1985 on voyages from the West to Pevek in the early period of spring and summer navigation (May, June). During the hull dock inspection at the Murmansk Ship Repair Yard in August 1986 the following damages were detected:

1. Dents within the ice belt at the construction waterline level in the area of:
    - fr. 169 - 175, $\mathbf{f} = 40$ mm,
    - fr. 100 - 106, $\mathbf{f} = 100$ mm (with frame webs being broken off the shell plating with a thickness of $\delta = 14$ mm and cracks developed along the welds).
2. Dents below the ice belt , between the lower edge thereof and double bottom, in the area of:
    - fr. 67 - 100, chain of dents, $\mathbf{f} = 20 - 35$ mm, $\delta = 14$ mm,
    - fr. 105 - 114, chain of dents, $\mathbf{f} = 40$ mm, $\delta = 14$ mm,
    - fr. 117 - 131, chain of dents, $\mathbf{f} = 30 - 50$ mm, $\delta = 20$ mm.

3. Extensive crimping of a shell plate portion below the ice belt in the area of fr. 17 - 57, **f** = 20 - 25 mm (δ = 13 mm), some bulges up to 50 mm.
4. Multiple bulges within bilge belt, in the area of the afterbody air-bubbling manifold, from fr. 110 sternwards, **f** = 30 - 40 mm (δ = 14 mm), cracks between air nozzle hatches.
5. Bulges of the bottom plates (up to 50 % of the bottom surface), from fr. 110 sternwards, **f** = 20 - 40 mm (δ = 16 mm).
6. Above the ice belt:
   - damages to the shell plate in the area of fr. 191 ÷ 193 (δ = 18 mm) and stem ("soft" bow, δ = 24 mm),
   - chain of longitudinal bulges along the ice belt edge, in the area of fr. 60 - 93, **f** = 20 - 30 mm (δ = 13 mm),
   - dent in the area of fr. 97 - 100, **f** = 80 mm.

During the navigation season of 1987, also under heavy ice conditions in the East Siberian Sea (with a great mass of multi-year and hummocked ice), extensive ice damages were caused to m/s *Kola*. As a result of the dock inspection in February 1988 the following hull ice damages were detected:

1. Within the ice belt in the fore part of the forepeak and within the bottom strakes in the area of the bilge (fr. 165 -173), a chain of dents from 1 to 12 m^2, **f** = 150 mm.
2. Dents below the ice belt, amidships, between the side and bilge, in the area of fr. 65 - 110, a chain of dents, **f** = 70 - 100 mm, in the neighbourhood of which partial buckling of frame webs was recorded (buckling of web portions abutting on the shell plate). The largest dents were found in the area of fr. 99 - 105 and 58 -73.
3. Multiple bulges and crimpings of the shell plating amidships and in the aft between the ice belt and double bottom:
   - from fr. 110 to the afterpeak over the strakes with δ = 13 - 16 mm, **f** = 10 - 60 mm,
   - over the air bubbling channel, in the area of fr. 68 - 101, **f** = 30 - 60 mm.
4. The aft shell plating below the ice belt had extensive crimping in the area of fr. 17 - 53, **f** = 30 mm.
5. Bottom plates (δ = 16 mm) and bilge plates in the area of the air bubbling channel (δ = 14 mm) had multiple bulges up to 40 mm across the bottom and up to 60 ÷ 70 mm across the air bubbling channel.

Attention is attracted to the similarity in nature of the structural deformations and distribution of ice damages over the hull surfaces of m/ss *Kola* and *Monchegorsk*. It should be also noted that damages of the same hull portions were recorded upon operation of these ships on the Eastern Arctic Routes as for back as 1983 - 1985 and were similar to damages of the *SA-15* type ships which were operating lately in the Eastern Arctic (m/ss *Arkhangelsk, Tiksi, Nikel, Kandalaksha, Bratsk, Igarka*). Figs.3.5 and 3.6 illustrate the typical extent of ice damages of the structures of m/s *Bratsk* which required full replacement in repairing.

The motorship suffered heavy damages during the navigation through the open floating old ice of the Eastern Arctic at an average speed of 10 - 12 knots in autumn 1984. Depth of dents in the forepeak reached 145 mm, in the bilge amidsips – 210 mm. These damages were accompanied by cracks and the water leakage.

At the same time m/ss *Tiksi, Nikel, Kola, Kandalaksha, Norilsk* having operated in 1983 - 1984 on the western lines (including those to Dudinka) suffered only moderate damages to the shell plating in the afterbody ($\mathbf{f} = 15 \div 20$ mm) and single bulges in bilges and bottom strakes, amidships ($\mathbf{f}_{max}$ up to 25 mm). These vessels being transferred to voyages in the eastern region of the NSR suffered during arctic navigations the above stated extensive ice damages of hull comparable with those caused to ships during the extreme heavy navigation of 1983 (m/ss *Arkhangelsk, Igarka, Monchegorsk, Okha* and *Nizhneyansk*).

Heavy ice damages in the form of extensive dents and multiple bulges (m/ss *Kola* and *Monchegorsk*) in the side and bottom divisions concentrate predominantly amidships and in the forepeak, covering a region from the bilge to the lower edge of the ice belt (including the lower part thereof). Similar damages are regularly recorded after navigation season in the eastern area of the NSR since 1984. Probability functions of the permanent deflections are shown in Figs.3.7, 3.8 and 3.9.

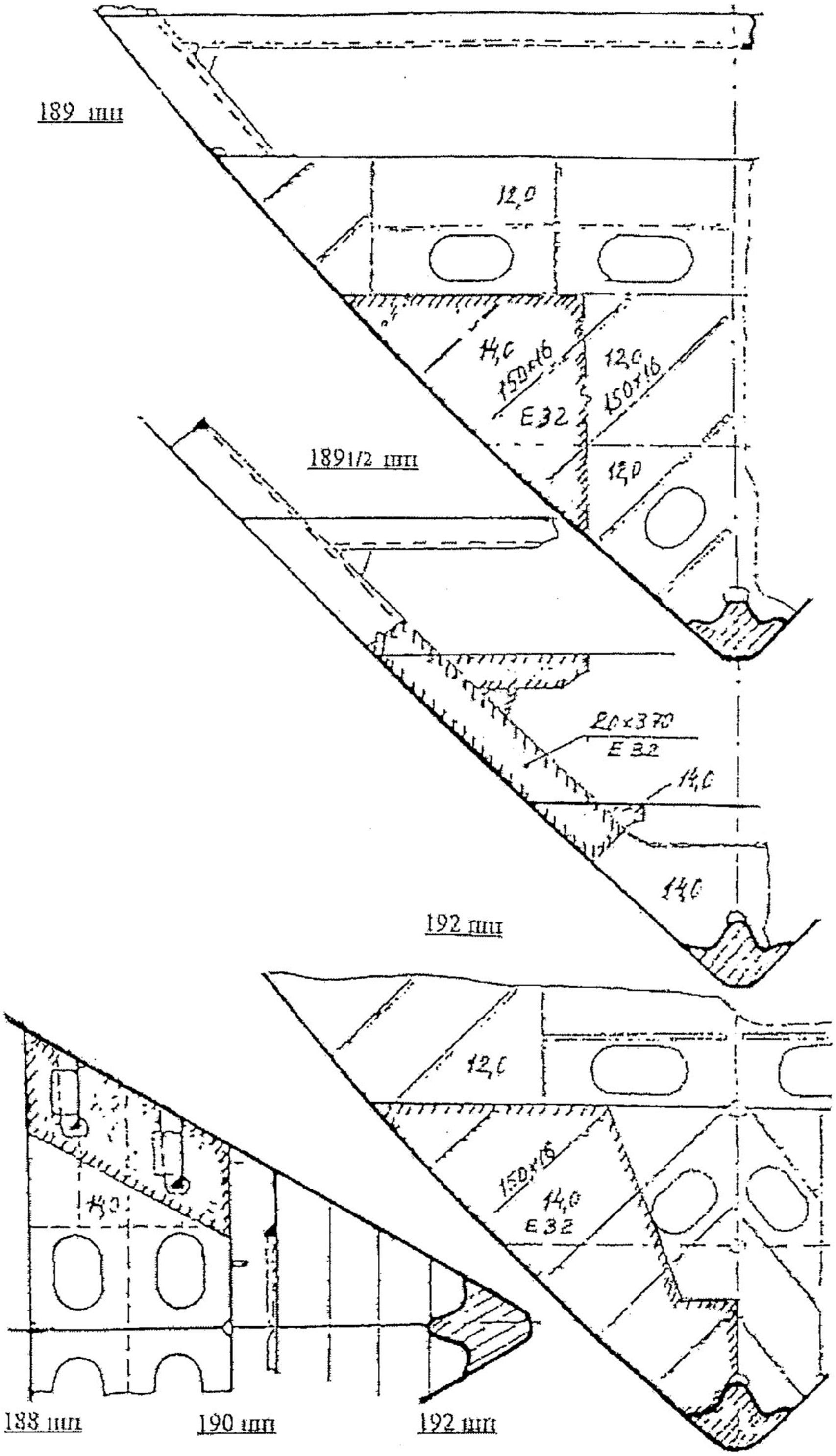


Fig. 3.5. Scheme of replacement of the damaged forepeak framing on m/s *Bratsk* in the area of fr. 187-192

Fr. 91 1/2, 92 1/2, 94 1/2, 95, 95 1/2 Fr. 93, 95 Fr. 93

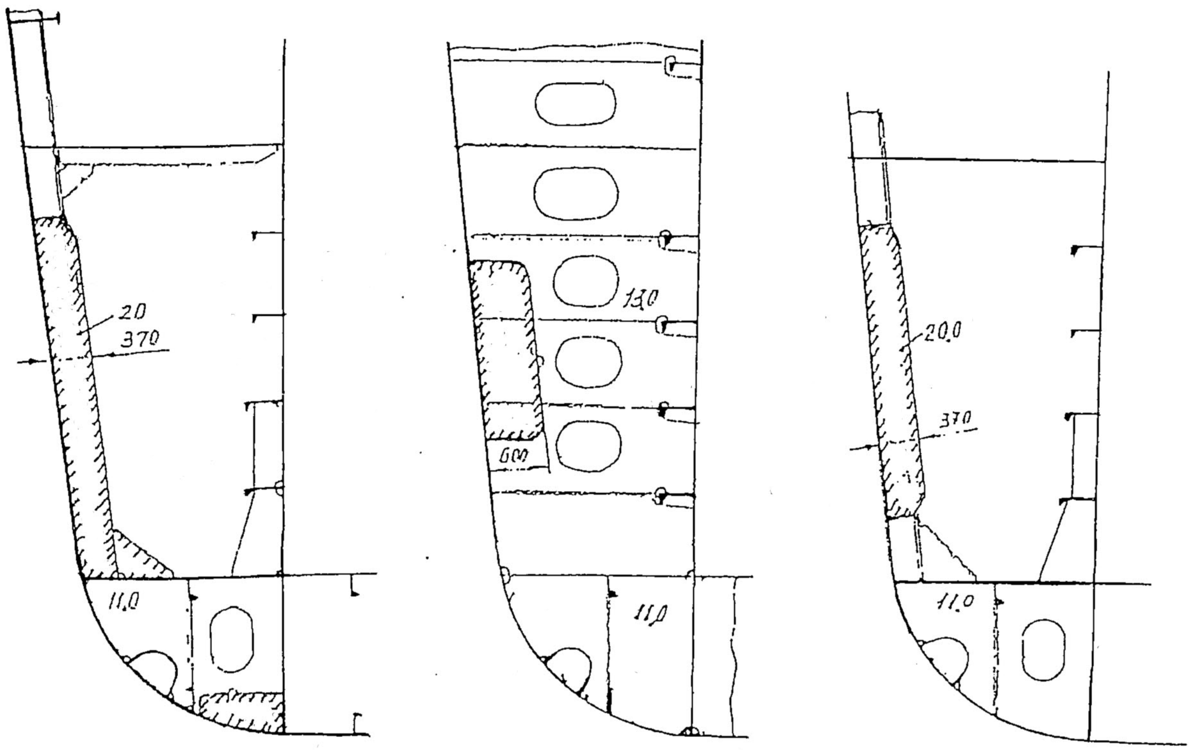


Fig.3.6. Scheme of replacement of the damaged framing in the midbody of m/s *Bratsk*

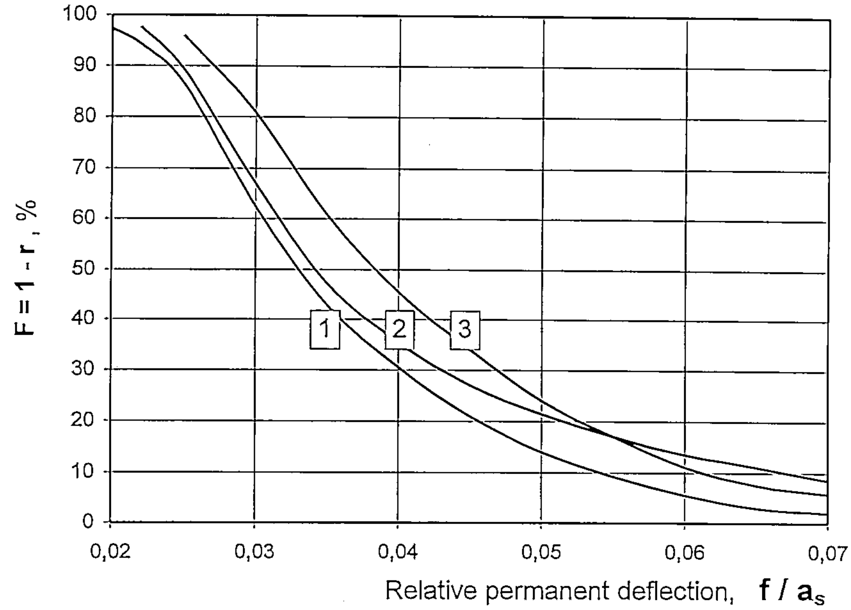


Fig. 3.7. Plot of the **F = 1 - r** function, where **r** – probability of the occurrence of a given relative permanent deflection value of bilge bottom plating areas in the bow (1) and in the stern (2) as well as of bilge (3) in the midbody of ships of the *SA-15* type (a_s – practical spacing)

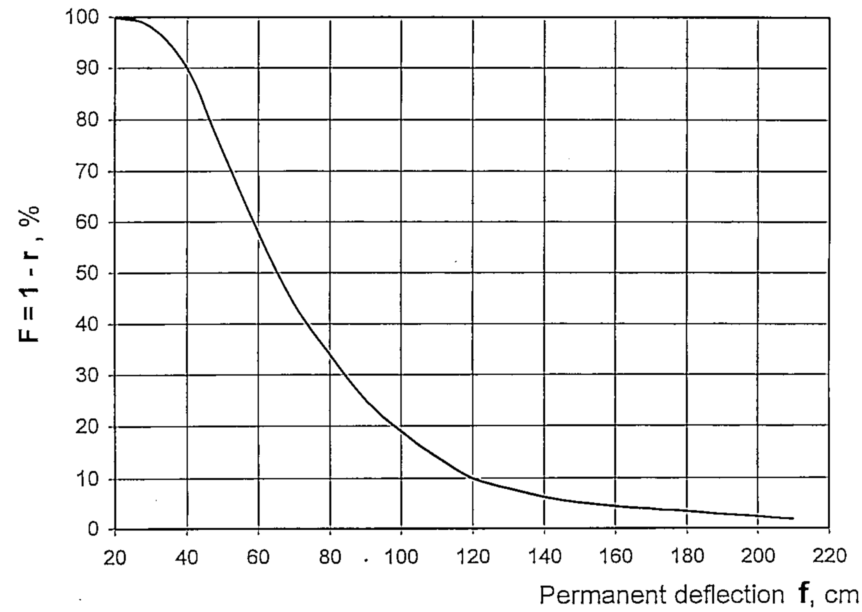


Fig.3.8. Plot of the **F = 1 - r** function, where **r** – probability of the occurrence of a given framing deflection value in the forebody

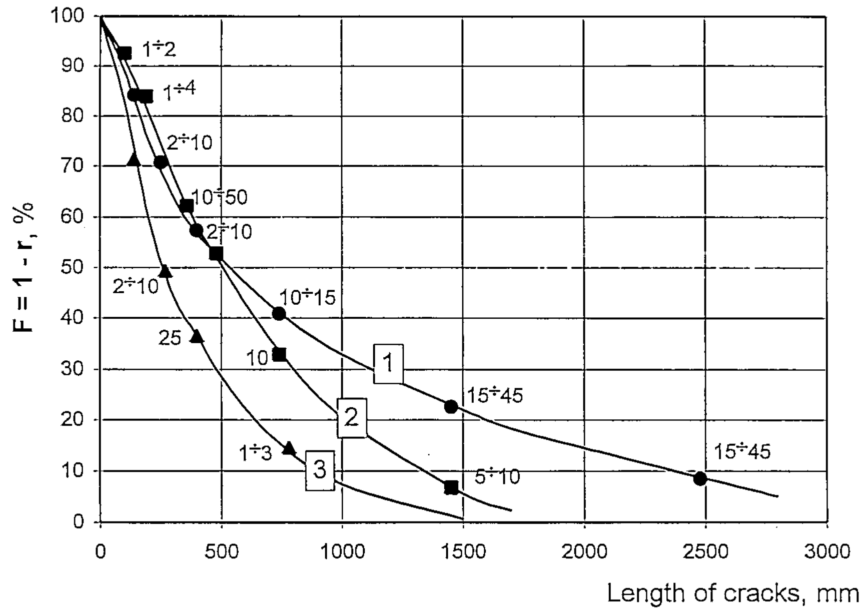


Fig.3.9. Plot of the **F** = **1** - **r** function, where **r** – probability of the occurrence of given lengths of ice holes (with the indication of width in mm) in the fore- (1), mid- (2) and afterbody (3) of ships of the *SA-15* type

3.2. Analysis of the reasons of ship ice damages in the Arctic

Ice impact strength investigations of ship hulls of the *SA-15* type conducted by CNIIMF in the process of their construction and during the first years of service showed that the similarity of the ice damage distribution over the hull areas was associated with structural defects peculiar to them and caused by both the unjustified deviation from the requirements specified by the MRS Rules for vessels of the ULA ice category and by the drawbacks of the Rules themselves which did not specify up to 1990 ice loads on the underwater hull of arctic ships, below the ice belt.

Mainly the same hull areas having substantial structural defects are subject to damages and these areas are as follows:

- bilge strakes in the area of the air bubbling channel and below with δ = 14 mm (yield point – 2400 kg/cm^2, spacing – 800 mm),
- side plating portion from the midsection sternwards, with δ = 13 and 14 mm (yield point – 2400 kg/cm^2, spacing – 400 and 800 mm),
- forepeak structures in the area abutting on the stem (damages are caused due to the insufficient steadiness of the forepeak diaphragm supporting the plating),
- bottom plating, especially at the bilge (δ = 14 and 16 mm, spacing – 800 and 620 mm) including the fore. area, where in spite of the Rule requirements the intermediate transverse framing was not fitted,
- side divisions amidships below the ice belt,
- side plating portions above the ice strake amidships and in the forebody (δ = 13 mm, spacing – 800 mm),
- plate members of the "soft" bow.

The analysis of hull damages has shown that principal reasons of the ice damageability of this type of ships in the Arctic are as follows:

1. Lack of the compliance between the ice category (ULA) and conditions of the operation of ship in the eastern area of the Arctic. Ships *Kola*, *Monchegorsk* and others were used during the too early periods of the opening of navigation in the eastern part of the NSR characterized by the most severe ice conditions.
2. Errors of navigators (in particular, in the form of the excess of safe speeds of movement through ice of a great thickness). Movement of the motorship *Bratsk* in the open floating old ice of the East Siberian Sea at average speeds of 10 ÷ 12 knots is an example of such errors.
3. Structural drawbacks of the ship and the imperfection of the MRS Rules.

3.3. Assessment of safe speeds of the movement of ships through ice

As the experience of the operation of ships in the Arctic has shown, during the movement in the open floating ice with a concentration of less than 4/10, under conditions of good visibility and reliable operation of radars, ship's operators fairly successfully avoid collision of hull with large or medium floes.

However, from the point of view of the selection of the safe level of speed of an ice ship the scenario of movement through open floating broken ice is a decisive factor when ship can develop a speed hazardous for the collision with ice.

In accordance with this scenario of the navigation of ship in ice, CNIIMF has developed methodology of the assessment of parameters of the safe movement (speeds) at which ice loads on the ship's hull **p** do not exceed those regulated by the MRS Rules.

Specification of the design ice loads as required by the Rules of the Russian Marine Register of Shipping is based on the solution of the hydrodynamic problem of the ship's hull / ice floe collisions obtained in AARI by Yu.Popov, D.Kheisin, V.Kurdyumov [7, 8]. As a result, the authors have derived a general formula for the intensity of ice loads:

$$p = 0.61\ V^{13/24}\ M^{1/6}\ (2R)^{-1/12}\ a_{ð}\ F_{ð}\ ,$$

where

V	- ship's speed,
M	- mass reduced to the point of collision,
R	- design radius of the floe (25 m),
$a_{ð}$	- ice crushing strength factor,
$F_{ð}$	- hull form influence coefficient.

This relation has been subsequently used as the basis for the ice load calculation in the MRS Rules for ships of all ice classes, where it is presented in a simplified form:

$$p = 10\ a_1\ f(D)\ f(\alpha, \beta)\ ,$$

$$f(\alpha, \beta) = f(\alpha^2 / \beta)^{1/4}\ ,$$

where

D	- displacement,
α, β	- angles of the slope of tangents to the waterline and frame at the point of collision.

The aggravation of the design ice conditions in the transfer from one class to another was defined by the time history of coefficient $\grave{a}_1$ in the following manner:

- ship of L1 category - 0.38
- ship of UL category - 0.54
- ship of ULA category - 1.00.

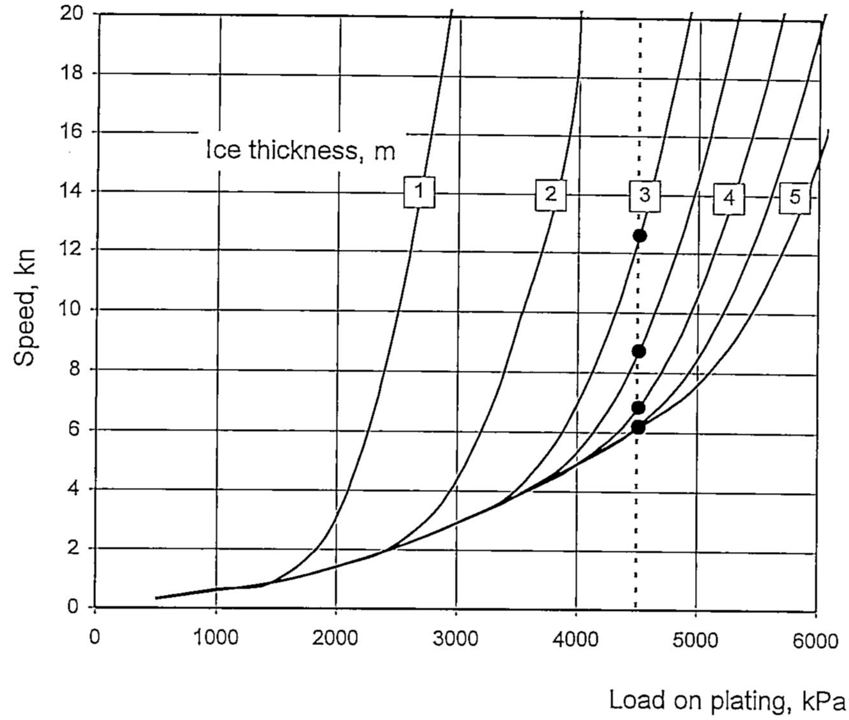
Methodology put forward by CNIIMF makes provision for the following sequence of calculation of parameters for the safe sailing under given conditions:

1. While using the method of the calculation of ice loads [8] securely proved in the domestic practice, dependences are constructed of the intensity of ice loads – **p** on the ship's speed – **V** at the collision with ice debris of different sizes (thicknesses, masses) taking into account the characteristics of ship (mass – **M**, hull shape – α, β) and ice strength parameters (σ, $\mathbf{a}_{\eth}$) – **ð** = f (**V**, **M**, σ, $\mathbf{a}_{\eth}$).

   Ice strength characteristics (σ, $\mathbf{a}_{\eth}$) as well as the design thickness of ice are related to the area, season of operation and the ice category of ship which are supposed to be used in a given region of the Arctic.
2. Designed values of ice loadings for each ice category of ship regulated by the Russian MRS are determined by formulas of appropriate sections of the Rules. After that, safe speeds of the movement of ships under set ice conditions are established as ordinates of the points of intersection of vertical lines graphically characterizing the Rules requirements to the ice loads for each class with the curves of relationships **ð** = f (**V**, **M**, σ, $\mathbf{a}_{\eth}$) mentioned above.
3. On the basis of the analysis of full-scale tests and theoretical computations a family of curves is constructed which defines a relationship between the achievable speed and shaft power – **V** = f ($\mathbf{N}_p$), ships moving through broken ice of different thicknesses **h** and concentration **S** , with due account of the ice impact strength corresponding to a given navigational season.

Transferring the obtained values of the safe speed onto graphs **V** = f ($\mathbf{N}_p$, **h**, **S**) a zone of safe (as to a value of developed power) modes of the movement of ship in ice of different thickness and concentration can be obtained.

Figure 3.10 represents the results of calculations of the safe speed and power values $\mathbf{N}_p$ = f (**V**, **h**, **S**) made by the above methodology and applied to ULA ice category ships of the *SA-15* type.



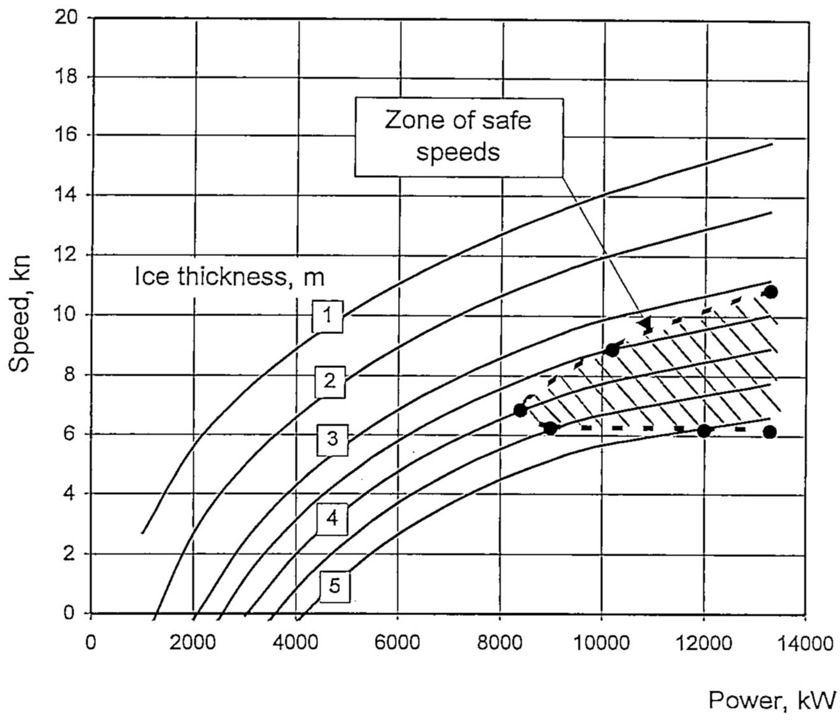


Fig.3.10. Conditions of the safe movement of ship of the *SA-15* type through ice with a concentration of 4/10 - 5/10

As one can see from the figure, during the movement of ships of this type through open floating old ice of considerable thickness (3 m and over) such movement at speeds of 10 - 12 knots becomes dangerous because in this case the design loads on the ship's hull may be exceeded. The analysis of damages of m/s *Bratsk* given in paragraph 3.1 proves the above stated.

3.4. Recommendations on the improvement of construction and on supplementary ice strengthenings of hull

To reduce expenses for the repair at ship repair facilities of the Murmansk and Far East Shipping Companies some structures were partially strengthened. It should be noted that on the basis of the gained experience based on the results of examination of the design documents still before operation in the Arctic, CNIIMF put forward proposals to strengthen hulls of the *SA-15* type ships. The implementation of these proposals began after construction of the prolonged series of ships designated conventionally as *SA-15 Super*. The prototype vessel of this series, *Anatoly Kolesnichenko*, was subjected only to minor strengthenings, that is bottom plates of $\delta = 13$ mm were replaced by those of $\delta = 16$ mm and an intermediate framework was fitted in the fore portion of the flat bottom (within the area of the bottom ice strengthening up to fr. 145). On last vessels of the series the thickness of side plating portions below the ice belt (including bilge) was brought up amidships to 20 - 22 mm and in the afterbody to 18 - 22 mm and the bonding between structural members in the forepeak was slightly improved. The measures to strengthen the hull were of a trade-off nature and not all the proposals were implemented in full. Therefore, notwithstanding the marked improvement of strength of the side plating including the bilge strake and flat bottom portion in the forebody the strength of the bilge and forepeak framework was not improved any significantly which has manifested itself in the retention of a rather high level of damage rate in these areas of the prolonged series vessels of the *SA-15* type.

The fact of the strengthenings fitted being not beneficial for radical improvement of the structural strength in the areas where extensive damages occurred, is attested by the ice impact damages to the hull experienced by all ships of the prolonged series (m/ss *Anatoly Kolesnichenko*, *Kapitan Man*, *Vasily Burkhanov* owned by FESCO; *Yury Arshenevsky*, *Kapitan Danilkin* owned by MSCO) during the first years of operation. However the extent of ice impact damages caused to ships of this series during the first years of operation is significantly less, in particular for the FESCO ships , than that recorded on the first series of ships of *Norilsk* type.

Thus, according to the information available from the FESCO engineering department the *SA-15* type ships suffered in 1987 the following damages:

m/s *Anatoly Kolesnichenko*

- dent in the starboard side division, fr. 61 - 65 (3000 × 1400 mm, **f** = 100 mm) with a deformation of the floor portions abutting on the shell plating (total area – 6 m^2).

m/s *Kapitan Man*

- bulges and dents in the forepeak plating in the boot-topping region, fr. 185 - 197; total area – 20 m^2,
- dents within the ice strake, fr. 169 - 173 (area – 8 m^2),
- bulges amidships, in the flat bottom region abutting on the bilge (area – 18 m^2),
- permanent warping (buckling) of the floor web portions abutting on the shell plating in the area of dents (floor plate thickness δ = 11 ; 12 and 15 mm), deformation of bulb bar over a length of 16 run.m (dimension 370 × 13).

m/s *Vasily Burkhanov*

- dents within the ice strake, amidships (fr. 70 - 100): on the starboard side – area 15 m^2, **f** = 200 mm,
  on the port side – area 13 m^2,
- dents within the bilge strake and side strake abutting thereon in the area of fr. 60 ÷ 70, **f** = 100 mm, area – 13 m^2,
- dents and bulges within the bilge strake in the area of the superstructure front (fr. 50 - 70), on the port side – total area 9 m^2.

A permanent warping was recorded in the floor plate portions abutting on the shell plating in way of dents; bulb bar was deformed over a length of about 10 run.m.

Ice impact damages were recorded also on ships operated by the Murmansk Shipping Company:

m/s *Yury Arshenevsky*

- dent and bulges on plate of the flat bottom portion in the area of the midbody bilge (fr. 103 - 113), **f** = 40 - 55 mm, at fr. 88 and 103 dimensions: 1700 × 2400 mm, at fr. 99 – 3150 × 1200 mm,
- single bulges within the bilge strake under the ABS channel at fr. 100 - 124, **f** = 9 - 12 mm,
- single bulges within the bilge strake in the afterbody in the area of fr. 25 - 33; **f** = 4 - 8 mm.

m/s *Kapitan Danilkin*

- dents in the flat bottom portion, extending to the bilge in the fore part of the vessel (fr. 163 - 180), total area – 30 m^2, supposedly caused by striking an anchor ice when berthing in the port of Dudinka.

As it is apparent from the comparison between the ice impact damages to ships having operated in the Western Arctic (MSCO ships: *Yury Arshenevsky*, *Kapitan Danilkin*), and in the east of the NSR (FESCO ships), the extent of ice impact damages to hulls of the latters is well in excess of those on ships of the same type having operated on Dudinka line, which may be attributed to much more severe ice conditions in the Eastern Arctic.

At the same time the occurrence of noticeable damages in the area where extra strengthenings were fitted, suggests that within the scope of the requirements imposed by the Register Rules now in force ice impact damages to hulls operating under the actual arctic conditions (in particular, in eastern areas) cannot be completely avoided.

To radically eliminate detected structural drawbacks on ships of the *SA-15* type it is necessary, in the opinion of CNIIMF, to fit the following additional strengthenings:

- to increase thickness of the side plating from fr. 110 sternwards as well as of bilge strakes and strakes abutting thereon from 13, 14 mm to 20 - 25 mm;
- to ensure conformity with the Register requirements for ships of the ULA ice category as applied to the bottom plating in the forebody up to fr. 145 by fitting the intermediate transverse framing;
- to strengthen the forepeak structure by bonding the horizontal platforms with the stem and by reinforcing portions of the sheet structures (diaphragms) abutting on the shell plating by additional stiffeners of rolled sections fitted normally to the plating; as the experience has shown, the ratio of the thickness of the plate supporting area and the distance between stiffeners should be at least 0.025;
- to strengthen additionally the bilge portions of the floor plates and bilge brackets along the full length of the ship by shaped stiffeners;
- to fit extra brackets to the bilge below the air bubbling channel;
- to strengthen additionally the side plates just above the ice strake and the portions of the "soft" bow above the forepeak platform with framework.

It should be as a whole emphasized that the ULA ice category of the Register Rules of 1985 edition is inadequate for operation of ships under heavy ice conditions of the eastern area of the Russian Arctic. This conclusion is particularly corroborated by severe damages occurred within the ice belt of ships having operated in the east of the NSR. The same conclusion may be drawn from a comparison between the damage rates of the hull structures of ships of this type having operated in the Western and Eastern Arctic.

It will be obvious that for reliable operation of ships of ice category ULA in the east of the NSR the Register requirements for ice strength of the bilge and bottom structures as well as side divisions amidships should be made more stringent.

As the experience of operation of ships of the *SA-15* type has shown that the Register Rules practically provide for the required ice strength in the strengthened area only for ships operating on the western arctic routes, it is advisable to develop and introduce into the Rules requirements a new supplementary ice category to fit severe ice conditions in the Eastern Arctic.

4. ASSESSMENT OF THE PROPULSION IN ICE OF SHIPS OF THE *SA-15* TYPE BASED ON THE RESULTS OF THE OPERATION ON THE NORTHERN SEA ROUTE

Information about the propulsion of ships of the *SA-15* type in drifting loose ice was gathered, as a rule, in passing, in the course of ice trials or commercial voyages. Substantial body of information was collected by scientists during the tests of ice performance, by captains of ships during numerous trips along the NSR as well as by the Staff of marine operations (Dickson Island).

4.1. Data on expedition voyages

The most considerable part of investigations was carried out on ships *Igarka* and *Kapitan Danilkin.* As to the first one, the compliance of actual ice performance with the guaranteed obligations of the building company was verified (see par.2.1), and on the second ship the ice strength parameters were measured (see par.2.2).

On the completion of ice propulsion tests in compact ice the assessment was made of the propulsion of m/s *Igarka* in drifting ice of the Kara Sea. In the natural first-year thin (30 - 70 cm) loose ice with a concentration of 8/10 - 10/10 the ship at full power was moving at a speed of 14 - 15 kn.

Trials of m/s *Kapitan Danilkin* in the Greenland Sea were conducted at the end of November 1987 in accordance with the programme of joint investigations of Russian and Finnish specialists. Location of the testing ground near the Spitsbergen Archipelago is shown in Fig.4.1 and coordinates of ship during performance of control manoeuvres – in Table 4.1.

Table 4.1

Coordinates of ship during the tests

Test number	1	2	3	4	5	6	7	8	9	10	11	12
Latitude	80°19'	80°01'	80°39'	80°38'	80°35'	80°35'	80°34'	80°51'	80°52'	80°32'	80°23'	79°58'
Longitude	6°30'	2°20'	7°45'	7°55'	7°57'	8°04'	8°04'	9°31'	9°51'	10°34'	10°12'	7°30'

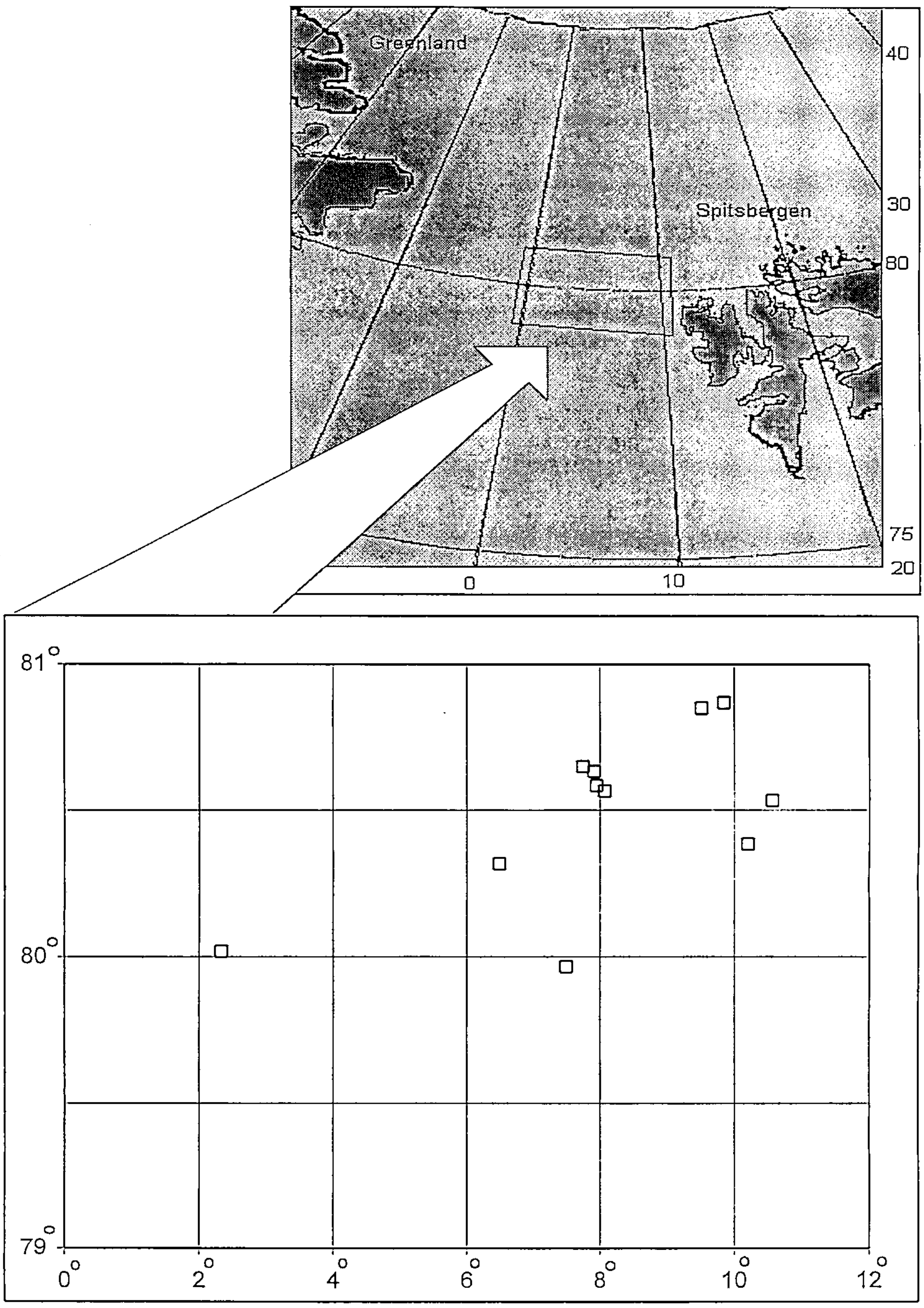


Fig.4.1. Scheme of the testing area in the Greenland Sea and location of m/s *Kapitan Danilkin* during the control sets of tests

Prior to each regime test the ice conditions were taken down with the indication of age, form, concentration, extent of decay and hummocking of ice as well as the presence of compacting. General characteristic of meteorologic and ice conditions in the testing area is given in paragraph 2.2.2. Principal symbols used on Russian ice maps and their relation with the World Meteorologic Organization (WMO) code are shown in Table 4.2. Detailed information on ice conditions in the testing area is presented in Table 4.3.

Table 4.2 Forms of Ice (Size of Floes)

Graphic Symbol	Type of Ice	Dimensions	Code of WMO
⬭	Giant Floe	> 10 km	7
⬡	Vast Floe	2 - 10 km	6
♡	Big Floe	500 - 2000 m	5
◊	Medium Floe	100 - 500 m	4
∪	Small Floe	20 - 100 m	3
O	Ice Cake	2 - 20 m	2
#	Small Ice Cake	<2 m	1

Table 4.3

Ice conditions during the tests of m/s *Kapitan Danilkin* in the Greenland Sea

N	Concentration and form of ice					Pressure[1]	Decay	Hum-mo-cking	Comments
	Multi-year	Second-year	First-year thin	Grey-white, grey	Nilas, open water				
1	2 O ∪	2 O ∪	-	5-6 ◊ O ∪	0-1	0	0	1-2	-
2	-	-	-	-	10	-	-	-	Fracture
3	1-2 O ∪	3-4 O ∪	-	3-4 ◊ O	1-2	0	0	2	Work by rammings
4	0-1 O ∪	4-5 O ∪	-	4 ◊ O ∪	0-2	0	0	1	Recon-naissance by hull
5	1 O ∪	3-4 O ∪	1-2 O ∪	3-4 ◊ O	0-1	0	0	1-2	Recon-naissance by hull
6	2 O ∪	4-5 O ∪	-	2-3 ◊ O ∪	0-2	-	-	-	Stop
7	-	6-7 ◊ O	3-4 ◊ O ∪	-	0	0	0	1-2	-
8	-	5-6 ◊ O	4 ♡ ∪ ◊	-	0-1	0	0	1	-
9	-	6-7 ◊ O	2 ◊ O ∪	0-1 ◊ O	0-2	0	0	1-2	-
10	-	7-8 ◊ O	1-2 ◊ O	-	0-2	0	0	1-2	-
11	2 O ∪	3-4 O ∪	2-3 ◊ O	1-2 ♡ ◊O	0-1	0	0	1	Impact against a large floe
12	-	4-6 O ∪	-	3-4 ♡ ◊O	1-2	0	0	0-1	-

[1] Compacting is defined by the 3-point scale : 1/3 – low, 2/3 – considerable, 3/3 – strong

While carrying out control maneuvers, coincidentally with the registration of ice conditions the records of shaft power and ship's speed were made. One can get the idea of the dependence of the latter on power and ice conditions from Table 4.4 and Fig.4.2.

Table 4.4

Power and speed of m/s *Kapitan Danilkin* while carrying out control tests

Test number	1	2	3	4	5	6	7	8	9	10	11	12
Power, kW	10400	7830	10350	8020	8430	7810	10540	10600	10700	10400	10330	10200
Speed, kn	4.0	8.7	1.5	4.5	5.5	0	8.8	2.5	2.5	3.5	7.0	9.0

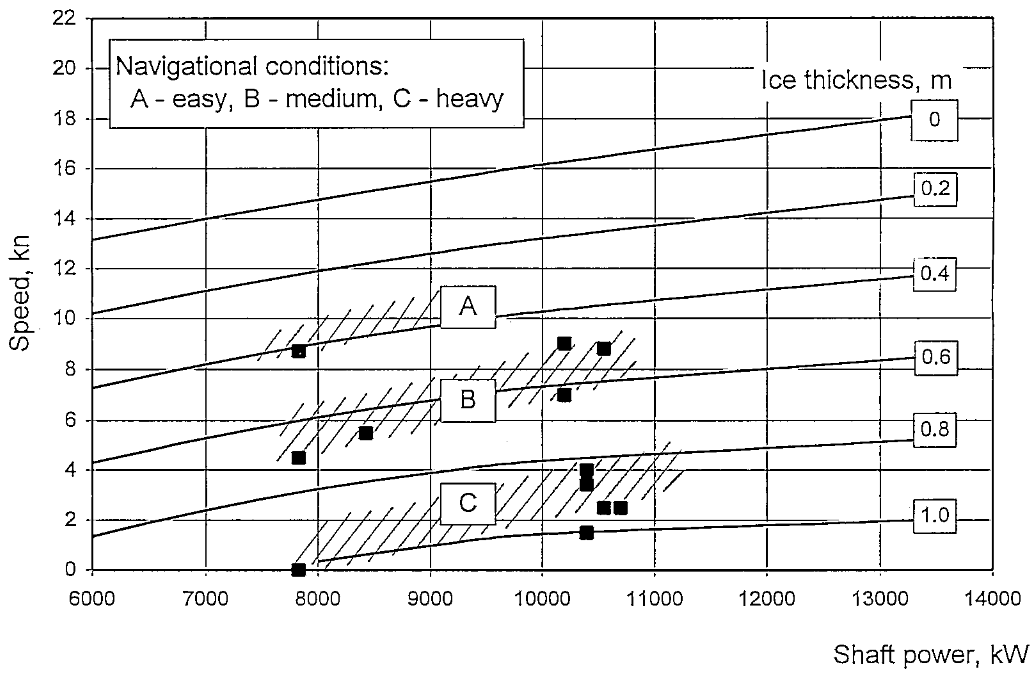


Fig.4.2. Influence of power and of navigational conditions in ice on the speed of m/s *Kapitan Danilkin* (based on the results of tests in the Greenland Sea

For the evaluation of the severity of navigation the figure shows calculated dependences of the ship's speed on the shaft power and the equivalent ice thickness. The last value takes into account hummocking, degree of decay and snow cover of the ice. Navigational conditions conventionally may be divided into three categories: *heavy*, *medium* and *easy*. Operation of ship in ice with a thickness close to its icebreaking capability falls into the first category, with a thickness of about 50 % of the icebreaking capability – into the second and under lighter conditions – into the third one.

The categories analysed are based on the relative thickness of ice, that is on the ratio between the equivalent thickness and the icebreaking capability of a certain vessel. The same ice conditions for a ship with high parameters of the ice propulsion and strength may be considered as *easy,* for a less powerful ship – as *medium* and for a ship little adapted to navigate in ice – as *heavy*. Besides, in the Russian practice there is a typification of ice conditions based on the length of route in ice on main arctic stretches. Type of the ice navigation is defined by the special method of calculation. Long-standing observations and practice of the ice navigation show that types of ice conditions of the navigation are of a cyclic character. Duration of a cycle is 4 years. Within one cycle the *easy* and *heavy* type of navigation are observed once, *medium* one – twice.

4.2. Data on the voyage reports of captains

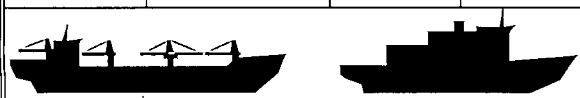
Substantial contribution into the augmentation of the body of information about the propulsion of ships of the *SA-15* type in drifting ice of arctic seas has been made by captains of these ships, direct participants of the ice navigation, and also by the Staff of marine operations exercising the general co-ordination of navigation. The present work cites fragments of the voyage reports of captains about the particular character of the sailing of ships independently and under the support of icebreakers along the NSR (Tables 4.5, 4.6, 4.7, 4.8 and 4.9). Besides, Table 4.10 shows the information of the Staff of marine operations about ice conditions in June-July and in September-October in the Kara Sea and about speeds of the movement of ships being a part of complex convoys.

Table 4.5 Sailing of m/s *Monchegorsk* during the voyage Murmansk – Pevek

Name of ship	*Mînchegorsk*
Route	Murmansk – Pevek
Beginning	03 June 1984
End	24 June 1984

Date	Time	Latitude	Longitude	Ice conditions and particular features of navigation
				Independent navigation
03 June	23:00 – 24:00			Open water
04 June	00:00 – 24:00			Open water
05 June	00:00 – 24:00			Open water
06 June	00:00 – 03:00			Open water
	03:00	76°45'	63°32'	First-year ice cake with a concentration of 8/10 - 9/10
	04:00	76°39'	64°23'	Small floe and first-year ice cake. Concentration – 7/10 - 8/10. Thickness – 40 - 50 cm. Speed –10 kn.
	19:30 – 24:00	76°10'	70°39'	First-year hummocked ice. Thickness – 100-120 cm. Concentration – 7/10 - 8/10. Drift in expectation of the icebreaker assistance.
07 June	00:00 – 24:00			Drift in expectation of the icebreaker assistance.
08 June	00:00 – 20:00			Drift in expectation of the icebreaker assistance.
	20:00 – 24:00			Independent sailing through the Kara Sea to the Izvestia Islands co-ordinated by the ice reconnaissance aircraft. Total concentration – 9/10 - 10/10: • vast floes of the first-year hummocked snow-covered ice 100 - 165 cm thick – 5/10 - 7/10, • small floe – 2/10 - 3/10, • nilas, thin ice – 1/10 - 2/10. The route of ship ran principally between floes through nilas and thin ice at an average speed of 6.0 - 7.5 kn. In the absence of diverging the movement was carried out by ramming against the floe joints at an average speed of 2 - 3 kn.

Continuation of Table 4.5

Date	Time	Latitude	Longitude	Ice conditions and particular features of navigation
10 June				Strong southern wind, compacting – 2/3 - 3/3. Drift for 5 h.
11 June				Strong southern wind, compacting – 2/3 - 3/3. Drift for 12 h.
12 June	14:00	75°52'	86°18'	Small floe of the first-year medium and of the first-year thick ice with a concentration of 10/10. Compacting – 2/3. Hummocking – 2/5. Snow cover – up to 10 cm. Drift in expectation of the icebreaker assistance.
				Sailing under the assistance of icebreaker *Arktika* [1]
16 June	22:00	76°55'	86°43'	Small floe of the first-year medium and of the first year thick ice with a concentration of 10/10. Hummocking – 3/5. Snow cover – up to 10 cm. Compacting – 2/3. In the channel behind the icebreaker, small floe and ice cake. Average speed – 9 kn.
17 June	16:00	77°31'	92°04'	Fast ice with a thickness of 100 - 120 Cm. Snow cover – up to 10 cm. In the channel behind the icebreaker, small floe and ice cake. Periodically the icebreaker works by ramming. Average speed – 4.0 - 4.5 kn.
19 June	10:00			From the Cape Chelyuskin the route was running to the north of the New Siberian Islands. Total ice concentration – 7/10 - 8/10: • first-year thick ice – 2/10 - 3/10, • first-year medium ice – 2/10 - 3/10, • first-year thin ice – 2/10 - 3/10. Hummocking – up to 2/5. At compacting the ship stopped and after the breaking down of ice by the icebreaker proceeded moving. Speed of movement on complicated stretches – 4 kn, on easy ones – 15 - 16 kn, average speed – 11.3 kn.
24 June	10:00			Port of Pevek. The voyage is completed.

1 Principal characteristics of the icebreaker are shown in the Annex, Table A.2

Table 4.6

Sailing of m/s *Monchegorsk* during the voyage Pevek – Petropavlovsk-Kamchatski

Name of ship	*Monchegorsk*
Route	Pevek – Petropavlovsk-Kamchatski
Beginning	05 July 1984
End	11 July 1984

Date	Time	Latitude	Longitude	Ice conditions and particular features of navigation
				Sailing under the assistance of icebreaker *Arktika*
5 July	03:00 – 18:00			From the Cape Shelagski and further on to the east small floe and first-year ice cake with a concentration of 6/10 - 7/10. Average speed of escorting – 13.3 kn.
				Independent navigation
5 July	18:00	69°34'	178°00'	Small floe and first-year ice cake with a concentration of 7/10 - 8/10. Ice decay – 2 - 3. Average speed – 11 kn.
		69°12'	179°11'	Separate floating ice floes. Concentration – 1/10 - 2/10.
6 July	17:00	66°41'	170°45'	Open water
11 July	01:30			Port of Petropavlovsk-Kamchatski. Voyage is completed

Table 4.7

Sailing of m/s *Monchegorsk* during the voyage Petropavlovsk-Kamchatski – Novy Port

Name of ship				*Monchegorsk*
Route				Petropavlovsk-Kamchatski – Novy Port
Beginning				28 July 1984
End				12 August 1984
Date	Time	Latitude	Longitude	Ice conditions and particular features of navigation
				Independent navigation
28 July	13:00			Open water
01 August	17:00–24:00	67°53'	173°08'	Drift in expectation of the icebreaker assistance.
02 August	06:15			Small floe of ice and first-year ice cake with a concentration of 8/10. Building up of a convoy of 5 ships.
				Sailing under the assistance of icebreaker *Arktika*
03 August	00:30	68°50'	176°09'	Small floe of ice and first-year ice cake with a concentration of 6/10 - 7/10. Average speed of escorting – 10 kn.
04 August	00:00 –00:30	70°06'	173°27'	Change of icebreaker
				Sailing under the assistance of icebreaker *Moskva* type
04 August	03:00 –24:00			Small floe of ice and first-year decayed ice with a concentration of 6/10 - 7/10. Average speed of escorting – 11.3 kn.
05 August	01:50	71°03'	162°07'	Ice with a concentration of 8/10 - 9/10: first-year medium – 5/10 - 6/10 with inclusions of thick ice (3/10). Decay – 3. Average speed of escorting – 8 kn.

Continuation of Table 4.7

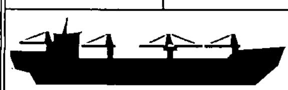
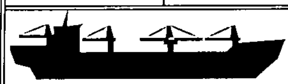
Date	Time	Latitude	Longitude	Ice conditions and particular features of navigation
06 August	20:00	73°50'	149°00'	Strait of Sannikov. Ice with a concentration of 9/10 - 10/10: first-year medium ice – 6/10, thick 3/10 - 4/10. Decay – 3. Average speed – 9 kn.
07 August	12:00	74°17'	139°58'	The Laptev Sea, to the north of the Stolbovoy Island. Concentration – 5/10. Fractures. Average speed – 12.5 kn.
08 August	17:00	75°10'	120°04'	The Taimyr ice mass. Ice with a concentration of 9/10 - 10/10: • first-year medium ice – 7/10, • thick ice – 2/10 - 3/10. Decay – 2 - 3. Average speed – 12.4 kn.
09 August	12:00 –23:00	77°33'	107°20'	Approach to the Strait of Vilkitsky. Ice with a concentration of 8/10 - 9/10: • first-year medium ice – 6/10, • thick ice – 2/10 - 3/10. Decay – 3.
	23:00	77°30'	100°00'	Exit out of the Strait of Vilkitsky. Way round the concentrated ice into the Strait of Matissen. Fractures in fields of the first-year ice, separate isthmuses (0.5 - 1.5 miles). At the exit out of the strait the ice with a concentration of 3/10 - 4/10, separate isthmuses of the first-year medium ice (3 - 5 miles). Average speed – 12.5 kn.
11 August	03:40			At the approach to the Port of Dickson the icebreaker escorting was completed. Open water.
				Independent navigation
12 August	21:00			Novy Port. Voyage is completed.

Table 4.8

Sailing of m/s *Kola* during the voyage Murmansk – Pevek

Name of ship				*Kola*
Route				Murmansk – Pevek
Beginning				13 June 1985
End				25 June 1985
Date	Time	Latitude	Longitude	Ice conditions and particular features of navigation
				Independent navigation
13 June	08:00 –24:00			Open water
14 June	00:00 –24:00			Open water
15 June	00:00			Ice edge near the Strait of Yugorsky Shar. Movement through the old channel at a speed on separate stretches of 15 knots. In the Kara Sea the ship forcing isthmuses continued moving through the Amderma and Yamal polynyas and from the Dickson Island passing round the islands of the Nordensheld Archipelago along the flaw polynya.
18 June	14:25	77°27'	99°34'	Fast ice edge at the Strait of Vilkitsky. Drift in expectation of the icebreaker assistance.
				Sailing under the assistance of icebreaker *Arktika*
19 June	08:00– 20:00	77°27'	99°34'	Movement through the fast ice along the old channel. Average speed – 12 kn.
	20:00			The Laptev Sea. The first-year thick ice with a concentration of 9/10 - 10/10. Compacting. Hummocking – 3/5 - 4/5 . Average speed of moving through the Taimyr mass taking into account stoppages and breaking down of ice near the ship – 10.1 kn.

Continuation of Table 4.8

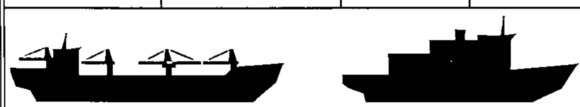
Date	Time	Latitude	Longitude	Ice conditions and particular features of navigation
21 June	16:00			Meridian of the Cape Anissiy.
22 June	16:00			The East Siberian Sea. Flaw polynya: second-year and first-year hummocked ice with a concentration of 3/10 - 4/10, ice isthmuses. Average speed – 8.8 kn.
25 June	13:00			Port of Pevek. Voyage is completed.

Table 4.9

Sailing of m/s *Kola* during the voyage Murmansk – Pevek

Name of ship Route Beginning End				*Kola* Murmansk – Pevek 14 May 1987 16 June 1987
Date	Time	Latitude	Longitude	Ice conditions and particular features of navigation
				Independent navigation
14 May	08:45 –24:00			Open water
15 May	00:00 –13:15			Open water
				Sailing under the assistance of icebreaker *Arktika*
15 May	13:15			Western edge of ice.
16 May	05:00			Exit through the Kara Strait to the Kara Sea. Course – Cape Zhelania. Novozemelskaya Polynya. Open water. Speed – 17 kn.
17 May	06:35– 10:50	76°15'	69°32'	Ice mass. Course – Strait of Vilkitsky.
	10:50– 24:00	76°11'	72°41'	Repair of the icebreaker. Drift in expectation of the icebreaker assistance.
18 May	00:00– 24:00			Drift in expectation of the icebreaker assistance.
19 May	00:00– 24:00			Drift in expectation of the icebreaker assistance.
20 May	00:00– 24:00			Drift in expectation of the icebreaker assistance.
21 May	00:20			Ice mass of the Kara Sea. Course – Strait of Vilkitsky.
22 May	14:30			Stoppage in the fast ice. Icebreaker is making the channel through ridges of hummocks. 7 miles were covered for 24 hours.

Continuation of Table 4.9

Date	Time	Latitude	Longitude	Ice conditions and particular features of navigation
25 May				Level ice 1.6 - 2.0 m thick. Towing of ship. Speed – 2 - 4 kn.
28 May	16:20			The fast ice edge is broken through. Exit to the Laptev Sea. Ice of the Taimyr mass is pressed to the fast ice edge (compacting – 2/3 - 3/3). Making of the channel by ramming, breaking down of ice near the ship. Distance covered – 81 miles.
29 May				Repair of the icebreaker. Drift in expectation of the icebreaker assistance.
				Escorting by two icebreakers of the *Arktika* type
	19:40			The first icebreaker is making the channel, the second one is towing the ship.
30 May				98 miles were covered for 24 hours.
31 May	05:40			Trouble on one of icebreakers. Distance covered for 24 hours – 74 miles.
01 June				Improvement of the ice situation. Distance covered for 24 hours – 197 miles.
02 June				Convoy entered the meridian of the Cape Anissiy.
				Sailing under the assistance of icebreaker *Arktika*
	18:40			Distance covered for 24 hours – 140 miles.
03 June				Compacting. Fog. For more than 7 hours the convoy was adrift in the expectation of the improvement of visibility. Distance covered for 24 hours – 70 miles.

Continuation of Table 4.9

Date	Time	Latitude	Longitude	Ice conditions and particular features of navigation
04 June				At the meridian of 145°E convoy entered the flaw polynya and to the south of the Vilkitsky Island penetrated into the ice mass. Distance covered for 24 hours - 161 miles.
05 June				Attempts to leave the ice mass and to break through to the flaw polynya.
				Escorting by two icebreakers of the *Arktika* type
06 June	06:00			The convoy entered the flaw polynya. In 5 hours the shearing of ice fields and hummocking started. The ice situation was considered as heavy one. The ship practically could not move. Icebreakers continuously were breaking down ice near it to reduce the ice pressure. Both icebreakers and ship were damaged.
13 June	15:40			After repair the convoy continued moving around fields of the fractured fast ice.
16 June	16:30			Port of Pevek. The voyage is completed.

Table 4.10
Ice conditions and speeds of ships navigating independently and escorted by icebreaker of the *Arktika* type in the Kara Sea

N	Concentration and form of ice					Pres-sure	Hum-mo-cking	Speed, kn	Com-ments
	Second-year	First-year thick	First-year thin	Grey-white, grey	Nilas, open water				
						Independent navigation			
1	-	-	8-9 O	-	1-2	0	-	13.3	
2	-	-	7-8 O ∪	-	2-3	-	-	10.0	Ice thickness 40-50 cm
3	-	-	7-8 O ∪	-	2-3	-	2	6.1	Ice thickness 100-120 cm
4	-	-	5-7	2-3 ∪	1-2	-	1	6.0-7.5	Ice thickness 100-165 cm
5	-	-	7-8 O ∪	-	2-3	-	-	11.0	
 						Sailing under the assistance of icebreaker			
1	-	-	9	-	1	-	-	11.4	
2	5	4-5	-	-	0-1	3/3	3-4	0.8	3 ships in the convoy
3	5	4-5	-	-	0-1	3/3	2-3	3.1	Towing
4	5	4-5	-	-	0-1	3/3	3-4	1.3	Towing
5	-	10	-	-	0	>0	2	5.6	
6	-	5-6 ◊ O	-	-	4-5	-	-	3.7	
7	-	4-5	-	-	5-6	-	-	11.2	
8	-	7-8 ◊	-	-	2-3	-	3	3.3	
9	-	10	-	-	0	-	-	2.7	Ramming
10	-	-	9-10 ⬡ ◊	-	0-1	-	1	10.6	
11	-	8	-	1-2 ◊	0-1	2/3-3/3	1-2	7.7	
12	-	5-6 ◊	-	2 ◊	2-3	-	2	3.8	
13	-	5-6 ◊	-	2 ◊	2-3	2/3	2	1.5	

Continuation of Table 4.10

N	Concentration and form of ice					Pres-sure	Hum-mo-cking	Speed, kn	Com-ments
	Second-year	First-year thick	First-year thin	Grey-white, grey	Nilas, open water				
14	-	8-9 ◊	-	1-2 O #	0	2/3-3/3	2-3	4.9	
15	-	-	1-3 ◊	-	7-9	-	-	8.7	
16	-	-	9-10 ◊	-	0-1	1/3	1	8.7	
17	-	-	3-5 ◊	-	5-7	-	-	12.4	
18	2	-	7-8	-	0-1	-	-	7.6	
19	-	-	1-3	-	7-9	-	-	11.6	
20	6	-	3	-	1	1/3-2/3		9.5	
21	2	-	5-6	-	2-3	-	-	9.6	
22	2-3	-	-	-	7-8	-	-	10.9	
23	5-6	-	-	-	4-5	-	-	10.5	
24	-	-	5-6	-	4-5	-	-	10.8	
25	-	-	7-8 ⬡ ◊	-	5-6	-	-	14.0	
26	-	-	2-3 ⬡ ◊	-	7-8	-	-	15.5	
27	-	-	7-8 ⬡	-	2-3	-	-	12.1	
28	-	-	7-8 ⬡ ◊	-	2-3	1/3	-	8.2	
29	-	-	8-9 ⬡	-	1-2	1/3	3	5.8	ice decay - 2

4.3. Determination of speeds of ships in different ice conditions

Ships are to navigate in different ice conditions: from open water up to the compact fast ice, from the first-year drifting ice up to multi-year ice, from level up to hummocked ice. Ice shearing is accompanied by the intensive compacting and the formation of hummocks. Safety of navigation and the successful solution of the transportation problems depend a great deal on the reliability of information about the ship's possibilities the navigator possesses. For this purpose the trials of ships are conducted, information on the operational experience under real conditions is gathered and systematized. Of the most interest for the practice of navigation is the analysis of speeds of ice cargo ships in the fast ice and drifting ice under the assistance of icebreaker and independently.

Icebreaking capabilities of ships of the *SA-15* type sailing independently through the compact level ice have been considered in section 2.1 and presented graphically in Fig.2.1. Information of sections 4.1 and 4.2 gives an idea of the propulsion of ships in drifting ice. Diversity of the latter complicates the task of the direct account of a number of factors in the determination of the relationship between speed and conditions of navigation. This is illustrated in Fig.4.3, which shows the influence of the concentration of ice of different age on the ship's speed at power close to the rated one.

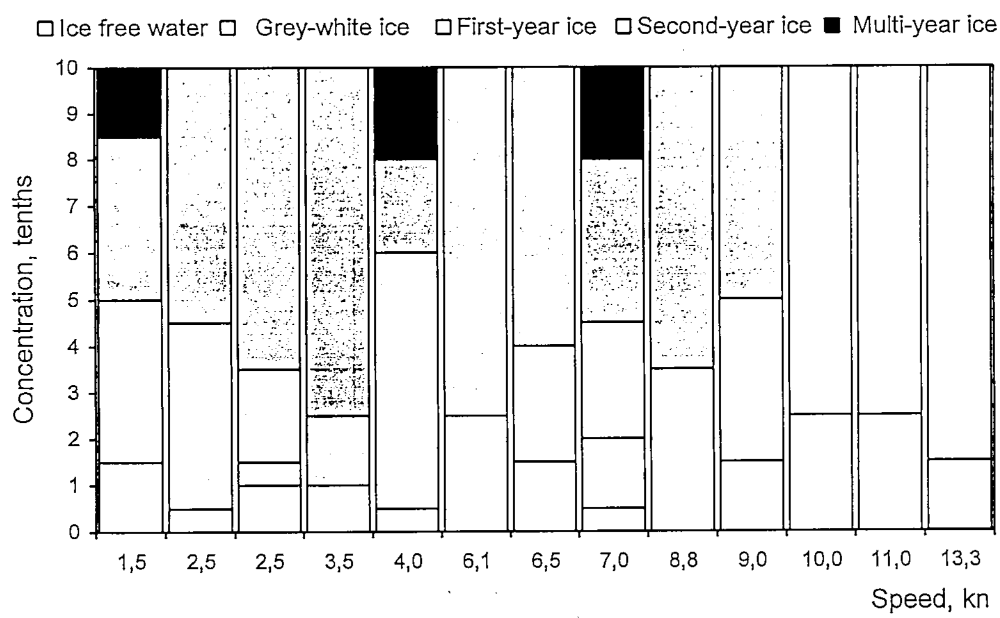


Fig.4.3. Variations in speed of ship of the *SA-15* type navigating in drifting ice of different concentration (hummocking 1/5 - 2/5)

Just the same, the investigations made by CNIIMF and AARI have permitted to obtain relationships between speeds of ships and ice thickness for a number of representing cases of operation [10]. Such cases include independent sailing and that under the icebreaker support in compact ice, medium and small floes with a concentration of 9/10 - 10/10 and 7/10 - 8/10.

Ice propulsion of ships of the *SA-15* type escorted by icebreakers has been considered in section 5 of the present paper. Below, Figs.4.4 and 4.5 show results of the analysis of the propulsion of these ships operating at full power in independent navigation under different ice conditions.

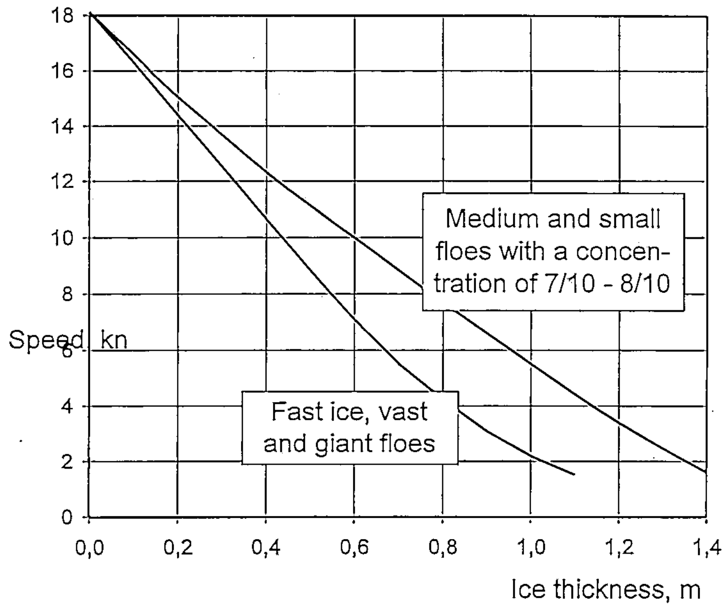


Fig.4.4. Propulsion of ships of the *SA-15* type navigating independently under different ice conditions

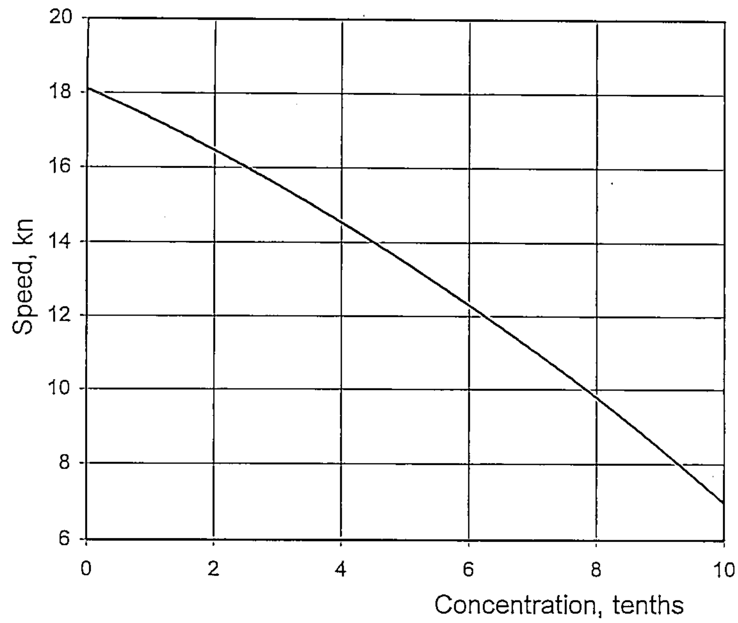


Fig.4.5. Influence of the concentration of ice on speed of the *SA-15* type ships during their navigation independently through the ice cake

Ship's speed/ice thickness relationships presented in the first figure permit to compare the ships' propulsion in the level compact fast ice and vast giant floes with the propulsion in medium and small floes with a concentration of 7/10 - 8/10. The second figure illustrates the effect of the concentration of natural ice cake on the ship's speed.

5. ANALYSIS OF THE EFFICIENCY OF THE NAVIGATION OF SHIPS OF THE *SA-15* TYPE UNDER THE ICEBREAKER ASSISTANCE

Main task in ordering multi-purpose icebreaking cargo ships of the *SA-15* type was to ensure reliable all the year round transportation of cargo in the western area of the Russian Arctic and during the extended periods of the summer arctic navigation in the eastern area using the traditional method of the escorting of ships in ice by icebreakers. Ships were designed on the basis of their compliance with powerful nuclear icebreakers of the *Arktika* type (55 MW) and this had to allow achieving maximum efficiency of the operation of these ships under the assistance of such icebreakers forming the main body of the domestic icebreaker fleet. Accordingly the substantiation and choice were made of dimensions, power, ice class and icebreaking capability of ships of the *SA-15* type. At the same time, the obtained fairly high icebreaking capability of ships of this type equal to 1 m enables them to navigate independently in freezing non-arctic seas as well as on the NSR in summer under favourable ice conditions. However the power of the *SA-15* type ships was chosen first of all on the basis of ensuring their compliance with powerful nuclear icebreakers carrying out their escorting in the Arctic during the winter-autumn period through the first-year medium and thick ice.

5.1. Icebreaker escorting by the method of leading

The method of leading involving the breaking down of ice near the stuck ships which follow the icebreaker in channel is the principal way of the escorting of ships in ice. Under heavy ice conditions characterized by the great thickness of ice, high degree of hummocking, considerable depth of snow cover and the presence of compacting of the drifting ice when practically there is no more possibility of the efficient leading through heavy stretches and ship is not capable of moving behind the icebreaker independently the latter takes the former in tow. Speed of the *icebreaker – ship* tandem, as the experience shows, is close to the speed of the independent movement of icebreaker under given ice conditions.

While following the icebreaker-leader the speed of ship is either equal to that of the icebreaker making the channel if the movement takes place through thick (heavy) ice and the ship in channel may catch up with the icebreaker, or the convoy moves at a speed of the ship when the icebreaker is making the channel through relatively thin (easy) ice and being substantially more powerful may break away from the cargo ship behind. It can be demonstrated in graph of Fig.5.1.

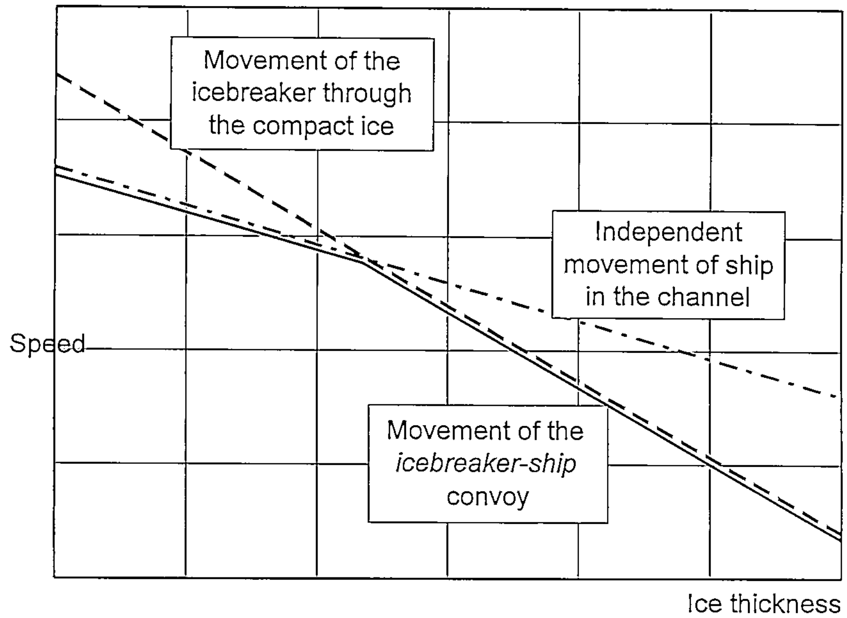


Fig.5.1. Dependences of the speed of the escorting of ship by leading icebreaker on the thickness of ice, speed of making the channel and speed of the movement of ship in the channel

Ice trials of the serial m/s *Igarka* and the experience of the operation of ships of the *SA-15* type have proved the satisfactory compliance of these ships with nuclear icebreakers of the *Arktika* type. Under typical conditions of the first-year medium ice (floes 70 - 120 cm thick, hummocking – 1/5 - 2/5 and concentration – 9/10 - 10/10) the ship can move in the channel following the icebreaker *Arktika* not lagging behind it, that is at a speed equal to that of the icebreaker making the channel, by the use of full power of the propulsion plant. This speed (speed of the convoy) is 11 - 13 kn.

Fig.5.2 shows the processed statistical data of the dependences of speeds of the escorting of the *SA-15* type ship by the *Arktika* type leading icebreaker on the design ice thickness during the movement of convoy through the fast ice and vast ice fields, through fragments of floes and natural small floes with a concentration of 7/10 - 8/10 and 9/10 - 10/10.

The experience gained for 15 years of the operation of ships of the *SA-15* type in the Arctic permits also to assess the capabilities of these ships while navigating with icebreakers under the heaviest ice conditions encountered on the NSR not more often than once in 20 years. With similar duration of the service period of ships practically each of them is sure to come across such conditions.

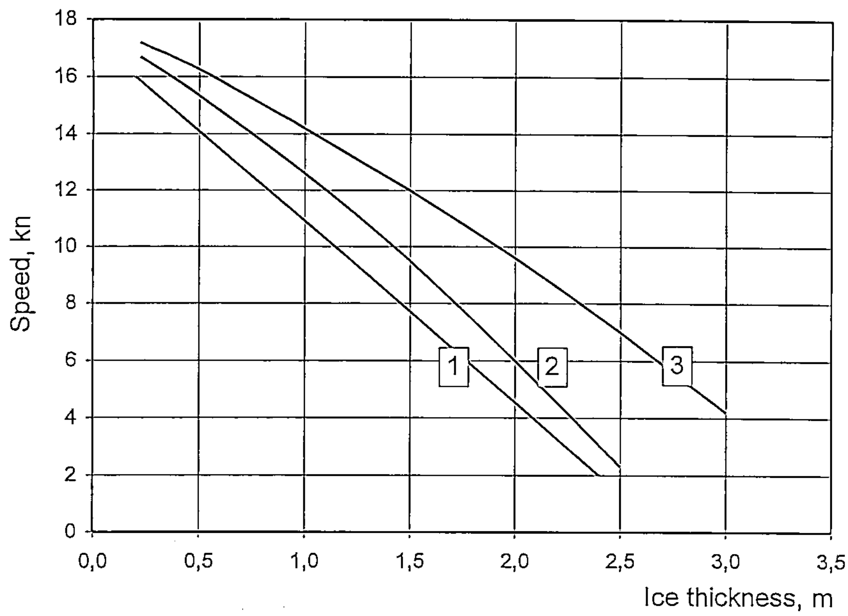


Fig.5.2. Propulsion of ships of the *SA-15* type during the navigation under assistance of icebreaker of the *Arktika* type in the fast ice and vast giant (1), medium and small floes with a concentration of 9/10 - 10/10 (2) and 7/10 - 8/10 (3)

The above extreme conditions took place in October-November 1983 in the eastern area of the Arctic. During this period in Pevek there were two ships of the *SA-15* type: m/s *Monchegorsk* and m/s *Okha*. The first ship had to be lead out of Pevek to the west, the second – to the east. Nuclear icebreaker *Arktika*, as a leader, participated in the operations of escorting ships through the Ayon ice massif which blocked the coastal routes of the East Siberian and Chuckchee Seas.

<u>Escorting of m/s *Monchegorsk* out of Pevek</u> to the west on 18-19 November 1983. Ice conditions on the way of movement of the convoy n/i *Arktika* – m/s *Monchegorsk* in the East Siberian Sea were characterized by the following data: ice concentration – 10/10 including permanent (second-year and multi-year) ice 200 - 400 cm thick in the form of breccia – up to 8/10, white ice (50 ÷ 70 cm) with separate nilas inclusions – up to 2/10; hummocking – 3/5 - 4/5; compacting – 0 ÷ 1/3. Outer air temperature was about –25°C.

Motorship *Monchegorsk,* assisted by n/i *Arktika,* passed a distance of 157.5 miles from Pevek to the Medvezhiy Islands for 27.5 hours. All this time the escorting by leading was conducted. Eventually the average speed of escorting was 5.7 knots. Both the icebreaker and ship operated at full power.

In the course of escorting m/s *Monchegorsk* 9 times stuck in the channel behind the icebreaker (due to the compacting in joints of ice fields, sharp turns of the channel and its excessive clogging with loose pack ice when crossing hummocked ridges). In five out of these cases the ship started to move after the breaking down of ice near the ship by the icebreaker (return of the icebreaker and its passing along the ship's side). In the remaining 4 cases the ship could move ahead only after it had been pushed by the icebreaker stem into the stern towing cut-out. Average duration of the *tandem* work of the ship and icebreaker until the former acquired steady independent motion was about 6 minutes. In these conditions, when the ship happened to be blocked in ice, the method of pushing turned out to be quite justified.

<u>Escorting of m/s *Okha* in the Strait Longa and in the Chuckchee Sea</u> to the east on November 25 1983. Ice conditions on the way of movement of the convoy n/i *Arktika* – m/s *Okha* were characterized by the following data: ice concentration – 10/10 including permanent (second-year) ice with separate incorporations of the multi-year ice up to 300 ÷ 400 cm thick in the form of breccia fields – 9/10, first year ice (70 - 100 cm) – 1/10; hummocking – 3/5 - 4/5; compacting in the joints of fields – 1/3 - 2/3; depth of snow cover – up to 50 cm. Outer air temperature was about –23°C.

Under such conditions the escorting of m/s *Okha* by the leading icebreaker *Arktika* lasted for 6 hours. Eventually the convoy advanced by 9 miles. Average speed of escorting was 1.5 kn and both ships worked at full power. During this period m/s *Okha* stuck 7 times - in 4 cases the ship started to move after the breaking down of ice near it and in 3 cases after having been pushed by the icebreaker by *tandem* method. Average duration of each case of pushing was about 5 minutes.

In that way the above cases of the work of ships of the *SA-15* type under the very rare extremely heavy ice conditions (with a frequency of approximately once in 20 years) permitted to practically reveal limiting capabilities of these ships while being escorted by powerful nuclear icebreakers of the *Arktika* class.

5.2. Escorting by tandem at the close tow

As it is known in practice, need in the escorting of cargo ships in tow arises mostly in the presence of compacting. With compactings[1] up to 2/3, after the breaking down of ice near escorted ships, the latters still could follow the icebreaker; the speed of movement can change from 0.5 to 3 - 4 kn depending on the ice thickness, power and dimensions of ship. In very hummocked compact fast ice more than 1 m thick at a high density of the small ice cake in the channel as well as compactings exceeding 2/3 in drifting ice the escorting of ships by leading is practically impossible. The icebreaker is to take ship in close tow and to operate with it by *tandem*. In this case the speed of ship's towing is close to the speed of icebreaker in corresponding ice conditions. The comparison of speeds of the escorting by the methods of leading and towing under similar ice conditions (hummocked ice or in the presence of ice compactings) shows that as aresult of towing the speed of escorting increases 2 - 3 times and in very heavy ice conditions may increase tens of times. Consequently the towing of ships by icebreakers allows to retain high rate of escorting, "stabilizes" the speed of ships at a level to the utmost probable for the given ice conditions, reduces the duration of stay of ships on the ice route this being very important if we bear in mind the great changeability of the ice situation and sometimes impossibility of its forecasting.

The experience of close towing of ships permitted also to reveal the admissible (from the viewpoint of the efficiency to use the *tandem* procedure) relations between the displacement of icebreaker and the towed ship. So, with a mass of the cargo ship exceeding that of the icebreaker the steerability of the icebreaker-ship convoy noticeably deteriorates. In this respect the displacement of ships of the *SA-15* type equal to about 25 000 t and commensurable with the displacement of icebreakers of the *Arktika* type (about 24 000 t) should be considered critical from the point of view of the steerability of the convoy.

As to the drawbacks of the method of close towing of ships by icebreakers one should also mention frequent damageability of the ship's forebody caused by the interaction with the stern towing cut-out of the icebreaker in the process of towage and manoeuvring in ice. This is associated with the imperfection of the existing towing appliances and inadequate strengthening of the forebody structure above waterline. However these drawbacks can be eliminated by the appropriate unification of form of the ship's forebody and of the icebreaker stern towing cut-out as well as improving the tow device and the ship's hull structure.

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[1] Compacting is defined by the 3-point scale : 1/3 – low, 2/3 – considerable, 3/3 – strong

The case of the escorting of m/s *Kola* in the transarctic voyage from the West through the fast ice of the Strait of Vilkitsky by icebreaker *Arktika* in May 1987 may serve as an example illustrating efficiency of the towage of ship of the *SA-15* type by icebreaker of the *Arktika* type.

During the sailing of m/s *Kola* and n/i *Arktika* in spring 1987 the fast ice thickness in the Strait of Vilkitsky was 160 - 200 cm. The convoy had to cross separate hummock ridges. Speed of the escorting of ship by leading amounted to about 2 knots and the movement was unstable. After the docking of ship and icebreaker the tandem speed under the same conditions increased almost twice and reached 4 knots, the movement became stable.

Fig.5.3 shows graphs of the design speeds of the movement of ship of the *SA-15* type in the fresh channel through the level compact fast ice and in drifting ice, escorted by icebreaker *Arktika* by the method of leading at compactings with a force of 1/3 - 2/3, as compared with the close towing of ship under the same ice compacting conditions.

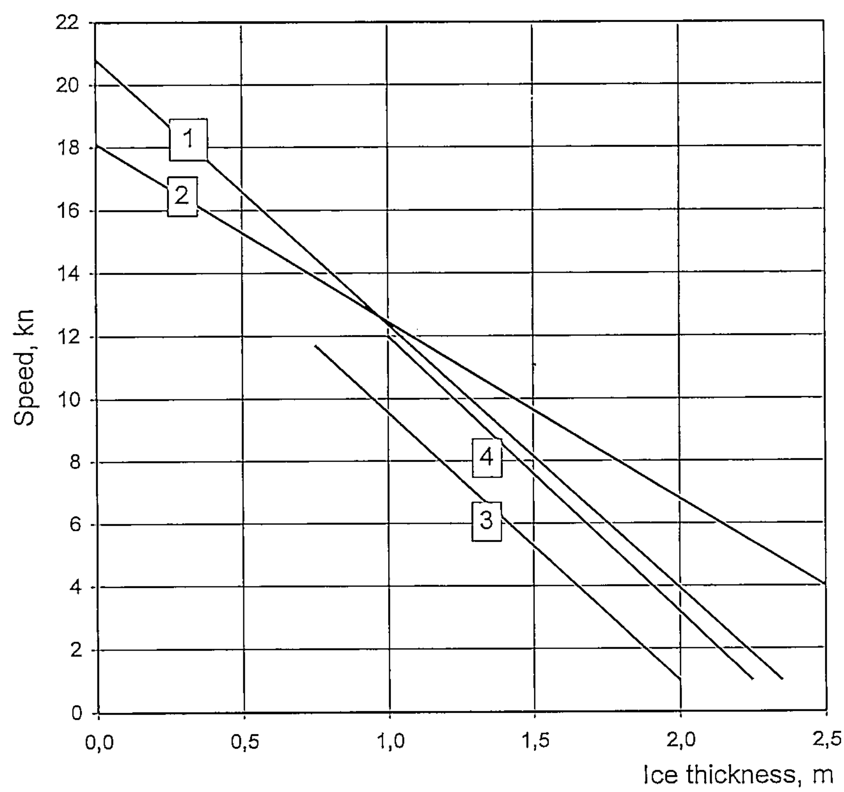

Fig.5.3. Linearized relationship between speed and ice thickness in making the channel by icebreaker *Arktika* in the level compact ice (1), during the movement of the *SA-15* ship through the channel in the level compact ice (2), escorting of the *SA-15* ship by leading (3) and by towing (4) under conditions of the ice compacting of 1/3 - 2/3

Apparently, with the great diversity of ice conditions different gain in speed can be obtained from the use of towing. However for the construction of reliable relationships the full-scale data are not sufficient. It is necessary to conduct special investigations.

The analysis made of data on the experience of operation of ships of the *SA-15* type on the NSR allowed as a whole to assess the need of these ships in the icebreaker assistance. As applied to transit voyages along the NSR and operations in the eastern area of the Russian Arctic to provide for safe efficient cargo transportation taking into account the possibility of the navigation under the "heavy" type of ice conditions the icebreaker support for the *SA-15* type ships will be needed approximately for 10.5 months a year. In the western area of the Arctic the need in the icebreaker assistance will be on the average for about 9 months.

6. ANALYSIS OF THE COMPLIANCE OF THE ICE PERFORMANCE OF SHIPS OF THE *SA-15* TYPE WITH OPERATIONAL CONDITIONS IN THE RUSSIAN ARCTIC

6.1. Assessment of the compliance of the ice class

As the statistics shows, the *SA-15* type ships which navigated in the eastern seas of the Arctic are mostly prone to ice damages.

Practically all the ships of this type regularly having made voyages in the eastern section of the NSR (especially in the autumn-winter period), for instance, *Arkhangelsk, Bratsk, Igarka, Monchegorsk, Okha, Nikel, Nizhneyansk, Anadyr, Kola*, suffered extensive heavy ice damages characterized by:

- dents in the shell plating below the ice strake (side and bottom) with permanent deflection of plates up to 50 - 60 mm in stern and with deflections of 30 - 60 mm in the middle part;
- numerous bulges and corrugations of bilge strake plates in the area of the air bubbling system aft of the midship ($\mathbf{f}_{max}$ = 50 - 60 mm);
- dents ($\mathbf{f}_{max}$ = 70 - 100 mm) and bulges in the bilge strakes below the air bubbling system collector and in the bottom strakes adjoining bilge in the middle and after parts ($\mathbf{f}_{max}$ = 45 - 50 mm);
  dents and bulges in the bottom plating in the forebody area of ice strengthenings – fr. 60 - 180 (plating – $\mathbf{f}_{max}$ = 50 mm, framing – $\mathbf{f}_{max}$ = 100 mm);
- deep dents with cracks and water leakage ($\mathbf{f}_{max}$ = 140 - 200 mm) in the forepeak in the area adjoining the stem.

In 1986, during the very first voyage in the eastern area of the Arctic, motorship *Kandalaksha* suffered heavy ice damages as a result of the rebound impact against a grounded hummock in shallow water (from 22 to 138 fr. over the bilge and the adjacent bottom strake there were bulges and longitudinal dents $\mathbf{f}$ = 100 - 200 mm with cracks). Motorship *Norilsk* also suffered serious ice damages in the eastern area while earlier, operating in the western area of the Arctic, it had no damages.

At the same time, on ships of the *SA-15* type during the period of their operation in the western part of the Arctic basin the number and sizes of ice damages and the expenses on the repair of hulls are, as a rule, several times as low at comparatively small permanent plating deflections with the exception of extensive (on all the ships) damages of bilge from the midship to aft and of side plating in the area of the propeller shaft projection the thickness of plates being insignificant – 13 mm (Table 6.1).

Table 6.1

Ice damages of ships of the *SA-15* type in the western area of the NSR

Name of ship	Damage area	Frame numbers	Type of damage	Permanent deflection, mm
Kola	Bottom	33, 20 - 60	Bulges	10 - 15
Tiksi	Bottom	10 - 60, 84 - 86, 109 - 110	Bulges	20
Nikel	Side, bilge Bottom, bilge	60 - 105 30 - 105	Bulges Separate bulges	10 - 25
Kandalaksha	Bilge Bilge, side	60 - 100 17 - 65	Bulges Separate bulges	17
Yury Arshenevsky	Bottom, bilge Side	99, 103 - 113, 100 - 124 25 - 35	Bulges Dents Bulges	10 - 15 40 - 55 9 - 12
Kapitan Danilkin	Bottom, bilge	163 - 180	Chain of dents	30

Numerous permanent sets of hull structures below the ice strake, most significant for ships having operated in the east of the NSR, show that ice loads of different intensity effect all the areas of the underwater part of hull of the ships navigating in the Arctic in the all-the-year-round and extended mode (notion "the ice strake" as the only zone of the application of ice loads under modern conditions of the operation of cargo ships in the Arctic should be certainly rejected). The choice of the category of ice strengthenings and design ice loads should be interrelated with the arctic area where the ship is intended to operate. Extent of ice damages of ships on the eastern sections of the NSR is much greater than, for instance, on the Dudinka line.

Differences in the frequency and sizes of ice damages of the same cargo ships during their operation in the western and eastern areas of the Arctic are first of all associated with considerably different ice conditions, more severe on eastern sections of the NSR.

Let us note the following particular conditions of the eastern area of the Arctic as compared with the western one:

- navigation only in summer and during extended periods (not all-the-year-round);
- higher (approximately 1.5 times) average thickness of the ice cover on the NSR (taking into account old ice);
- larger extent and thickness of the old ice (including pack) on some stretches of the route in ice reaching 100 %;
- practically total lack of the possibility to sail without the icebreaker support on several sections of the NSR;
- frequently repeated compactings in heavy ice due to the shearing of large ice masses defining the ice situation on route; to avoid compactings captains of icebreakers increase the speed of convoys this resulting in higher contact forces at the impact with ice.

Analysis of ice loads actually having affected the damaged areas by the permanent sets of plating and framing below the variable waterline caused by these loads [10, 11] has shown that they are commensurable with those which are set for the ice strake by the Russian Register Rule and provide for a satisfactory strength of structure of this part of hull of ships operating only in the western sections of the NSR. Judging from the results of the analysis, actual ice loads in the forebody area of ice strengthenings for bottom and bilge strakes (up to 0.25 **L**) was 90 - 100 % of the design loads for the area of variable waterlines. In the intermediate hull area (0.3 - 0.4 **L**), at the bilge level, actual loads amounted to 60 - 70 % of values determined by the Register Rules for the ice strake.

As a result of the assessment of ice forces by permanent deflections of frames of the midbody emerged after voyages of m/s *Monchegorsk* and m/s *Kola* through ice of the eastern area of the Arctic it was found that side grillages were subject to the effect of ice forces being 30 - 60 % above the loads specified by the MRS Rules for the ice strake framing of ships of the ULA category.

The heaviest ice damages of framing of ships of the *SA-15* type occurred during arctic navigations in the eastern section of the NSR (dents with deflection $\mathbf{f}_{\mathbf{max}}$ =200 mm in the forepeak and in the middle part of bilge) to a considerable extent are due to the insufficient stability relative to thin framing walls supporting the shell plating near dents. For ships navigating on the eastern sections of the NSR (in contrast to western ones) such damages are of the mass character, therefore for the improvement of the reliability of the operation of cargo ships in the eastern Arctic it is necessary to take supplementary measures (increase of thickness, number of supporting ribs, profile dimensions etc.) to ensure the flatness of walls under the impact of concentrated ice loads. Experience of the operation has shown that when supporting framing walls with ribs of rigidity (installed normally to the plating) the ratio of thickness of the supported area of the wall to distance between ribs should be not less than 0.025 [12].

The above differences of ice conditions and hence the damageability levels of hulls of cargo ships bear witness to the fact that requirements to ice strengthenings of hulls even for the ULA category of the Rules in force do not quite comply with the operational conditions of fleet in ice of the eastern area of the Arctic, much more severe as to the ice cover and strength of ice.

To reduce high damageability of cargo ships while working under conditions of the extended navigation in the east of the Arctic basin, more rigid requirements should be imposed to the hull strength (especially to bottom and bilge sections) as opposed to those specified by the MRS Rules for the ULA category including substantial increase of design loads on the plating below the belt of variable waterlines in the forebody transitional area, presetting of design loads on bilge and bottom strakes in the ship's midbody and stern and increase of the ice loads on the side framing amidships. These requirements should be based on the results of investigations published earlier [10, 11, 12, 13] as well as on those cited in the present work. Due to the change of the extent of requirements for the design loads relative to the ULA category of the MRS Rules it is advisable to specify an additional category of ice strengthenings of the hulls of ships designated to predominantly navigate under ice conditions of the eastern area of the Arctic and this will be especially topical in the transition to the all-the-year-round navigation over the entire length of the NSR.

The introduction of an additional category of ice strengthenings is advantageous economically this being proved by the amount of expenses on repair of hulls of ships of the *SA-15* type having operated in the Arctic: after the work on eastern lines these expenses are 3 - 5 times higher than on Dudinka and other lines of the western area.

6.2. Assessment of the sufficiency of icebreaking capability

The experience of the operation for 15 years of ships of the *SA-15* type in the Russian Arctic as well as work of these ships during the heaviest navigation of 1983 in the eastern area provide grounds of regarding their icebreaking capability and accordingly power as sufficient. With the use of the icebreaker assistance they quite satisfactorily comply with the capabilities of powerful nuclear icebreakers of the *Arktika* type, as it was shown above.

Forthe assessment of the efficient application of ships of the *SA-15* type independently navigating in arctic seas, along with the gained experience of their operation, data on the long-term work of the icebreaker fleet in the Arctic were also used. Fig.6.1 represents the relationship between the duration of navigation in the Arctic and the icebreaking capability of icebreakers escorting cargo ships through ice. Graphs in this figure were obtained proceeding from the prerequisite to ensure safe guaranteed sailing in the Arctic with due account of the possibility of carrying out operations on corresponding sections of the NSR under the heavy type of ice conditions which may have a frequency of once in four years.

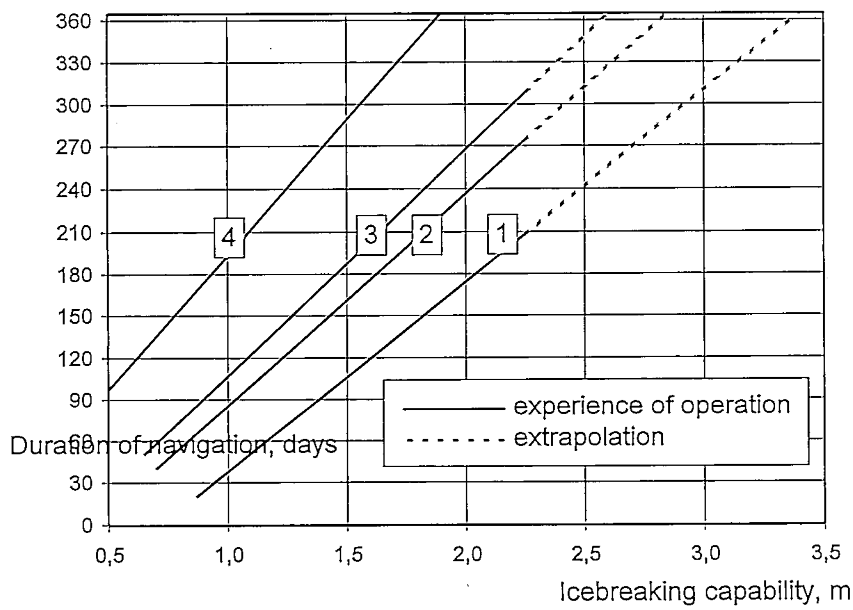

Fig.6.1. Relationship between the duration of navigational period in the Arctic and the icebreaking capability of icebreakers:

1 – transit navigation along the NSR and in the eastern area of the Arctic,
2 – western area of the Arctic,
3 – western part of the Kara Sea,
4 – Pechora Sea

Apparently the icebreaking cargo ship, while navigating independently, at the same icebreaking capability will be inferior to the icebreaker both in maneuverability in ice and during the work under conditions of ice compacting as well as in the capability of getting released out of sticking. This is explained by the fact that icebreakers have noticeably smaller length/width ratio, there is no parallel midbody and they are equipped with special heeling and trimming systems which provide for the release out of sticking. Nonetheless, making use of the relationships presented in Fig.6.1 and on the basis of the icebreaking capability of the *SA-15* ship equal to 1 m, one can evaluate the possibility of the independent navigation of these ships in different areas of the Arctic [14]. Proceeding from the above stated it is possible to expect that the *SA-15* ships are capable to ensure safe and efficient transportation of cargo without the icebreaker assistance approximately for one month during the transit sailing along the NSR and in the eastern part of the Arctic, for 2.5 months in the western area of the Arctic, for 3 months in the western part of the Kara Sea and for 6 months in the Pechora Sea.

CONCLUSION

Gathering, generalization and analysis of data on the experience of design and operation in the Arctic of modern multi-purpose icebreaking cargo ships of the *SA-15* type, ULA category of the Russian Marine Register of Shipping, permit drawing the following principal conclusion on the efficiency and compliance of these ships with navigational conditions in ice of arctic seas washing the Russian Federation.

Ice performance of ships of the *SA-15* type meet the requirements of their efficiency to operate in ice under the support of powerful nuclear icebreakers all the year round in the western part of the Russian Arctic and during the traditional period of the summer navigation in the eastern area thereof. These ships possess the satisfactory ice propulsion and dimensions matching the ability of nuclear icebreakers of the *Arktika* type and the sufficient ice strength for navigation under the above conditions. At the same time, bearing in mind the future of the development of cargo traffic in the Arctic on new high latitude routes and during the extended, up to the year round, periods of navigation on traditional routes in the eastern area, the construction of icebreaking ships of the new generation mainly characterized (if compared with the existing ULA ships) by a higher category of hull ice strengthenings will be required. CNIIMF has prepared technical and operational requirements for such ships including recommendations on the hull structure and ice strength. Taking into consideration the international IACS requirements being now developed and the IMO Code on ships navigating in polar waters, new icebreaking cargo ships will have to be of at least PC4 polar class to ensure safe and efficient work under the assistance of powerful icebreakers all the year round over the entire length of the Northern Sea Route.

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ANNEX

Table A.1

List of ships of the *SA-15* type

1	Name	Year of construction	Shipowner
1	*Norilsk*	1982	MSCO
2	*Nizhneyansk*	1983	FESCO
3	*Igarka*	1983	FESCO
4	*Tiksi*	1983	MSCO
5	*Okha*	1983	SakhSCO[1]
6	*Monchegorsk*	1983	MSCO
7	*Arkhangelsk*	1983	MSCO
8	*Bratsk*	1983	FESCO
9	*Kola*	1983	MSCO
10	*Amderma*	1983	FESCO
11	*Kemerovo*	1983	SakhSCO
12	*Kandalaksha*	1984	MSCO
13	*Nikel*	1984	MSCO
14	*Anadyr*	1984	FESCO
15	*Anatoly Kolesnichenko*	1985	FESCO
16	*Kapitan Man*	1985	FESCO
17	*Yury Arshenevsky*	1986	MSCO
18	*Vasily Burkhanov*	1986	FESCO
19	*Kapitan Danilkin*	1987	MSCO

[1] Sakhalin Shipping Company

Table A.2

Principal characteristics of icebreakers

Characteristics	*Arktika*	*Moskva*
Length, m		
• overall	148	122.1
• on design waterline	136	112.4
Breadth, m		
• overall	30	24.5
• on design waterline	28	23.5
Draft, m		
• maximum	11	10.5
• design	11	9.5
Depth, m	17.2	14
Design displacement, t	23460	13290
Open water speed, kn	20.8	18.3
Icebreaking capability at 2 kn, m	2.25	1.45
Type of propulsion plant	Nuclear	Diesel-electric
Type of power transmission	Electric	Electric
Total shaft power, kW	49000	16200
Total bollard pull, kN	4700	2200
Power distribution by shafts	1 : 1 : 1	1 : 2 : 1
Type of propeller	FPP	FPP
Number of propellers	3	3

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20 June 1998

REVIEW OF THE INSROP PAPER BOX B/WP5 -"COLLECTION OF SA-15 OPERATIONS DATA"

Mr. Claes Ragner
Deputy Head, INSROP Secretariat
The Fridtjof Nansen Institute
P.O. Box 326
N-1324 Lysaker NORWAY

Dear Claes,

I have thoroughly reviewed this report regarding the SA-15 multipurpose cargo ship and found it comprehensive and highly informative. The data presented - in particular the ice performance of the class, summary of ice damage, and actual voyage scenarios -are very relevant and valuable to INSROP. The SA-15's are (together with the Canadian M/V ARCTIC) in many respects "prototype" icebreaking cargo ships and this report provides a frank assessment of operational performance and a history of hull damage. I found the voyage reports of the SA-15 captains (4.2) very useful in understanding the problems of transits taken early in the navigation season.

Here are several comments for the authors:

(1) The translation into English is generally fine. It will be imporved by the INSROP process.

(2) References- The English titles of the papers should be provided as well as the English translations of the journal/book titles.

(3) Page 5, paragraph 2 - resistent should be low friction INERTA-160 paint.

(4) Page 56, Figure 4.2 - In the caption it would be useful to know the limits/boundaries of "Easy, Medium and Heavy navigational conditions"......brief definitions would be helpful.

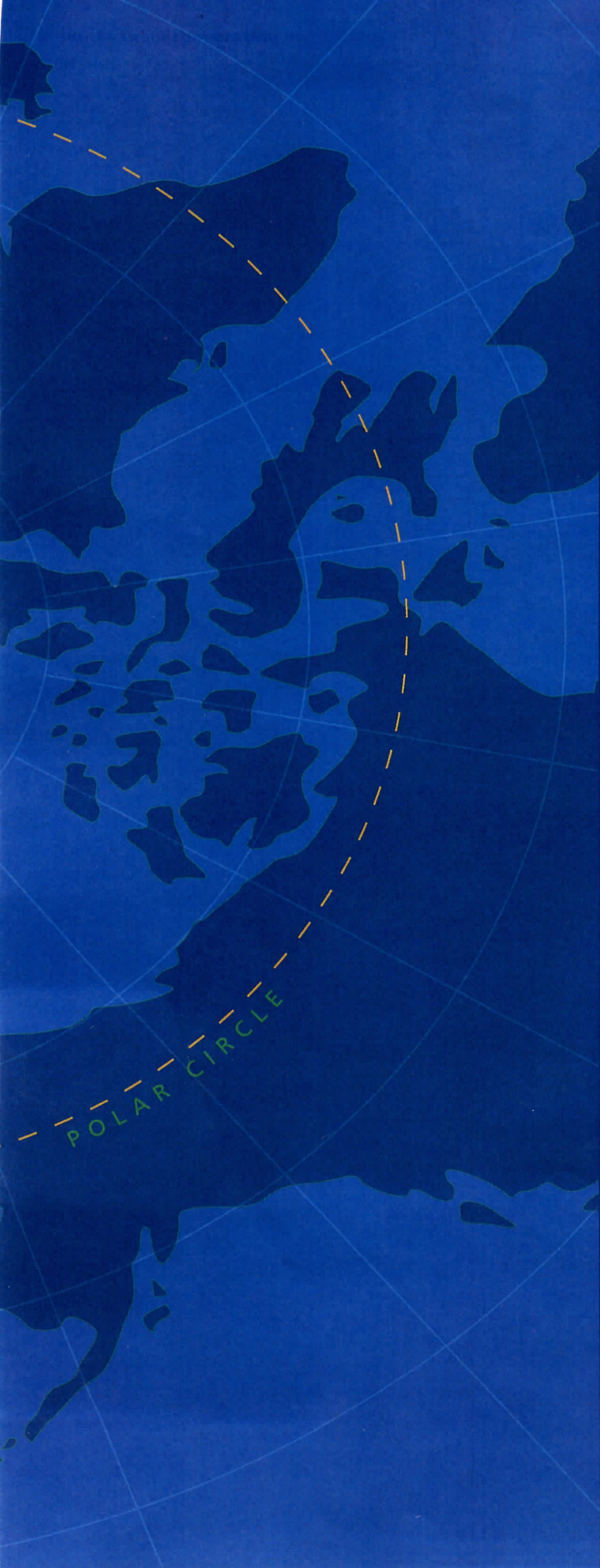
(5) Tables 4.5 to 4.9 - "Drift in the expectation of icebreaker" should read "Drift awaiting icebreaker assistance"

(6) Page 76, second line - "With compactings up to 2"....unknown meaning.....is this ice pressure or ice compression and what is the relative scale?

I recommend publishing the report following a thorough editing of the English and inclusion of the above changes, where possible. This report contains solid, practical information on ice navigation.

Respectfully,

Lawson W. Brigham
Captain, U.S. Coast Guard (Retired)
Scott Polar Research Institute



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.