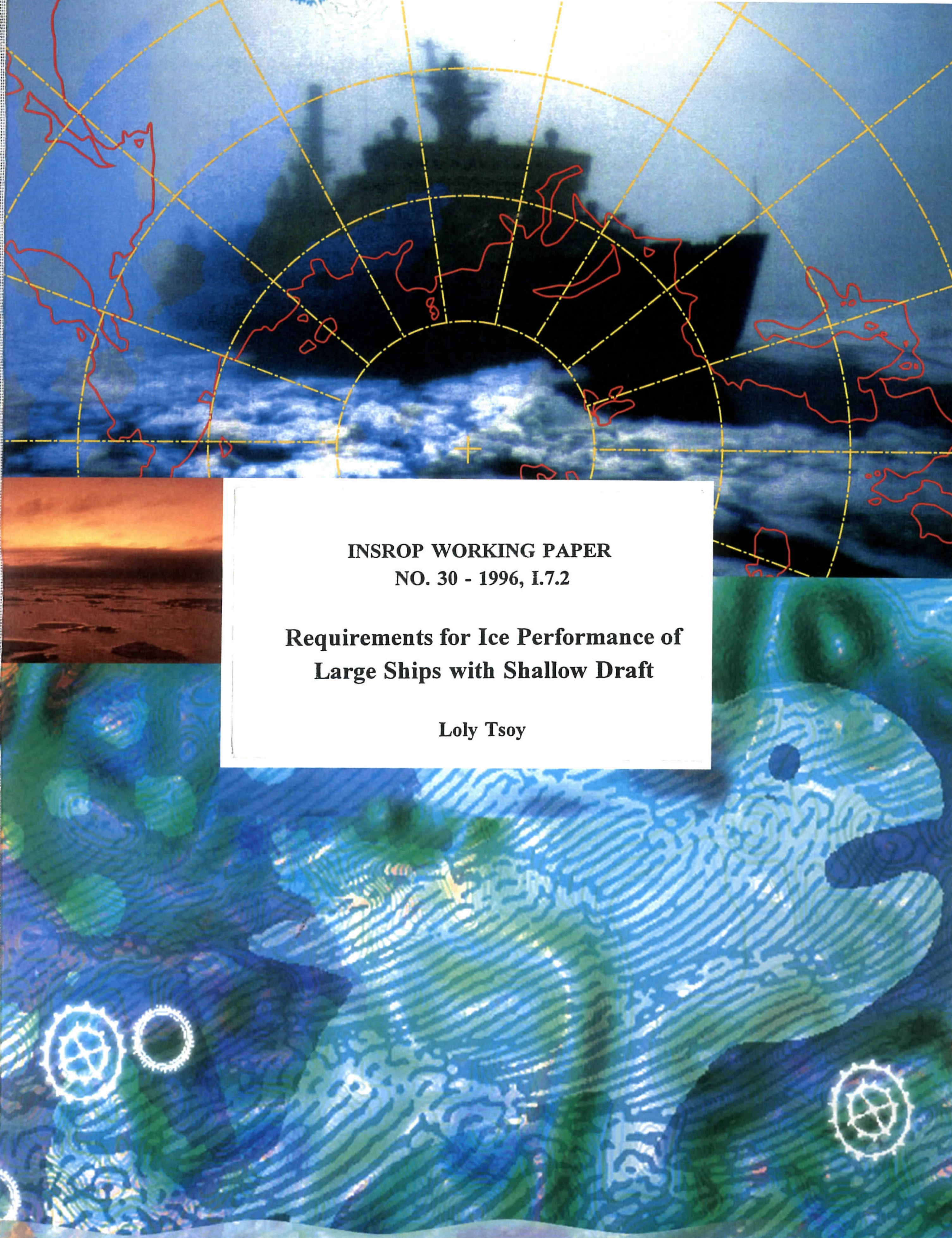

INSROP WORKING PAPER
NO. 30 - 1996, I.7.2

Requirements for Ice Performance of Large Ships with Shallow Draft

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Sub-programme I: Natural Conditions and Ice Navigation.

Project I.7.2: Requirements for Ice Performance of Large Ships with Shallow Draft (1994 project work).

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Date: 22 January 1996.

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

FOREWORD - INSROP WORKING PAPER

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

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

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

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

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GENERAL

The purpose of this work was to investigate the effect of a shallow draft of ship and shallow water on ice performance of large ice ships. The necessity to construct such ships results from the perspectives of the development of shipping in the Arctic and in particular from the necessity of the transportation by sea of hydrocarbons out of Arctic shelf areas.

A distinctive feature of the Russian Arctic is the vast shallow along the Northern Sea Route, which necessitates strict draft requirements to transport ships and icebreakers for arctic navigation. To increase the cargo-carrying capacity of ships intended for the export of raw materials from the Arctic, non-traditional ratios of their dimensions will be required which may unfavourably affect the ship's icebreaking capability. At the same time up to the present no special investigations have been made to explore the effect of the shallow water and of a large breadth/draft ratio on the ice performance of ships.

Within the scope of this Project accomplished in accordance with the plan of investigations for 1994 the effect of a breadth/draft ratio on the icebreaking capability was considered on the basis of systematic model trials and full-scale data. The influence of the shallow water on the characteristics of a propulsion system was evaluated and an under-keel clearance, minimum from the point of view of the safety of navigation and the effectiveness of operation, determined.

The results obtained may be used for the development of recommendations on the account of the effect of draft restrictions upon the ice performance of shallow-draft ships in their design as well as for the evaluation of economic efficiency to use large shallow-draft ships in the Arctic.

Author is deeply thankful to the reviewer, Kimmo Juurmaa, Manager of the Arctic Research and Development from the Kvaerner Masa-Yards Technology of Helsinki, Finland, for the detailed and thorough review of the report on Project I.7.2 (review and author's comments on it are attached). One should agree that the subject broached is a complex one and the investigations in the directions defined by the reviewer should be further developed. Unfortunately the program of works for 1995 - 1996 does not envisage the continuation of the research pertaining to Project I.7.2.

SUMMARY

Summarized and analysed are the results of experimental investigations of the influence of the small draft of large ice ships on the hull form and icebreaking capability. Evaluation is given of the dependence of the power efficiently processed by propellers upon the ship's draft. The effect of the small under-keel clearance on the propulsive performance, ice propulsion and safety of ships navigating in shallow water has been considered. Recommendations are formulated on taking into account the effect of the draft restriction on ice performance of ships in their design. At the same time, the conclusions drawn should be considered as preliminary ones. Requirements for ice qualities of shallow-draft ships should be made more accurate in each particular case depending on purpose and operational conditions of ship.

KEY WORDS

ICEBREAKING SHIP, HULL SHAPE, ICE PERFORMANCE, ICEBREAKING CAPABILITY, SMALL DRAFT, SHALLOW WATER, MODEL TESTS, FULL-SCALE TESTS, PROPULSIVE PERFORMANCE.

CONTENTS

INTRODUCTION

Perspectives of the development of cargo traffic along the Northern Sea Route, especially in connection with the export of raw materials (oil, natural gas, ore etc.), from the arctic shelf of Russia, predetermine the construction of large ice transport vessels. At the same time, taking into consideration the existence of shallow water in the Russian Arctic there will be a need for the construction of these ships with unusual ratios of main dimensions, in particular with a large breadth/draft ratio. This necessitates the carrying out of special investigations to find out the effect of a restricted draft on the ice properties of ships.

The present report contains the results of the research made within the scope of the INSROP Programme on the influence of a small draft of large ice ships upon their hull shape and icebreaking capability. Consideration was given also to the effect of a small under-keel clearance on the propulsion characteristics, ice propulsion and safety of ships navigating in shallow waters.

These results will allow to assess both the safety to use in the Arctic large shallow-draft ships and the efficiency of their operation under ice conditions. Accordingly recommendations were formulated on taking into account the influence of draft restrictions upon ice qualities of ships for their design.

1. INVESTIGATION OF THE EFFECT OF SHALLOW DRAFT UPON THE ICEBREAKING CAPABILITY OF SHIPS

1.1. Comparative assessment criteria of the ice propulsion of ships

In the practice of icebreaker building, a maximum thickness of level compact ice broken by the ship in continuous movement is taken as a principal criterion characterizing the ice propulsion of a ship, bending strength of ice and continuous speed of movement being specified. As a rule, speed equal to 1.5-2.0 kn is taken as a minimum continuous one.

The principal criterion defining the capability of an icebreaker to move through level compact ice at a minimum continuous speed is expressed by the term "icebreaking capability" generally adopted among shipbuilders and operators.

It is apparent that the icebreaking capability though being a reliable characteristic for the comparison of icebreaking properties of ships, does not give exhaustive information on the ice propulsion of a ship within the whole range of ice thicknesses: from zero (movement in clear water) up to a maximum thickness, when the icebreaker is forced to break through ice by ramming [1].

It is really possible to build two icebreakers with the same icebreaking capability, but with different speeds at lower ice thicknesses (at maximum power) as illustrated by graph in fig. 1.1. As one can see from this graph, an icebreaker with ice propulsion diagram $N = f(h)$ limited from the top by curve 2, will be appreciably inferior in operation than icebreakers with the diagram limited from the top by curve 1 despite the equality of value h_i. While assuming the linearity of the relationship $V = f(h)$ it is sufficient to know along with h_i also the speed V_0 in clear water in order to obtain information on the ice propulsion of the ship.

Accordingly, bearing in mind the above stated, consideration is given to the effect of the restricted draft on the speed of movement in clear water and on the icebreaking capability of ships.

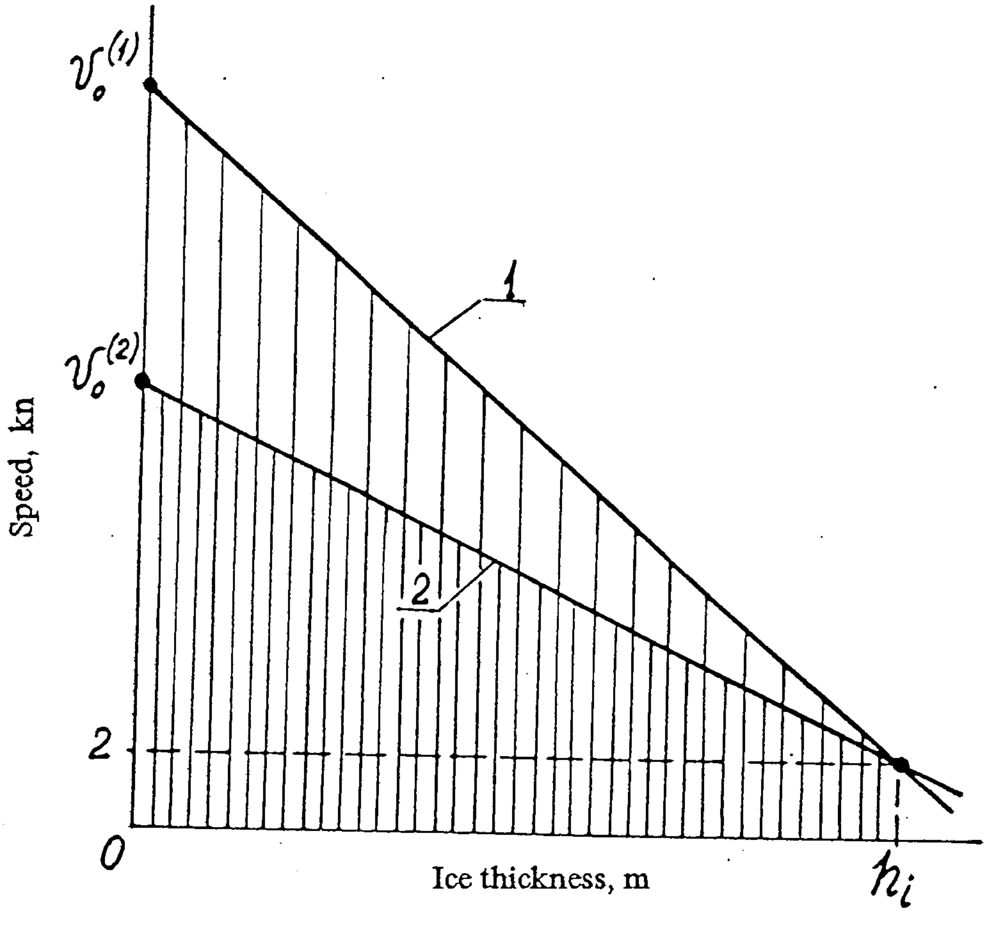


Fig. 1.1. Relationship between the speed of an icebreaking ship and the thickness of ice to be broken through (ice propulsion diagram)

1.2. Assessment of the influence of draft on the efficiently processed power

Experience of construction and operation of domestic icebreakers shows that the maximum power which may be efficiently (without aeration and cavitation) processed by propellers depends on propeller diameter and consequently on ship's draft [2, 3, 4].

For the estimation of a limiting value of the efficiently processed power depending on the ship's draft and diameter of propeller the empirical formula of V.A.Belyashev (Krylov Institute) as applied to ice propellers may be used:

$$N_{cr} = 50.5\, d^2 \{[10.1 + d\,(T/d - \delta/d - 0.5)] / [2.85 - 0.2\, A/A_d + 0.25\, H/d]\ A/A_d\}^{3/2}, \text{ kW}$$

where:

d - propeller's diameter, m;
T - vessel's draught, m;
δ/d - relative thickness of blade which is equal to 0.06 for ice propeller;
A/A_d - blade-area ratio which is equal to 0.75-0.85 for ice propeller;
H/d - pitch ratio which is equal to 0.8 for ice propeller.

Fig.1.2 shows the relationships obtained by this formula between the critical value of power (N_{cr}) and the draft and the relative propeller diameter of the icebreaking ship with a three-shaft plant. Also here data on shaft power of *Taimyr* and *Arktika* type icebreakers are given.

As one can see from the plot, with the decrease of ship's draft the critical value of power is considerably reduced. Taking into account the necessary diminution of the ice/propeller interaction, maximum admissible diameter of side propellers should not exceed 0.6 of the ship's draft. These restrictive conditions concerning power and propeller diameter in its turn, impose substantial limitations on achievable icebreaking capability of shallow-draft ships. To increase the icebreaking capability it is necessary to further improve the ship's hull shape.

Corresponding difficulties arise ensuring maximum speeds in clear water. At the same time, the experience of the design of ships with traditional icebreaking form of lines shows that with the decrease of draft the hydrodynamic pattern of flow around hull occurs not so much along water lines as along buttocks. As a result the decrease of draft favourably affects the reduction of water resistance to the movement and the increase of speed.

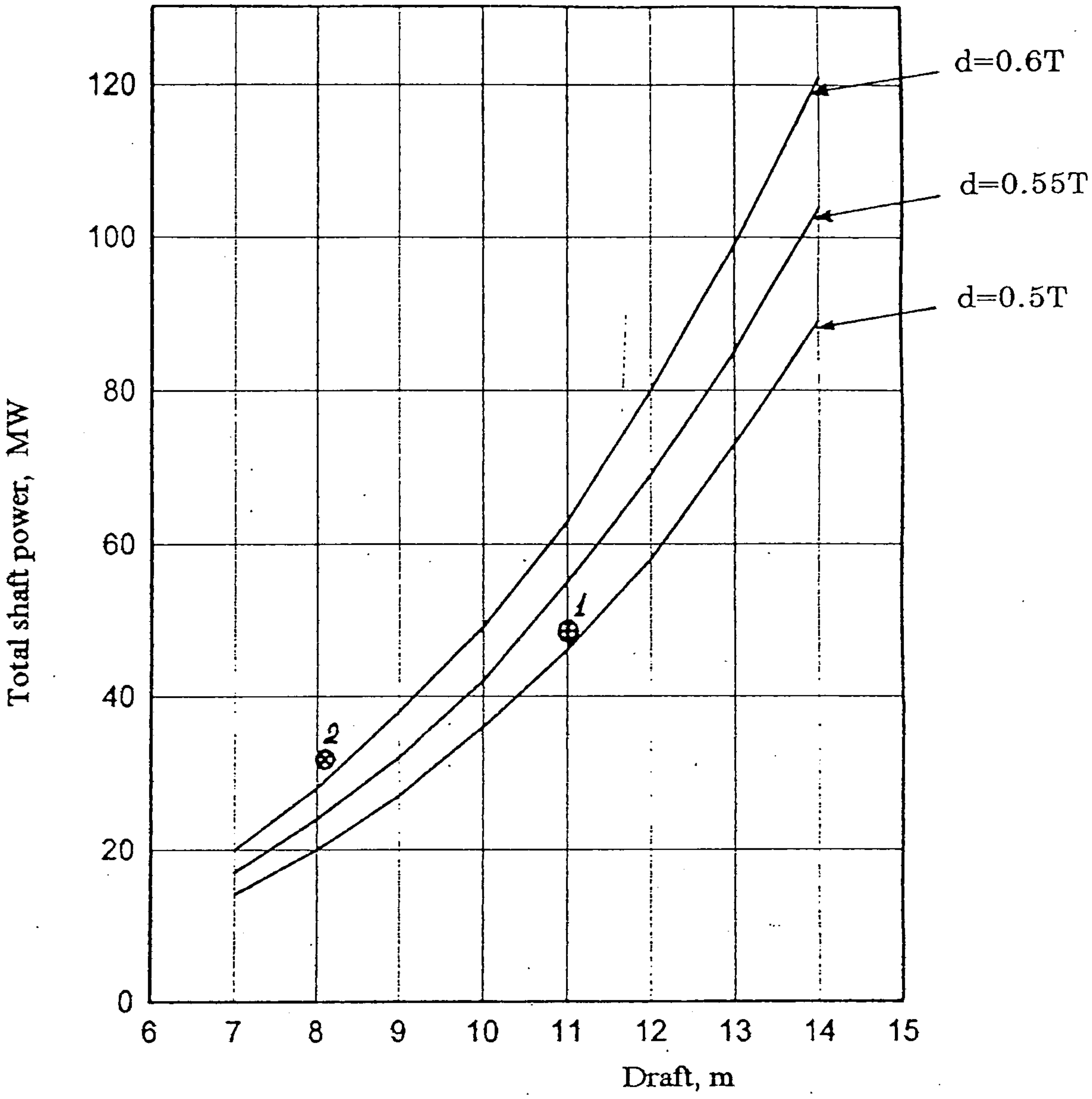


Fig. 1.2. Relationship between the power efficiently processed by the propellers, ship's draft and the relative diameter of the propeller.
1 - icebreaker *Arktika*; 2 - icebreaker *Taimyr*

Empirical formula for the determination of achievable speed of icebreaking ships [5] is given below:

$$V_o = 2.55\ (N_p)^{1/7.3}\,(L/T)^{1/5}\,(\delta)^{-1/6}\,, \qquad \text{(knots)}$$

where:

N_p - shafts horsepower, kW
L - length on CWL, m
T - CWL draught, m
δ - hull block coefficient.

As one can see from the formula which gives fairly reliable results, other conditions being equal, the reduction of draft contributes to the increase of speed in clear water. This to a certain extent permits to make up for power restrictions of shallow-draft ships.

1.3. Results of tests in the ice basin of icebreaker models with different breadth

The absence until recently of systematic investigations on the effect of the hull form characteristics and the dimension ratios of icebreaking ships upon the ice propulsion did not permit to distinguish the most important factors concerning the ice resistance, making it very difficult to choose the most appropriate lines and dimensions for newly designed icebreakers. Icebreaker design with the use of prototypes and also of separate non-systematic model tests does not guarantee that the best possible technical solutions will be chosen. Besides, without knowledge of the significance of each separate factor it is impossible to further improve analytical methods of the calculation of ship's ice propulsion.

Taking into account the above stated, in the model ice basin of the AARI, to order of CNIIMF, comparative tests of models were carried out, each model being different in the shape of hull lines and principal dimensions. The main task consisted in the construction of a series of models differing only in one of the lines shape or principal dimensions parameters keeping other values unchanged. Reference model in relation to which the investigated parameters were changed was that of the icebreaker of *Moskva* type. Study of the effect of principal dimensions was made in scale 1:70. Main characteristics of the different hull breadth models tested, are shown in table 1.1. Principal dimensions here correspond to those on design waterline.

Table 1.1

Main model characteristics of the icebreaker with different breadth

Characteristics	Versions		
	B_1	B_2	B_3
Length L, m	1.61	1.61	1.61
Breadth B, m	0.34	0.28	0.22
Draft T, m	0.14	0.14	0.14
Displacement D, kg	37.0	33.2	27.8
Block coefficient δ	0.508	0.535	0.568
Angle of bow rake φ, deg	26	26	26
Design water line entrance angle α_0, deg	24	24	24
Side flare angles, deg			
at frame line No. 0, β_0	40	40	40
at frame line No. 2, β_2	40	40	40
at frame line No. 4, β_4	28	28	28
at middle frame line, β_{10}	18	18	18

Tests carried out according to methods of the AARI were of towing character in the level compact ice corresponding to a full-scale thickness of 1.2 m at constant thrust [6]. Model speeds in ice changed within the range of 0.1-0.5 m/s. The results of the obtained experimental data were represented in the form of model full ice resistance / speed relations $R_i = f(V)$.

Fig.1.3 shows the influence of the hull breadth. As one can see, the hull breadth appreciably affects the ice resistance. It proved the results of investigations known earlier. As follows from the relationships obtained, when the icebreaker breadth changes within 16% the ice resistance changes proportionally with the hull breadth. With more substantial hull breadth changes the resistance changes to a lesser extent. From the results of present tests the reduction of the icebreaker hull breadth by 30% resulted in the reduction of ice resistance by 20%. Such ambiguous influence of the hull breadth may be attributed to difference in the hull/ice interaction obtained during tests. The observations show that in the first case there was a double-lane breakage of ice and in the second - single-lane breakage. It should be also noted that considerable change of the icebreaker breadth at a constant draft leads to a substantial change of the breadth/draft ratio B/T which inevitably has an effect on the geometry of bow lines even if the frame inclination angle to the design water line is kept unchanged.

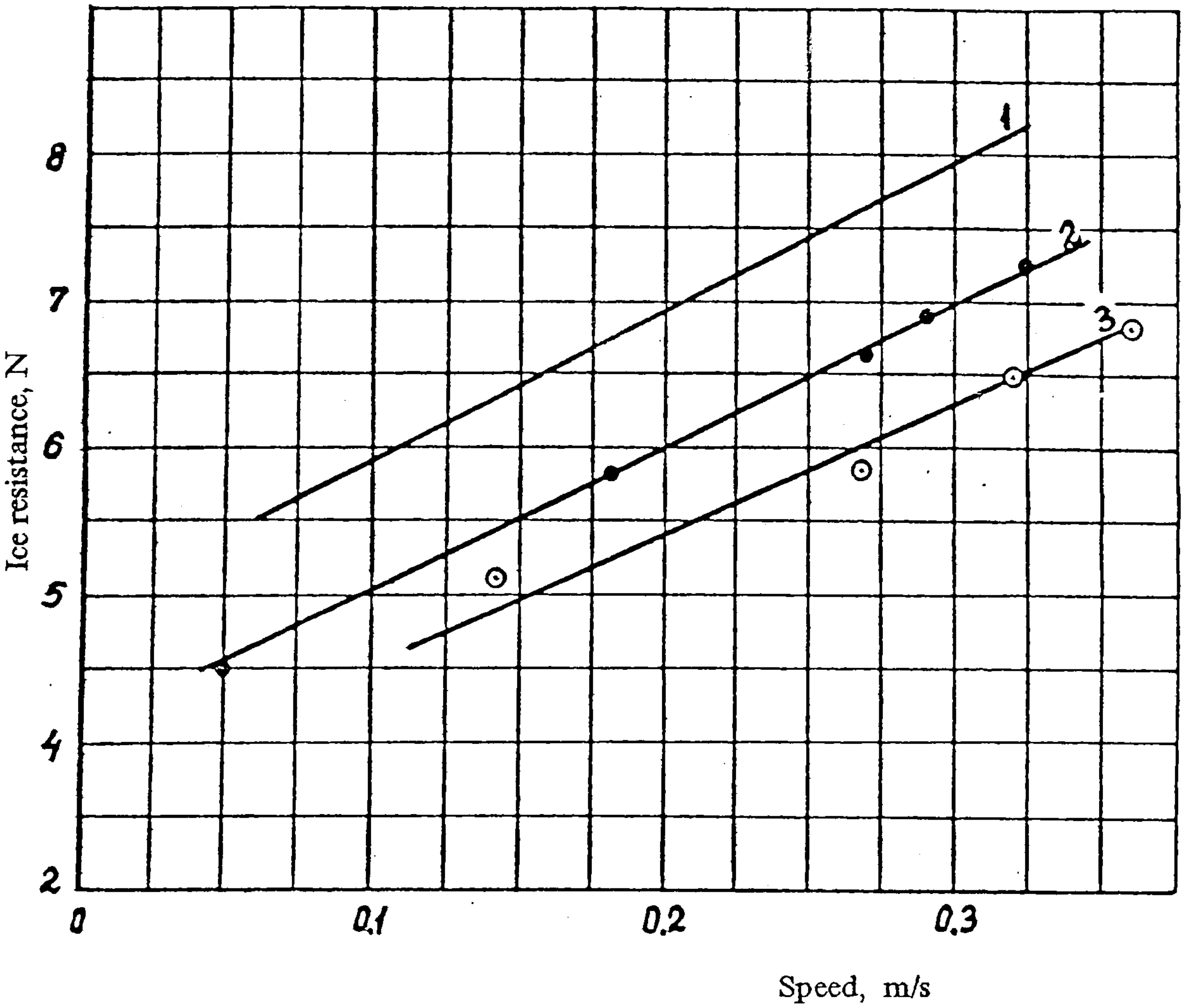


Fig. 1.3. Ice resistance of icebreaker models with different hull breadth:
1 - version B_1; 2 - version B_2; 3 - version B_3

An attempt was made simultaneously to assess the effect of draft on the icebreaking capability of icebreaker. Change of the ice resistance was checked up by the model of the icebreaker *Moskva* with maximum and minimum possible drafts at which the hull lines' shape in the water line area practically did not change. Results of these tests are presented in fig.1.4 from which one can see that in this case the change of draft had no effect on value of the ice resistance. It should be borne in mind, however, that during this experiment, with the draft change, icebreaker breadth and length also underwent changes.

1.4. Results of tests in the ice basin of icebreaking cargo ship models with different draft

To investigate the effect of the hull shape and principal dimensions ratios on the ice propulsion of icebreaking and cargo ships a series of models has been developed in CNIIMF and then tested in the ice basin of AARI these models being distinguished by systematic change of angle bow rake φ, design water line entrance angle $\alpha_{O.}$, main frame side inclination angle β_{10}, ship's length/breadth ratio L/B and breadth / draft ratio B/T [7]. Total number of models of this series was 17. In the development of the series, a 15000 DWT modern ship of *SA-15* ULA class built by A/O "Wartsila Marine" was taken as an original version of the hull lines' form of an icebreaking cargo ship. The power of the propulsion plant (PP) of the ship is 15.4 MW, icebreaking capability - 1 m, speed in clear water - 18.1 knots.

When line drawings of ships were constructed and agreed, use was made of the technique which enables to produce line drawings by the computer [8]. The after end form parameters of the series of ships were not specially varied.

The salient feature of the considered series was the length equal to 3.2 m taken the same for all models. Based on the above, the ship's breadth/draft ratio B/T was altered due to the change of draft T, the length/breadth ratio L/B being the same.

Characteristics of models of different B/T ratio are given in table 1.2.

Models in the ice basin were tested in the level compact ice of different thickness h at a constant towing force equal on a scale 1 : 50 to the propeller thrust of the *SA-15* ship being in full-scale 1400 kN.

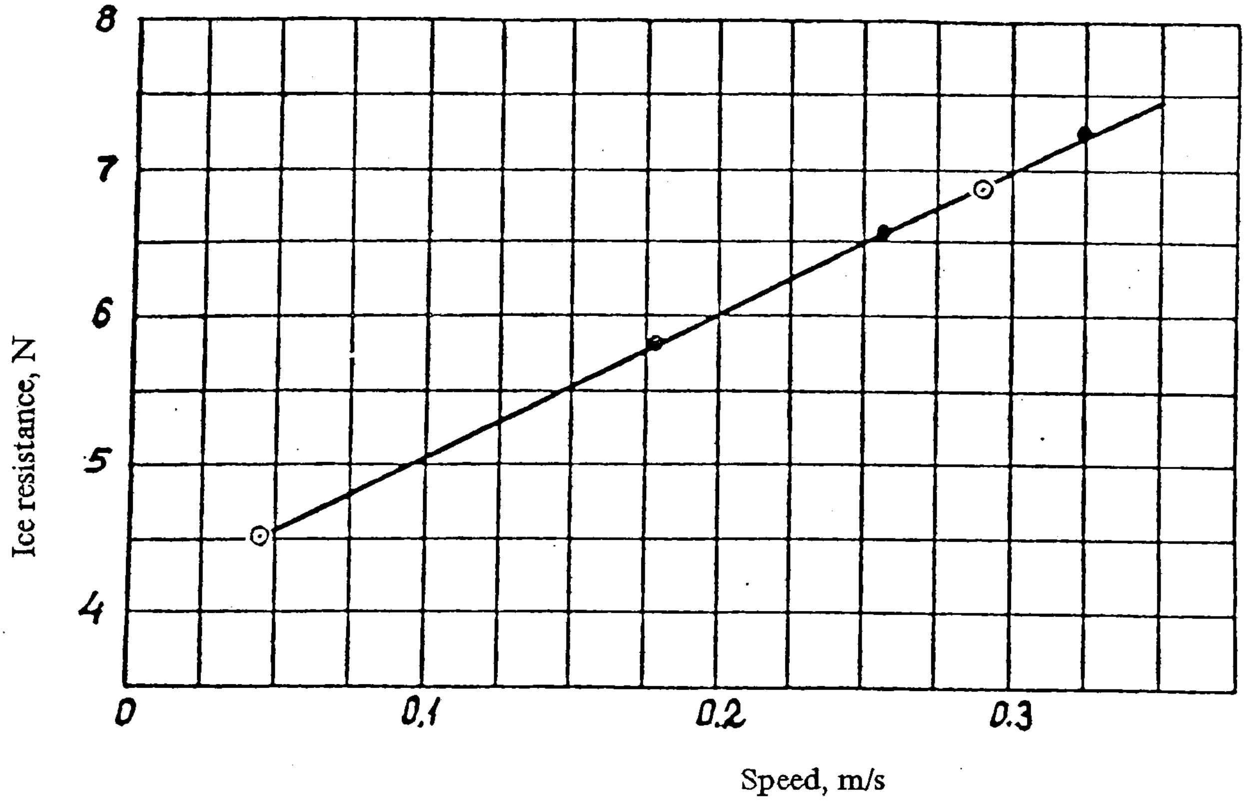


Fig. 1.4. Ice resistance of icebreaker models with different draft:

● ● ● - T = 0.08 m
o o o - T = 0.14 m

Table 1.2

Models of the icebreaking cargo series with different draft

No.	L, m	B, m	T, m	L/B	B/T	φ, deg	α_o, deg	β_o, deg	β_{10}, deg	δ
1	3.2	0.492	0.197	6.5	2.5	30	30	41	7	0.657
2	3.2	0.492	0.164	6.5	3.0	30	30	45	7	0.664
3	3.2	0.492	0.141	6.5	3.5	30	30	55	7	0.674
4	3.2	0.492	0.098	6.5	5.0	30	30	45	7	0.666

The obtained change of the icebreaking capability of models depending on B/T is shown in fig.1.5. In the process of the experiment, variations of B/T were attained by changes of draft with model breadth remaining constant. It may be seen from fig.1.5 that the relative breadth affects materially the ice propulsion. The increase of B/T at the expense of draft reduction results in the reduction of ice resistance and accordingly in the increase of ship's icebreaking capability. Earlier investigations showed that ship's draft did not practically affect the ice resistance. However, experiments were performed with one model changing its draft by ballasting within the limits ensuring the maintenance of lines' shape between extreme water lines. In this case a new line drawing was constructed for each of the varying drafts and though the angle of bow rake and design water line entrance angle remained constant and equal to 30°, the forebody frame flare noticeably changed and increased with the increase of B/T. That affected favourably the decrease of ice resistance. Consequently, when the B/T ratio is increased only at the expense of breadth (at constant draft) the adverse effect of breadth on the icebreaking capability may be also compensated by the positive influence of greater side flare near the entrance. The result obtained makes it possible to come to the conclusion that a forced increase of ship's breadth with draft restrictions for the purpose of increasing its cargo-carrying capacity may lead to the selection of more rational hull bow lines in relation to the reduction of ice resistance.

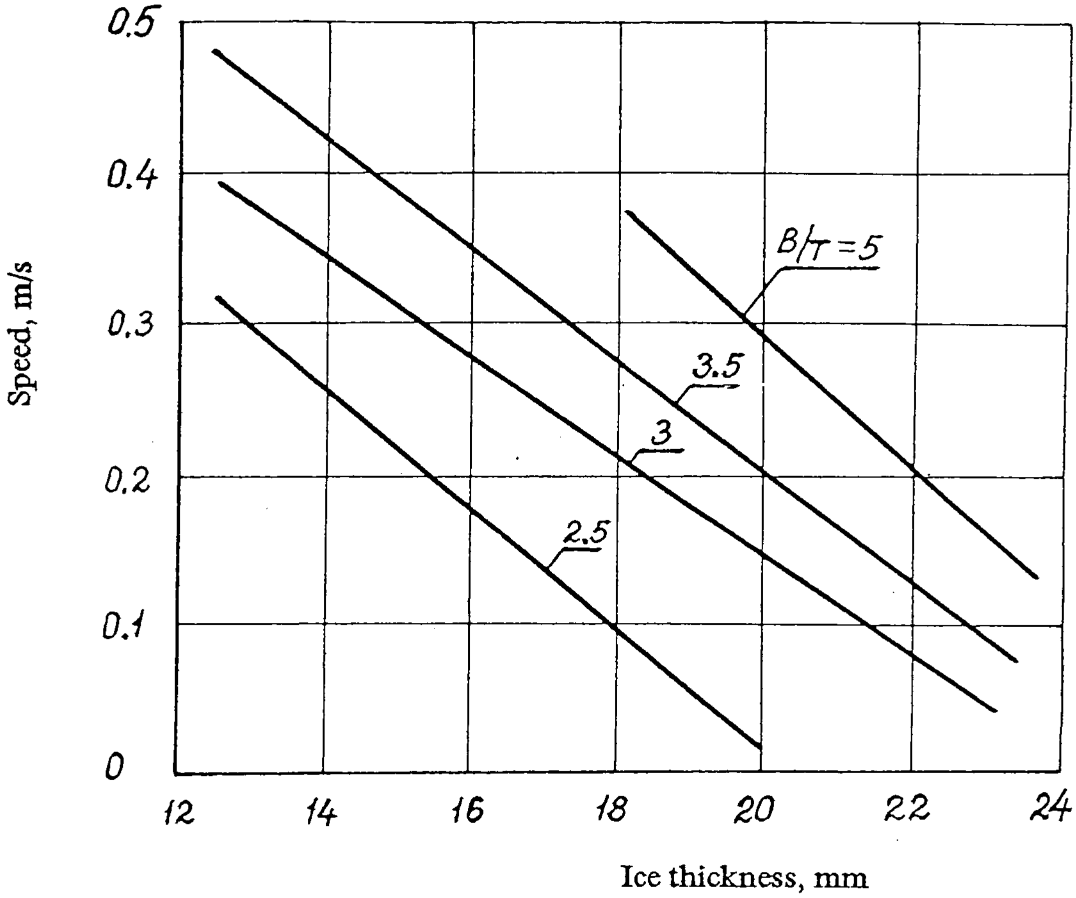


Fig. 1.5. Relationship between the model towing speed with different B / T values and ice thickness

2. INVESTIGATION OF THE EFFECT OF SHALLOW WATER ON ICE PROPULSION OF SHIPS

When ships sail in conditions of shallow water, from the point of view of safety of navigation, it is necessary to consider minimum possible under-keel clearance. Besides, while moving in shallow water the propeller thrust loss and reduction of the icebreaking capability should be taken into account. Shallow water also adversely affects the longevity of stern tubes, and the reliability of work of the ship's power plant cooling system.

These factors are considered below and their significance has been assessed by particular numerical examples.

2.1. Evaluation of a minimum admissible under-keel clearance while sailing in clear water and in ice

According to the Codes of the Technological Design of Seaway Channels the total navigational under-keel clearance of a ship should be no less than a value determined by the formula [9]:

$$Z = Z_0 + Z_1 + Z_2 + Z_3 \;, \qquad \text{(m)}$$

where:

Z_0 - margin for roll of the ship due to its asymmetrical loading or sharp putting of the helm, m;

Z_1 - minimum navigational clearance required to provide the steerability of the ship, m;

Z_2 - wave margin in the immersion of ship's end in the seas, m;

Z_3 - speed margin in changing the trim on the move in calm water as compared to the trim at standstill, m.

Margin for roll of the ship Z_0 is determined by the formula:

$$Z_0 = 0.5\,B \;\; \mathrm{Sin}\;(\Theta + \Theta_d)\,, \qquad \text{(m)}$$

where:

B - breadth of ship, m;

Θ - rolling angle induced by wind, deg.;

Θ_d - dynamic rolling angle, deg.

For gas-carriers the rolling angle Θ at a wind relative bearing from 60° to 90° and its speed up to 20 m/s is taken as 1°. At a calculated wind speed of 22 m/s and over $\Theta = 2°$.

Dynamic rolling angle in the no-wind condition for all ships of the above types at a movement speed up to 10 knots is taken equal to 1°.

The minimum navigational clearance Z_1 is determined depending on the ship's draft T and the type of bottom. For alluvial bottom (sand, shells, gravel) $Z_1 = 0.05$ T, for rocky bottom, boulders etc. $Z_1 = 0.07$ T.

Wave margin Z_2 is determined depending on wave height, direction of seas, ship's length L and the Froude number ($Fr = V / \sqrt{gL}$). Table 2.1 shows the wave margin value for ships 200-400 m long at a Froude number about 0.1 (which corresponds to a movement speed of 9-12 knots) depending on the wave height of 3% probability.

Table 2.1

Wave margin at Fr = 0.1 in the system of waves of the most dangerous direction

Ship's length, m	Wave height, m			
	1.0	2.0	3.0	4.0
200	0.10	0.35	0.75	1.15
250	0.05	0.25	0.65	1.05
300	0	0.20	0.50	0.90
350	0	0.15	0.40	0.80
400	0	0.10	0.35	0.70

In fore-and-aft directions of the seas in relation to the general course of the ship's movement the wave margin Z_2 decreases approximately twice.

The speed margin Z_3 is determined using the method of successive approximations depending on the sum $Z_{1-3} = Z_1 + Z_2 + Z_3$, the Froude number and draft of the ship.

For large ships at speed up to 10 knots ($Fr \approx 0.1$) the speed margin is within 0.3-0.5 m depending on the draft.

Table 2.2 represents the results of calculation of the necessary total navigational under-keel clearance as applied to a shallow-draft tanker 250 m long and 40 m wide. The tanker's draft was varied within 9-13 m with due account of eventual restrictions in the Arctic.

Table 2.2

Total navigational under-keel clearance of a large shallow-draft tanker at drafts 9, 11 and 13 m

Draft, m	Z_0, m	Z_1, m	Z_2, m	Z_3, m	Z_{0-3}, m
9	0.35	0.45	0.38	0.2	1.38
11	0.35	0.55	0.38	0.22	1.50
13	0.35	0.65	0.38	0.24	1.62

The calculation was made for the following reference conditions:

- bottom near the shelf of arctic seas is alluvial (sand, shells, gravel);
- ship's speed at minimum depth - 8 knots;
- wave height in coastal areas does not exceed 3 m in consideration of the possibility of manoeuvring the ship in the seas and keeping it on wave-to-course angles.

Thus, as calculations have shown, the minimum navigational under-keel clearance for large ships according to the Codes of the Technological Design of Seaway Channels may be 1.4-1.5 m. Besides the determination of maximum admissible draft of the ship intended for sailing in certain areas of the Arctic, a small under-keel clearance causes additional difficulties in the design of shallow-draft icebreaking ships to ensure the reliability and safety of work in ice. Special attention should be paid to problems of the design of the propulsion system, stern tubes, power plant sea water cooling system.

In order to determine a margin for trim of the icebreaker in operation in compact ice the analysis of the test data of the Krylov Institute, CNIIMF and AARI which were gathered during full-scale and model tests of various icebreakers has been made. The analysis has shown that the movement of the icebreaker in compact ice is of a cyclic pattern and is accompanied by the periodical crawling of the forward end over ice and its falling through with the destruction of ice cover. The periodical submersion of stern accordingly occurs, this submersion being 2-3 times less than the crawling of the forward end over the ice. On the average, the icebreaker's trim by the stern is practically commensurable with the thickness of the surmounted level ice. Thus, the icebreaker *Arktika* in the movement through ice of a thickness of 2.3 m, maximum for this icebreaker, will have a trim by the stern of about 1° which corresponds to 2.4-2.5 m. Fig.2.1 shows an experimental relationship between the trim by the stern and the thickness of level compact ice for the icebreaker *Arktika*.

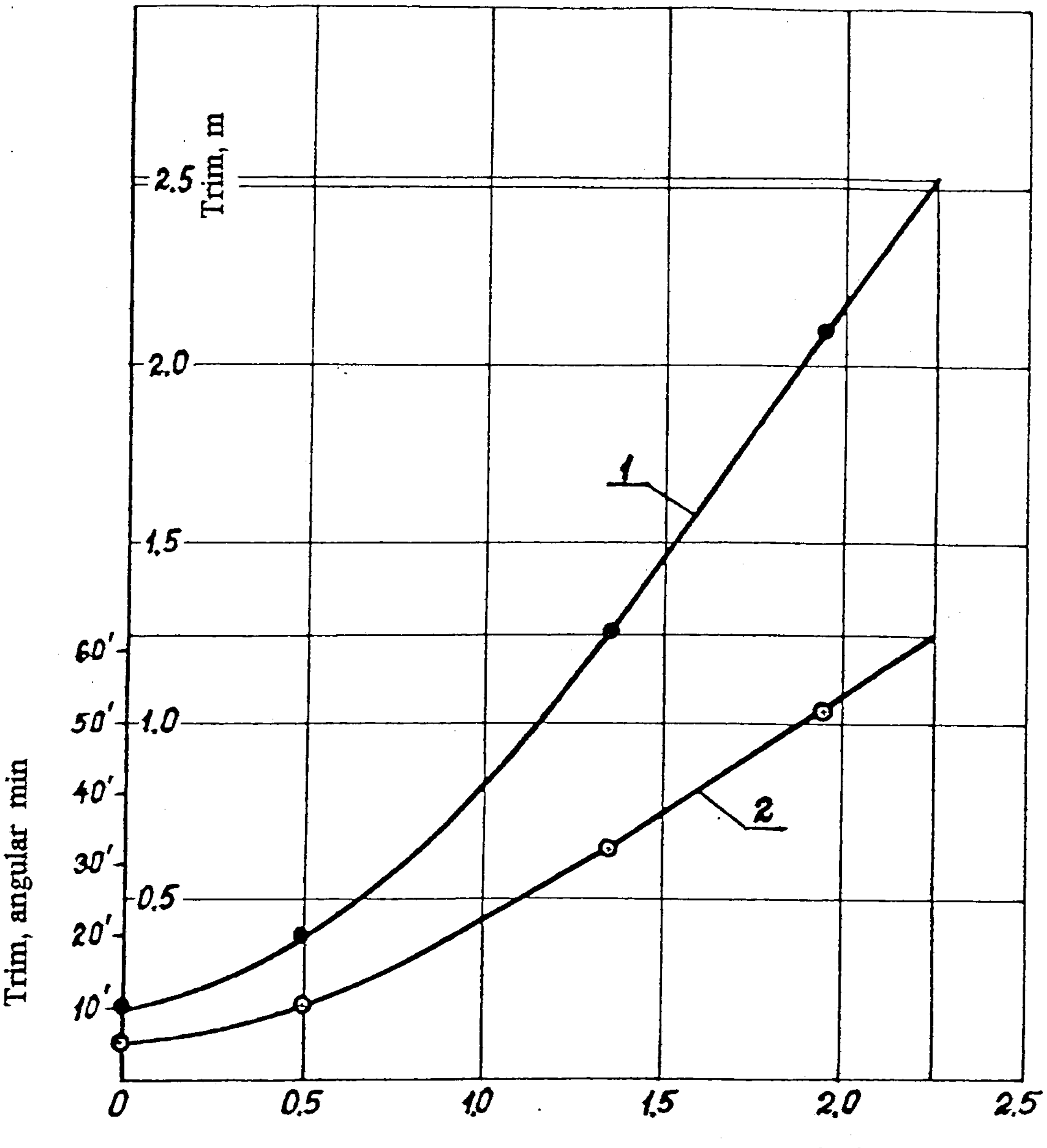


Fig. 2.1. Dependence of the icebreaker trim by the stern on the thickness of the broken through compact ice
1 - icebreaker trim in m;
2 - icebreaker trim in angular min

From the above reasoning it should be expected, that for the icebreaking ship with an icebreaking capability of about 2.5 m the stern sinking will make up not more than 0.7-0.8 m.

It is also known that the icebreaker while moving in compact ice makes regular rocking motions rolling over from one board to another. According to the operating experience connected with icebreakers of *Arktika* and *Ermak* types the maximum angle of roll is not more than 2°. However, as shown by rough drawing, the above roll will not bring about the additional increase of the ship's draft by the stern with allowance made for the roundness and elevation of the stern frames of icebreaking ships. Consequently, when the icebreaking ship continuously moves in the first-year fast ice with a maximum design thickness up to 2.5 m the draft increment of the stern will not exceed 0.8 m. The submersion of the stern of the icebreaker can be considerably deeper only in operation by rammings in heavy ice of a thickness beyond the limiting value (including consolidated ice, rafted ice, hummocks). In this case the speeds of rammings should be restricted (as is being done in practice) under shallow water conditions, even if there is a sufficient depth under the keel, proceeding from the condition of preventing the ship's sticking. Usually the ramming speed does not exceed 8 knots.

Thus the analysis made has shown that in order to provide for safe operation of icebreaking ships no additional requirements are needed for the increase of the under-keel clearance in comparison with that determined by the Codes of the Technological Design of Seaway Channels.

2.2. Assessment of the influence of the under-keel clearance on the propeller thrust

The Krylov Institute has developed methods for the determination of the reduction of the total propeller thrust in shallow water depending on the under-keel clearance. These methods are based on specially carried out investigations of the effect of shallow water on the water resistance to the motion of ship with icebreaking hull lines and the propeller / hull interaction coefficients. The icebreaker of *Moskva* type was taken as an object of investigation. Major attention was paid to the study of the propeller thrust drop in the mode of operation close to bollard pull conditions.

Fig.2.2 shows the relationship between the total propeller thrust and the under-keel clearance obtained by calculation at the A/O "Iceberg" from the above methods applied to a perspective double-draft icebreaker with a shaft power of about 60 MW [10]. The calculation was made for the icebreaker speed equal to 3 knots. As one can see from the example of this calculation, at a minimum under-keel clearance of 1.5 m the propeller thrust drop is only about 4%. This corresponds to the decrease of the icebreaking capability not more than by 2%. Consequently the effect of shallow water on the propeller thrust is insignificant. Really observed more substantial reduction of the icebreaking capability under conditions of shallow water is apparently associated first of all with the change of the character of the ship's hull/ ice interaction: in particular when the ice thickness is commensurable with the under-keel clearance.

At the same time, it should be noted that somewhat different assessments about the influence of shallow water on the propeller thrust were obtained by the A/O "Wartsila Marine". According to the data of this company shown in fig.2.3, at the under-keel clearance of 1.5-2.0 m the propeller thrust loss of the shallow draft icebreakers *Taimyr* and *Kapitan Sorokin* designed and built by this company, if compared with deep water, reaches 13-14%. Draft of the nuclear icebreaker *Taimyr* is 8.1 m and of diesel-electric icebreaker *Kapitan Sorokin* - 8.5 m. However, investigations carried out by the A/O "Wartsila Marine" also confirmed the fact of more significant effect of the increase of the ice resistance during the motion of icebreaker in shallow water on the reduction of the icebreaking capability. Fig.2.4 shows the relationship between the ice resistance of icebreakers *Taimyr* and *Kapitan Sorokin* and the water depth at a speed of 2 knots in level compact ice 1.5 m thick. As one can see from fig.2.4, at an under-keel clearance of 1.5-2.0 m the icebreaker ice resistance increases approximately twice.

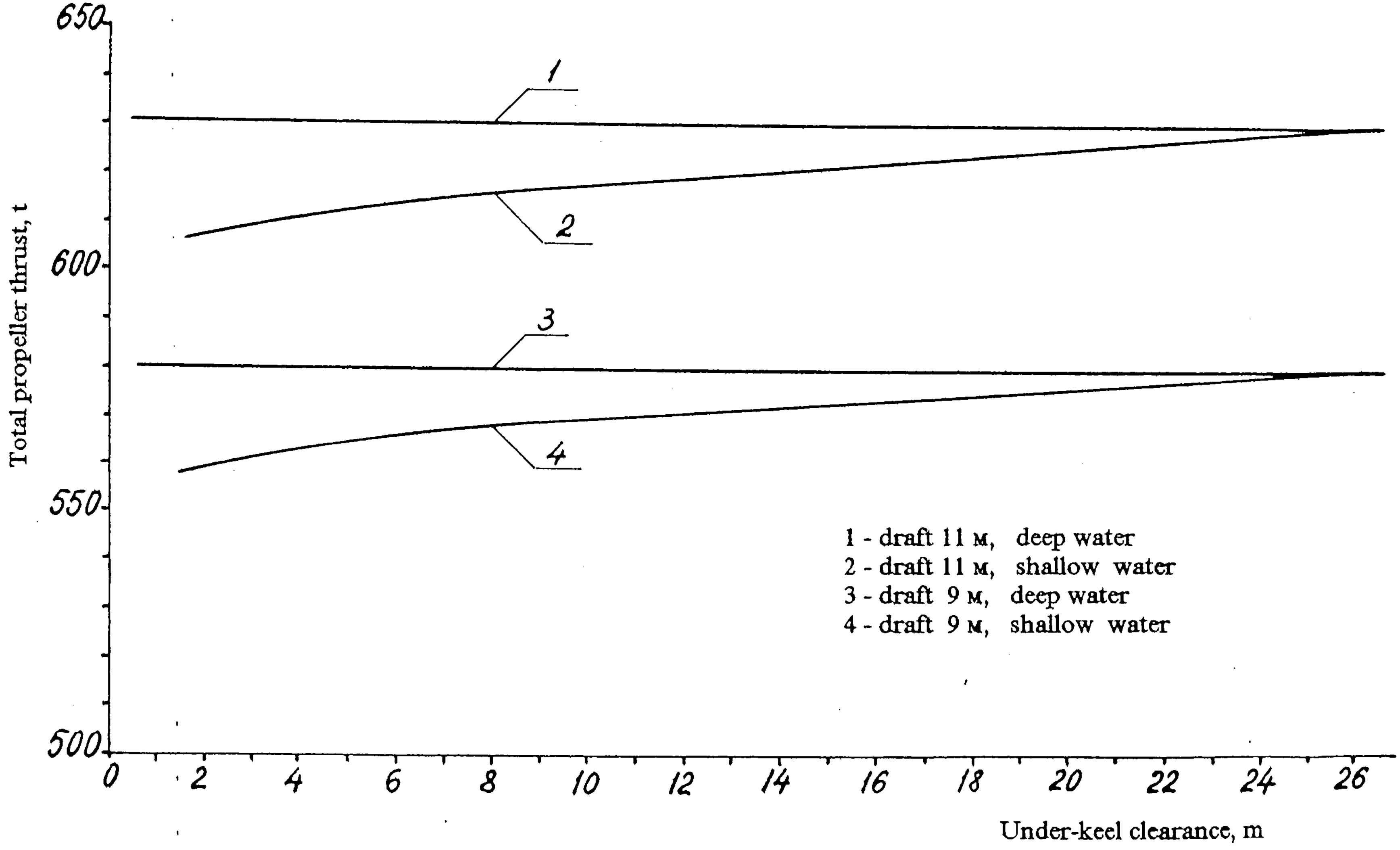


Fig. 2.2. Icebreaker propeller thrust plotted against the under-keel clearance

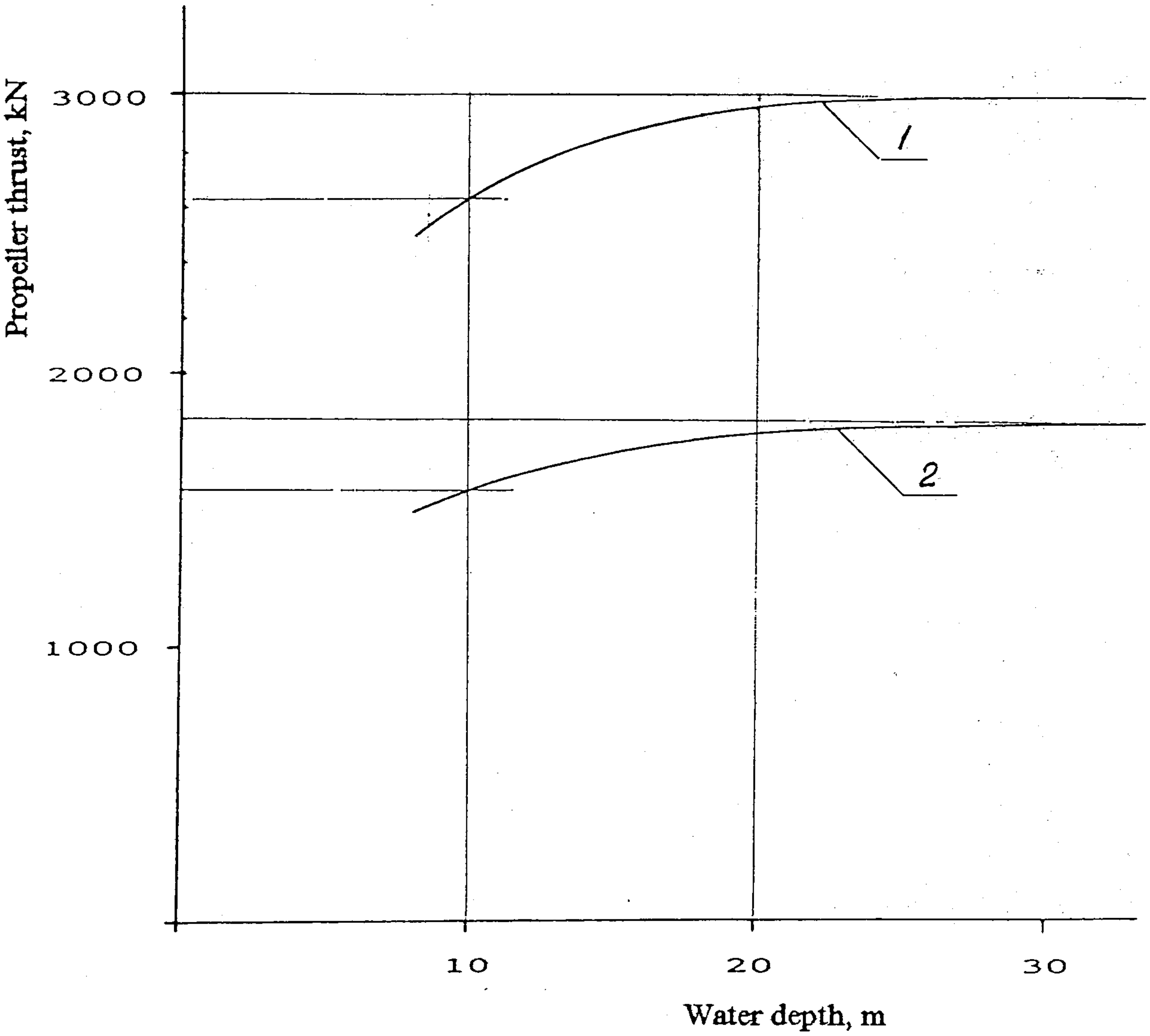


Fig. 2.3. Change of the propeller thrust in bollard-pull mode of operation of icebreakers *Taimyr* (1) and *Kapitan Sorokin* (2) depending on water depth

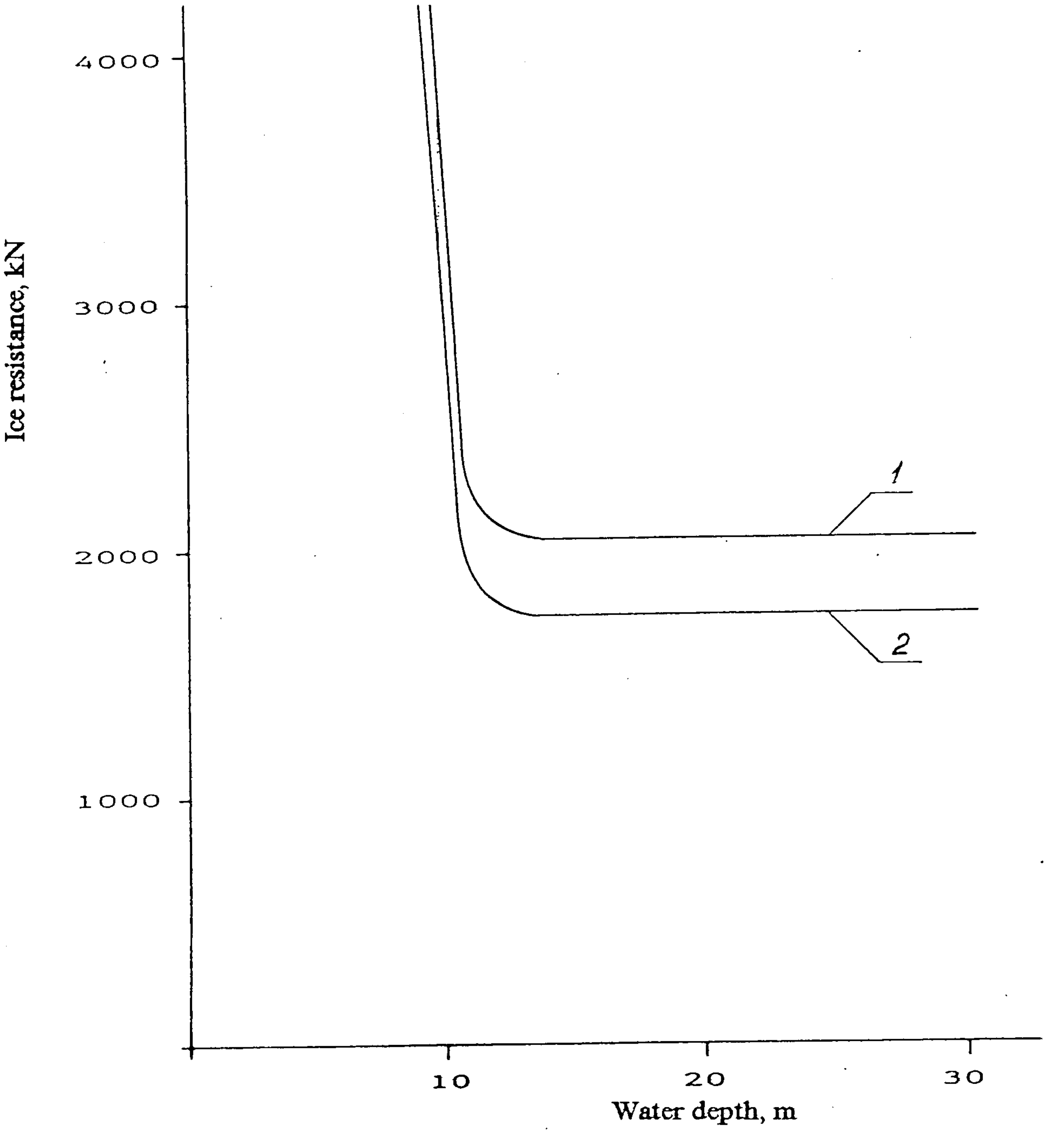


Fig. 2.4. Ice resistance of icebreakers *Taimyr* (1) and *Kapitan Sorokin* (2) plotted against the water depth

2.3. Experimental investigations of the effect of shallow water on the ice propulsion of icebreaking ships

2.3.1. Model tests

In the process of the construction of the nuclear shallow-draft icebreaker *Taimyr* special model test were carried out in the WARC ice basin for the detection of the effect of shallow water on the icebreaking capability of the icebreaker. Conditions of tests are illustrated in fig.2.5.

Model tests have brought to light the substantial effect of shallow water on a maximum thickness of level compact ice broken through by the icebreaker at a minimum speed of 2 knots. So, the icebreaking capability of the icebreaker *Taimyr* equals, if recalculate for the full-scale, in deep water to 1.77 m, at an under-keel clearance of 2 m is reduced to 1.38 m, i.e. by 22%. Fig.2.6 shows data on maximum for the icebreakers *Taimyr*, *Kapitan Sorokin* and *Murmansk* ice thickness as a function of the water depth obtained by Finnish specialists by calculation and model tests (separate points).

These results were made more accurate after full-scale tests of constructed icebreakers.

2.3.2. Full-scale tests

Shallow water influence on the ships' ice propulsion manifesting itself in the reduction of speed of motion over small depths was for the first time found out during the tests of the icebreaker *Murmansk* of *Moskva* type in the autumn-winter navigation 1973-1974 [11, 12]. Tests were performed in compact ice 60-120 cm thick with snow cover and in the channel proper with different age stages of freezing of broken ice in it. Under other similar conditions during the tests the water depth was measured. The degree of depth limitation was characterized by the water depth / ship's draft ratio H_w / T.

The tests enabled bringing to light the depth range at which the influence of shallow water occurs . The most pronounced influence of the shallow water is to be found at depths less than a double draft of ship. Such effect becomes practically imperceptible at H_w / T ratio exceeding 3.0-3.5. The salient feature is that the shallow water manifests itself at modes of operation close to that of the bollard pull, that is during the movement in ice of maximum thickness. For instance, the icebreaker with a shaft power of 13.6 MW was moving at a continuous speed of 2 knots in level compact ice 120 cm thick (snow cover being 20 cm deep), when the relative depth H_w / T was 1.7. However, at $H_w / T = 1.25$ the icebreaker could reach the same 2 knots only in ice with a thickness of 110 cm (with the same snow cover), while at a depth equal to 1.7 drafts in this ice the icebreaker had a speed of 3.6 knots.

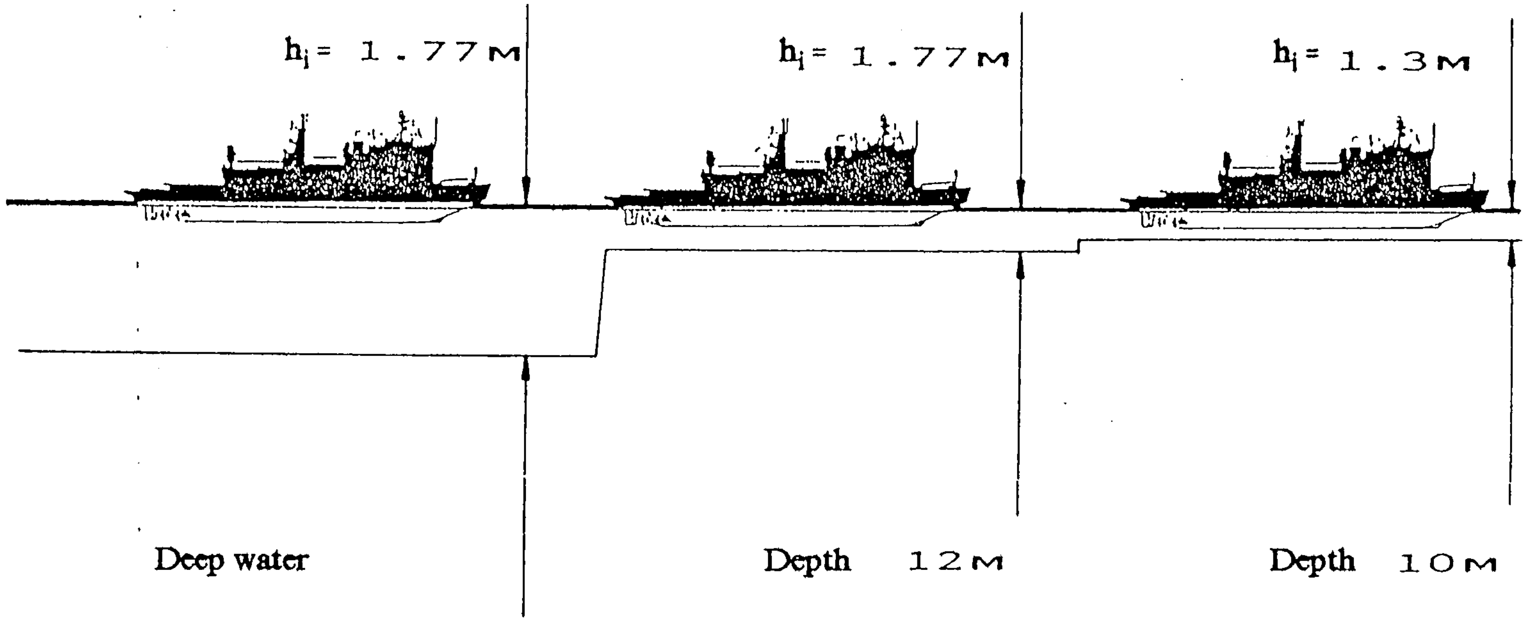


Fig. 2.5. Conditions of model tests of the icebreaker *Taimyr* for the determination of the effect of shallow water on the icebreaking capability

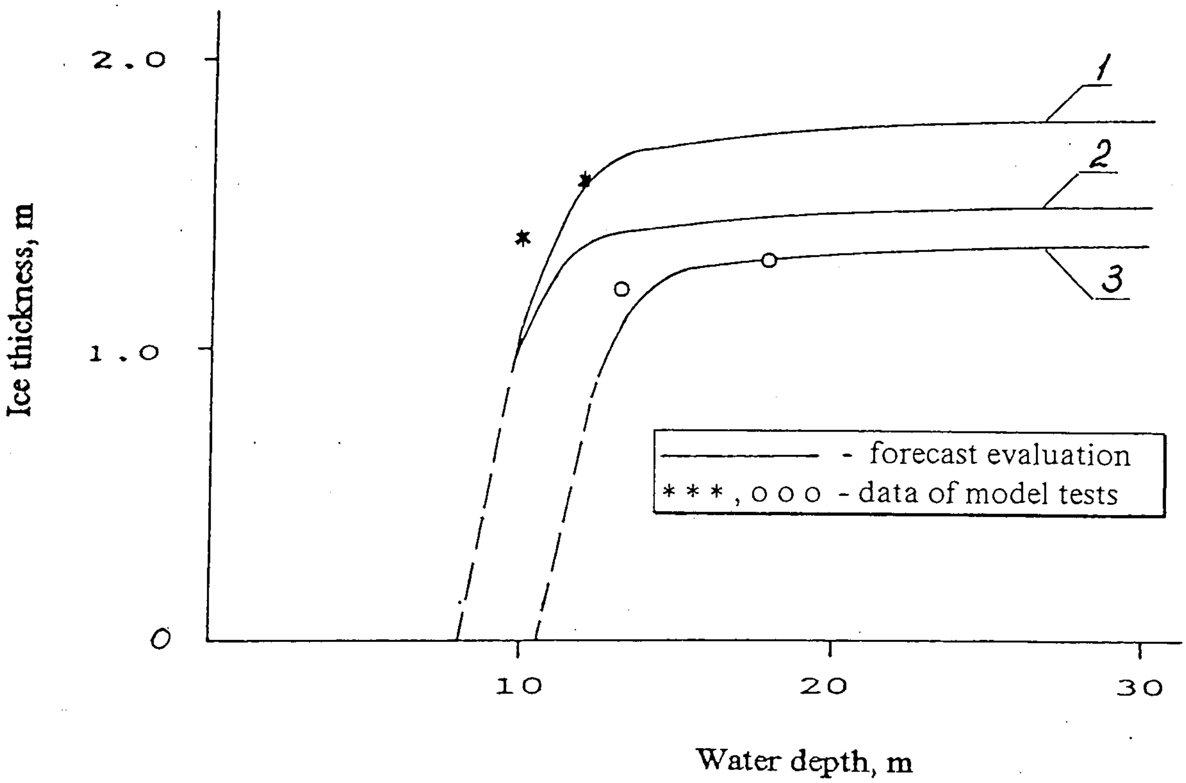


Fig. 2.6. Relationship between the maximum ice thickness broken through by the icebreaker at a speed of 2 knots and the depth of water:

1 - icebreaker *Taimyr*
2 - icebreaker *Kapitan Sorokin*
3 - icebreaker *Murmansk*

The analysis of experimental data of the icebreaker *Murmansk* has shown that with a decrease of depth H_w / T from 3.5 to 1.15 the icebreaker speed in compact ice reduces 2.3 times. To reach the same speed of movement at relative depths 1.15 and 3.5 in level compact ice 110 cm thick with a snow thickness of 20 cm the difference in power consumption amounted to about 30% that is equivalent to the change of the icebreaker icebreaking capability by 13-15%.

Tests of the icebreaker in a freshly made channel have shown that change of the relative depth from 3 to 1.5 results in a loss of speed by 20-25%.

For an approximate determination of the change of the ship's speed in ice in shallow water one may use the plot of fig.2.7 put forward by B.N.Syistunov (AARI) and based on the results of full-scale tests of the icebreaker *Murmansk* in level compact ice in deep and shallow water.

Under conditions of shallow water also the icebreaker *Taimyr* after its construction by the Finnish "Masa-Yards" in 1990, the icebreaker *Kapitan Nikolaev* after the conversion by the same company in 1990 and the icebreaker *Kapitan Sorokin* after the conversion by the German company "Thyssen Nordseewerke" in 1991 were tested. All these tests were carried out in the fast ice of the Yenisei Gulf.

Table 2.3 contains comparative data on ice tests of the i/b *Taimyr* in deep and shallow water. The icebreaking capability was compared at the same power of electric engines equal to 33.5 MW and a speed of steady motion of 2 knots (1 m/s).

Table 2.3

Icebreaking capability of the icebreaker *Taimyr* in deep and shallow water according to full-scale tests in 1990

Test conditions	H_w / T	T mean, m	h_i, m	Reduction of icebreaking capability
Deep water	≥2.5	8.4	2.21	-
Shallow water $H_w = 11.2\text{-}11.4$	1.28	8.8	1.98	10%

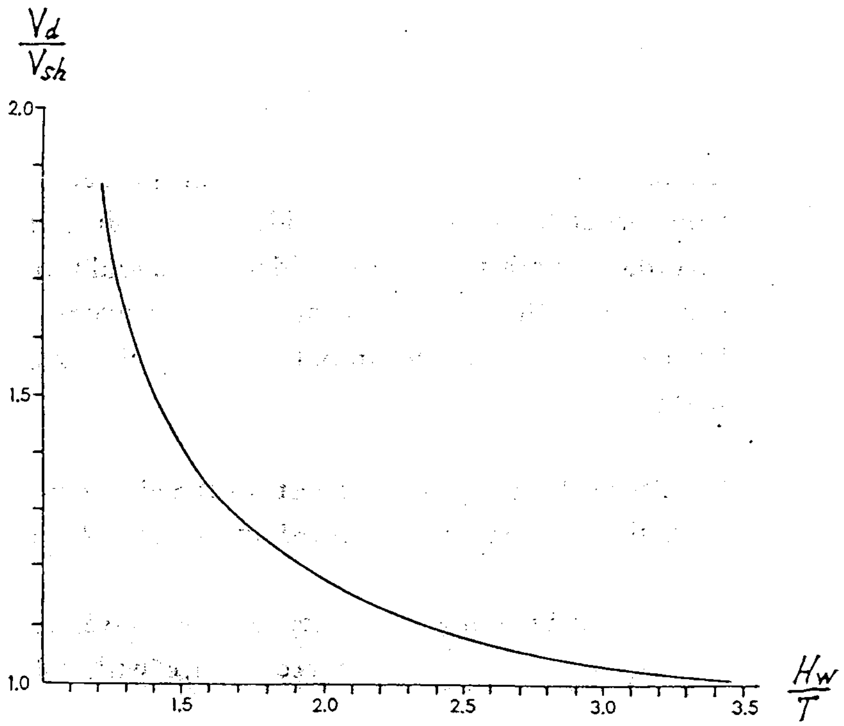


Fig. 2.7. Dependence of deep / shallow water speed ratio (V_d/V_{sh}) on the relative water depth (H_w/T) during the ship's movement through ice

As one can see from the table, the icebreaking capability of the icebreaker *Taimyr* in shallow water ($H_w / T = 1.28$) decreased by 10%. This decrease turned out to be less than expected. According to model tests (see fig.2.6), at $H_w / T = 1.28$ one could expect reduction of the icebreaking capability by 14% and over. In reality it was about 10%.

Fig.2.8 shows the results of full-scale tests of the ice propulsion in the fast ice of the Yenisei Gulf of icebreakers with non-traditional hull lines: converted icebreaker *Kapitan Nikolaev -90* with the traditional forebody replaced by the so-called conical bow developed by the A/O "Wartsila Marine" (see fig.2.9) and icebreaker "Kapitan Sorokin-91" with a new forward end of the *Thyssen-Waas* system (see fig.2.10). Both icebreakers have structural characteristic properties providing for driving the broken ice from under the hull bottom aside, thus reducing propeller shafts/ice interaction. In accordance with the authors' idea this should also stimulate the reduction of the ice resistance to the i/b movement in shallow water. So, .,the icebreaker *Kapitan Nikolaev* has ice-removing battens in bottom and icebreaker *Kapitan Sorokin* - an ice-removing wedge.

Results of the analysis of ice tests of the above mentioned icebreakers under conditions of shallow water are presented in tables 2.4 and 2.5.

Table 2.4

Icebreaking capability of the converted icebreaker *Kapitan Nikolaev* in accordance with full-scale tests in 1990

Test conditions	H_w / T	T mean, m	Power of electric engines, MW	h_i , m	Reduction of icebreaking capability
Deep water	≥ 2.5	8.3	17.4	1.80	-
Shallow water H_w= 9.4-11.3 m	1.25	8.3	17.4	1.63	10%

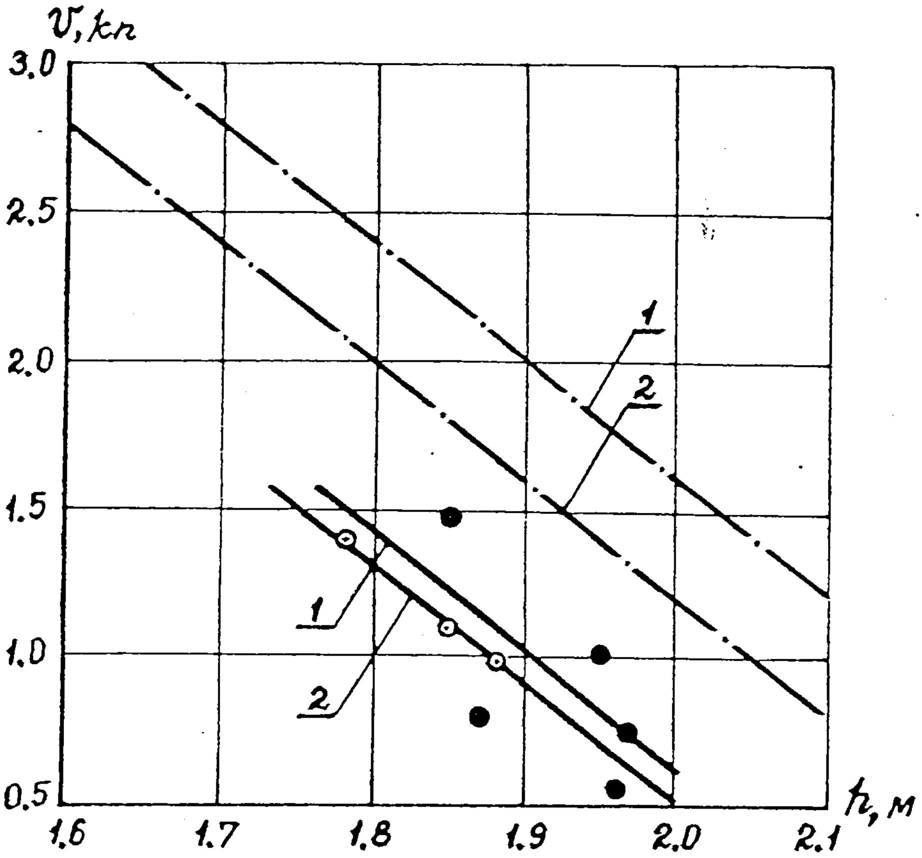
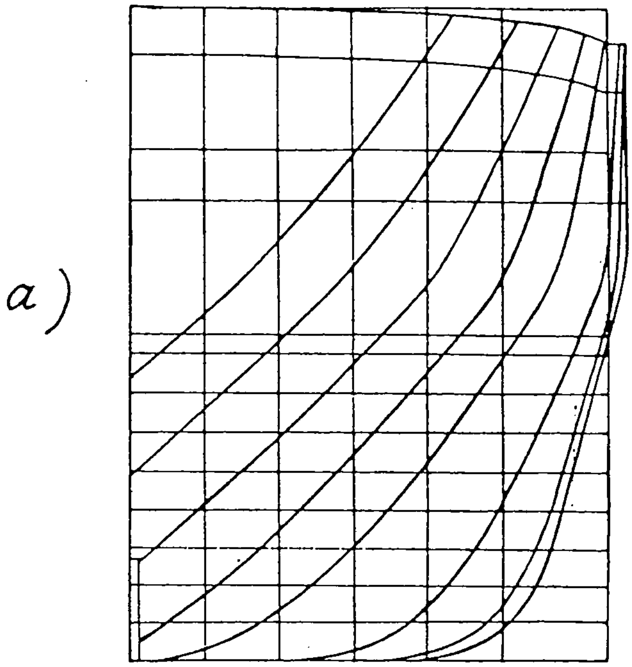


Fig. 2.8. Propulsion in headway movement of icebreakers *Kapitan Sorokin - 91* (1) and *Kapitan Nikolaev - 90* (2)

——————— in shallow water

— · — · — in deep water


ORIGINAL BOW

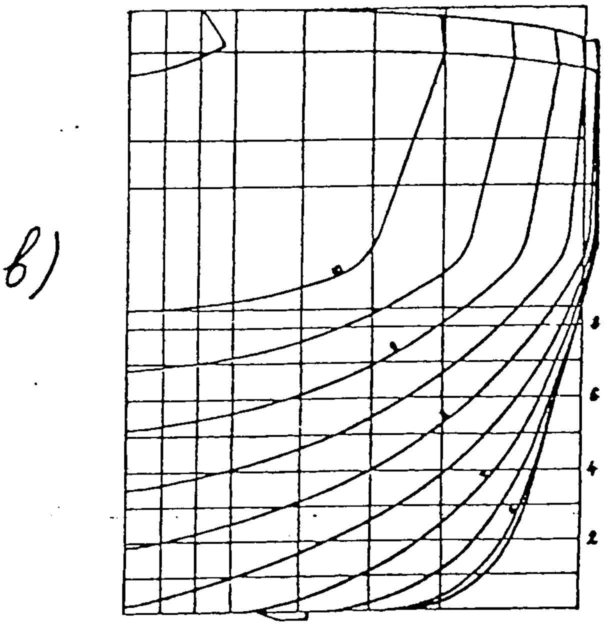

CONICAL BOW

Fig. 2.9. Traditional (a) and conical (b) hull lines of the icebreaker *Kapitan Nikolaev* prior to and after conversion accordingly

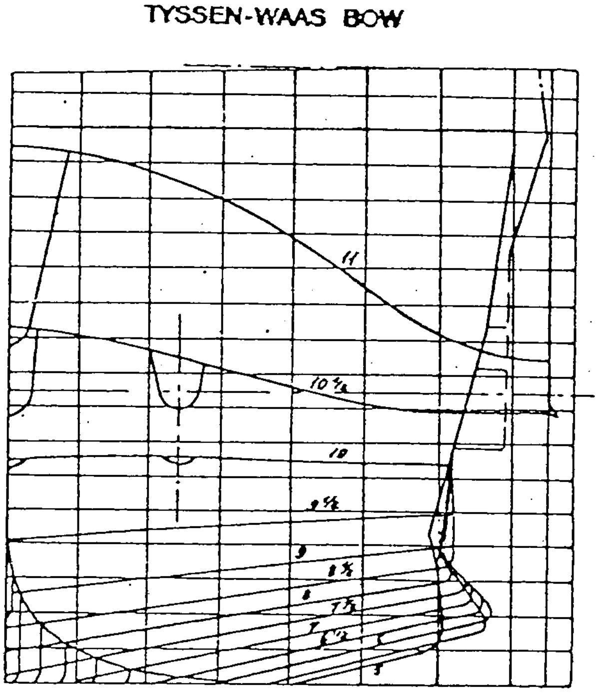


Fig. 2.10. Forward end lines of the *Thyssen-Waas* system of the icebreaker *Kapitan Sorokin*

Table 2.5
Icebreaking capability of the converted icebreaker *Kapitan Sorokin* in accordance with full-scale tests in 1991

Test conditions	H_w / T	T mean, m	Power of electric engines, MW	h_i, m	Reduction of icebreaking capability
Deep water	≥ 2.5	8.5	16.6	1.90	-
Shallow water $H_w = 10.6\text{-}11.4$	1.29	8.5	16.2	1.66	13%

One can see from the tables that the icebreaker *Kapitan Nikolaev* has a similar reduction of icebreaking capability as the icebreaker *Taimyr.* The loss in the icebreaking capability of the icebreaker *Kapitan Sorokin* practically under the same shallow water conditions turned out to be somewhat more (13% instead of 10%). Probably the influence of shallow water on the ice propulsion depends on the ship's hull shape characteristics. Besides, it should be noted that the power of the electrical engines of the icebreaker *Kapitan Sorokin* during the shallow water tests was somewhat lower than in deep water.

Thus latest tests have also confirmed the reduction of the icebreaking capability of ships under conditions of shallow water. However. this reduction in the presence of reasonable (acceptable) under-keel clearance within 2-2.5 m can scarecely have serious consequences relative to operational and economical characteristics of the work of the ship. Similar conclusions were made on the results of construction, tests and operation of shallow-draft river icebreakers of *Kapitan Chechkin* and *Kapitan Evdokimov* types [13].

3. CONCLUSIONS AND RECOMMENDATIONS WITH DUE REGARD FOR DRAFT RESTRICTIONS IN THE DESIGN OF LARGE ICE SHIPS

Investigation of the effect of a shallow draft on the ice propulsion of ships allows to the following statement:

1. Construction of large ships with a restricted draft will require the use of unusual dimension ratios for these ships. At a small draft the increase of displacement, and accordingly of ship's cargo carrying capacity, may be reached mainly at the expense of an increase in the ship's length and breadth. With the traditional length/breadth ratios retained, unusually large will be the breadth/draft ratio. In the case of large ships with restricted draft one may expect an increase in the breadth/draft ratio up to 4-5. Though the increase of ship's breadth leads to the growth of ice resistance, large breadth/draft ratio favourably affects the traditional icebreaking shape of lines of the ship's forebody. This is associated with the increase of bow frame flare angles and the water line entrance angle. As model tests in the ice basin and also the experience of the construction of shallow draft icebreakers have shown, the adverse effect of the ship's breadth on the icebreaking capability may be compensated by the favourable, from the point of view of ice propulsion, influence of a small draft on the hull shape at large breadth/draft ratios. Consequently an increase in the breadth/draft ratio should not excite serious apprehension as far as the deterioration of ice qualities of the ship is concerned. One may also expect certain compensation of the adverse effect of the ship's breadth on the icebreaking capability by the positive influence of the increase of mass of a large ship [14, 15, 16].

2. The most serious difficulties associated with the provision of the required icebreaking capability of shallow draft ships are to be expected relative to the rigid restriction of power which can be efficiently processed (without cavitation and aeration) at a small draft. Investigations have brought to light substantial dependence of power on draft and accordingly on propeller diameter. Therefore the requirement for high power of large ships of active ice navigation with shallow draft, predetermines the application of multi-shaft propulsion plants. For instance, on shallow draft icebreakers of *Kapitan Evdokimov* type specially built for Siberian rivers use is made of a four shaft propulsion plant [13].
The use on ships of arctic navigation of non-traditional hull lines with the purpose of the reduction of required power (for instance, of conical lines as proposed by the company "Wartsila Marine" or of lines of the *Thyssen-Waas* system), as the experience of the conversion of domestic icebreakers has shown, does not seem promising [17].

3. As estimation calculations show, the minimum safe, in navigational respect, under-keel clearance of ship may be 1.5-2.0 m. This circumstance should be borne in mind while ensuring operational safety of large ships with a restricted draft in the process of their design. In particular, special attention should be paid to the design of the stern tube and of the power plant sea water cooling system. Taking into account higher ice damageability of bottom and bilge areas of the ship's hull under conditions of shallow water it is also necessary to take appropriate measures to ensure structural safety of shallow draft arctic navigation ships. These problems require special investigation.

The experience gained in Russia on the construction and operation of icebreakers in the Arctic would recommend the use on icebreaking ships of closed type stern tubes with water lubrication. It will tend to minimize the abrasive wear of seals of propeller shaft liners and stern bearings and in this way relieve any additional restrictions pertaining to the operation of stern tubes in shallow water.

The sea water cooling system on shallow draft ships should by all means include bottom and side ice boxes. The required water intake capacity should be equally ensured both by bottom and side ice boxes.

4. In accordance with theoretical studies the propeller thrust drops during sailing in shallow water. Calculations made in compliance with the existing technique show however that this drop is not significant. The deterioration of the icebreaking capability of icebreakers in shallow water is apparently to a greater extent associated with the increase of ice resistance to the ship's motion under conditions of small under-keel clearance, especially when this clearance is commensurable with the thickness of ice to be broken through.

5. As full-scale tests of icebreakers in water depths close to minimum admissible ones from the point of view of the safety of navigation have shown, actual deterioration of the icebreaking capability in these conditions did not exceed 10-15%. Therefore the problem of deterioration of the icebreaking capability in shallow water is hardly of practical interest, when we consider that the operation of icebreakers in limited depths is of episodical character. At the same time it is understandable that the degree of reliability and safety of ship navigation in shallow water areas of the Arctic is less than in deep water. Proceeding from that, higher requirements should be imposed on the screw-rudder system and other appliances and systems providing for necessary ship's ice qualities including good manoeuvrability in ice.

RESUME

On the basis of the investigations carried out concerning the effect of small draft and shallow water on ice qualities of large icebreaking ships one may conclude that as far as the provision of ice propulsion is concerned the main problem is ensuring the efficient processing of high power when constructing shallow draft ships. Expected comparatively small reduction of the icebreaking capability during the sailing under conditions of shallow water can scarcely be considered as related to the most important problems requiring solution during the design of ships with restricted draft.

Present investigations have corroborated the feasibility in principle of the construction of large shallow draft ships for the Arctic. Main attention here should be paid to problems of the guarantee of ice strength of hull and reliable action of the screw-rudder system, stern tubes and sea water power plant cooling system. The experience of the construction and operation of the Russian icebreaking fleet shows that these problems are practically soluble.

At the same time, the summarized conclusions made should be considered as preliminary ones. Requirements for the ice propulsion have to be defined more accurately in each specific case depending on purpose and operational conditions of the ship concerned. The advisability of making certain technical decisions along with the guarantee of necessary safety of navigation should be assessed by the economic efficiency criteria.

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Appendix

Project review

Review and comment
on INSROP

October 1995

I.7.2. REQUIREMENTS FOR ICE PERFORMANCE OF LARGE SHIPS WITH SHALLOW DRAFT

Authors: Dr. L.Tsoy, CNIIMF, supervisor

The authors are to be congratulated for this attempt to draw useful guidelines for the future development of novel vessels and concepts for new areas of Arctic shipping, based on the vast experience gathered during decades of research, testing and exploitation of the existing tonnage. The results that decreasing draft may lead to hull forms with advantageous ice resistance and thrust is not deteriorating excessively in shallow waters is certainly wellcomed by all the audience concerned.

However, depending on what is ment by "large ships" and "shallow draft" the reader may feel the scope of the paper rather thin. The reference vessels presently operating in the Arctic displace abt. 25000 tonnes or less, and are neither "large" nor "shallow draft" vessels in the real meaning of these words, compared to, for instance 40000 or 90000 dwt tankers, or even 150000 tonners that may be plying these waters, if or when the Arctic hydrocarbon reservoirs are on full stream. This size vessels would make almost all navigable Arctic fairways "shallow" and "extremely shallow" when approaching harbours and loading terminals. River icebreakers with B/T-ratios from 5 to 6 would then be closer references, rather than *Arktika*, *Sorokin* and *Taimyr*, with B/T from 2.5 to 3.5.

In 1.2 with associated fig. 1.2 a formula is discussed for estimating the efficiently processed power. In fig. 1.2 more curves could be shown for higher d/T-values, which are familiar for really shallow draft vessels, being 0.8 for the *Evdokimov* and 0.74 for the deeper *Chechkin*- type. Some sources also tell, that cavitation on *Arktika*- class propellers in full power bollard pull condition is already harmfull, could the authors comment on that?

The main dimensions should depend on each other somehow in 1.3 and 1.4, perhaps the displacement could be kept constant, not to draw the conclusion that excessive breadth or minimum draft could be advantages, as fig. 1.5 could be read. In real world, all available draft would be used and beam should be kept as small as possible, so far a shallow-draft icegoing ship is concerned. Also, in 1.2 the formula for achievable speed tells that at the same power the lesser draft vessel, that is the smaller one, if other conditions are equal, can achieve higher speed.

For the under-keel clearance, could a smaller clearance be used during the ice period than in open water? In heavy ice conditions there might not be roll or pitching due to the sea and effect of speed and steering are negligible, stern trim due to icebreaking and squat due to the propeller suction through the ice-filled clearance between sea bed and ships bottom being the only significant factors. For *Arktika* type the maximum stern immersion increment of 0.8 m is given.

Every decimeter less clearance, with more draft and deadweight, would be valuable for the ship operator and perhaps for the feasibility of the whole project.

It is delightfull that icebreaking capability of the tested icebreakers was reduced only slightly in shallow water, as shown in the tables 2.3, 2.4 and 2.5, but one must remember that the tests were run in smooth solid level ice in river estuary, that is in "laboratory conditions" that seldom exist in nature. More likely the ships meet rafted or hummocked ice or ridges, that are grounded in shallow water, or have to traffic in an old channel in these conditions. In all of these situations the thickness of ice flowing under the ships bottom easily exceeds the underkeel-clearance despite that the nominal thickness of the level ice does not. Due to the large B/T-ratio almost all ice is put under the hull rather than aside resulting in higher ice resistance. Situation like this would also require heavily ice strengthened bottom construction as correctly stated in the paper, which increases the lightweight and draft of the vessel.

All restricted draft vessels tend to be very long and the full bow and stern forms further increase the length of the parallel midbody which ruins the turning capability in ice. Are there general requirements or other considerations, perhaps local, concerning the minimum acceptable steering capability in ice conditions? Multiple rudder arrangement increases steering force but affects the thrust and thus icebreaking capability, especially backwards. How do the authors emphasize the importance of reversing capability? Today's icebreakers normally reverse without problems but they have electric motors that change direction of revolutions and fixed pitch propellers for ample reverse thrust, while cargo ships only have reduction gears and CP-propellers with limited backing thrust. Due to her low ice resistance and her hull form the *Evdokimov* quit easily can get into situation, where icebreaking resistance and friction force of the thick ice floating under the bottom stop the vessel, and backwards thrust, lower than the thrust forward, can not loose her.

Low ice resistance is essential for all icebreaking ships but especially for those with shallow draft, because their potential to use high power efficiently is limited as stated in the paper. One way to decrease ice resistance is use of low friction surfaces, smooth paints or stainless steel plating. Low friction surfaces also effectively help to loosen a stuck vessel. Have the authors summarized experiences of the effect of these methods used onboard existing vessels?

Another method for resistance reduction are the auxiliary icebreaking systems, that is heeling, trimming, water flushing, air bubbling etc. What are the recommendations of the authors concerning these systems, based on their operational records in shallow waters?

One point to consider is also the low ballast draft of cargo vessels. Icebreakers float on quite even waterlines due to their relatively small deadweight and large ballast capacity, especially nuclear ones, cargo vessels normally submerging much less in ballast than in loaded condition, and means to increase ballast draft are scarce. According to this paper this means decreased ice resistance but problems with power processing and propeller-ice interaction are obvious. Can the authors give recommendations on minimum ballast performance forwards and backwards? Should there be a requirement of minimum admissible ballast draft in relation to the ice thickness or navigation area?

The conclusion, that non-traditional hull lines seem not promising is contradictory to that the authors presented in Icetech-94 in the paper "On the efficiency to use non-traditional hull lines of icebreakers", at least when conical bow form is concerned.

To the end how do the authors see the operation philosophies change with real large arctic cargo vessels? This size vessels would be much broader than existing icebreakers making them more difficult to escort, and by displacement they overrun the icebreakers several times. Should this size vessels be able to traffic more independently than the existing cargo tonnage, and what would be the required icebreaking for them in this case?

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Kimmo Juurmaa
Kvaerner Masa-Yards Technology Arctic R&D

Comments of Dr. L.Tsoy - supervisor and executor of Project I.7.2, on the review of Mr. K.Juurmaa, Kvaerner Masa-Yards Technology

The author thanks Mr. Juurmaa for a detailed and thorough review of the work in question. The interest shown to this work and great number of questions can be considered as evidence of the fact that the subject is of current concern and the investigations in this direction should be continued. Among issues of high priority referred to by the reviewer as being subject to the consideration in future one should mention the study of manoeuvrability of ships in ice including parameters of reversing, assessment of the efficiency of auxiliary means to improve the icebreaking capability taking into account specific character of the work in shallow water, the development of the requirements to minimum ballast draft, the determination of need in the icebreaker assistance of large icebreaking cargo ships.

As to concrete comments pertaining to the work made one should note the following.

1. The wish of increasing the propeller diameter of ships with a restricted draft to efficiently process high power is quite natural. It should be borne in mind however that the question is of the ships navigating in the Arctic. Damages of the propellers the blades of which are near the waterline are inevitable. The experience of building and operation of icebreakers in polar areas shows that the admissible diameter of side propellers does not exceed 0.6 of the icebreaker draft. For cargo ships, as it was correctly stated by the reviewer, the ballast transit draft reduction should be also taken into consideration.

2. Icebreaker *Arktika* under the bollard pull mode of operation is capable to develop full power of main turbines. At the same time there are grounds to believe that at the adopted propeller diameter the subsequent power increase would result in the development of the second stage of cavitation and aeration of side propellers.

3. The formula put forward in the work for the determination of achievable speed of an icebreaking ship in open water seems to be physically well-grounded. It is known that the decrease of the ship's draft under other equal conditions leads to the decrease of water resistance and accordingly to higher speed.

4. Possibility to reduce the under-keel clearance during the operation of ship in ice in comparison with the Codes of Technological Design of Seaway Channels should apparently be evaluated for each particular case depending on ice conditions (compact ice, ice cake, hummocks), extent of hydrographic exploration of a shallow area, operability of the main engines cooling system, reliability of stern tubes etc.

5. As to the perspectives to use conical form of the forebody lines for a ship of arctic navigation one should note their high efficiency while working in ice even despite higher sensitivity of the flat bow to the snow cover. At the same time, as the experience of the refitted icebreaker *Kapitan Nikolaev* has shown, the icebreaker with conical forebody cannot be normally operated under conditions of seaways. In the head sea the icebreaker experiences high slamming resulting not only in the unacceptable habitability, but also in the destruction of ship structures. Therefore the use of conical hull lines may be recommended only for ships regularly (all the year round) operating in ice.

Loly Tsoy
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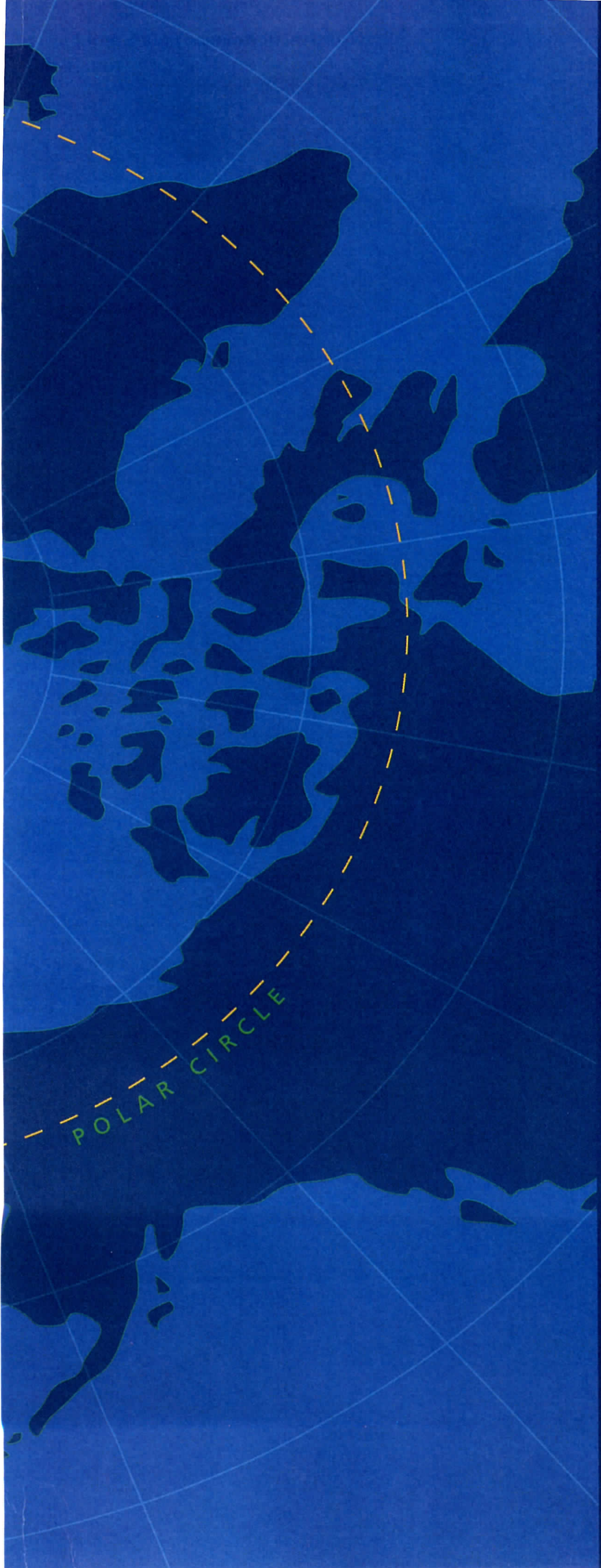

The three main cooperating institutions of INSROP

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.