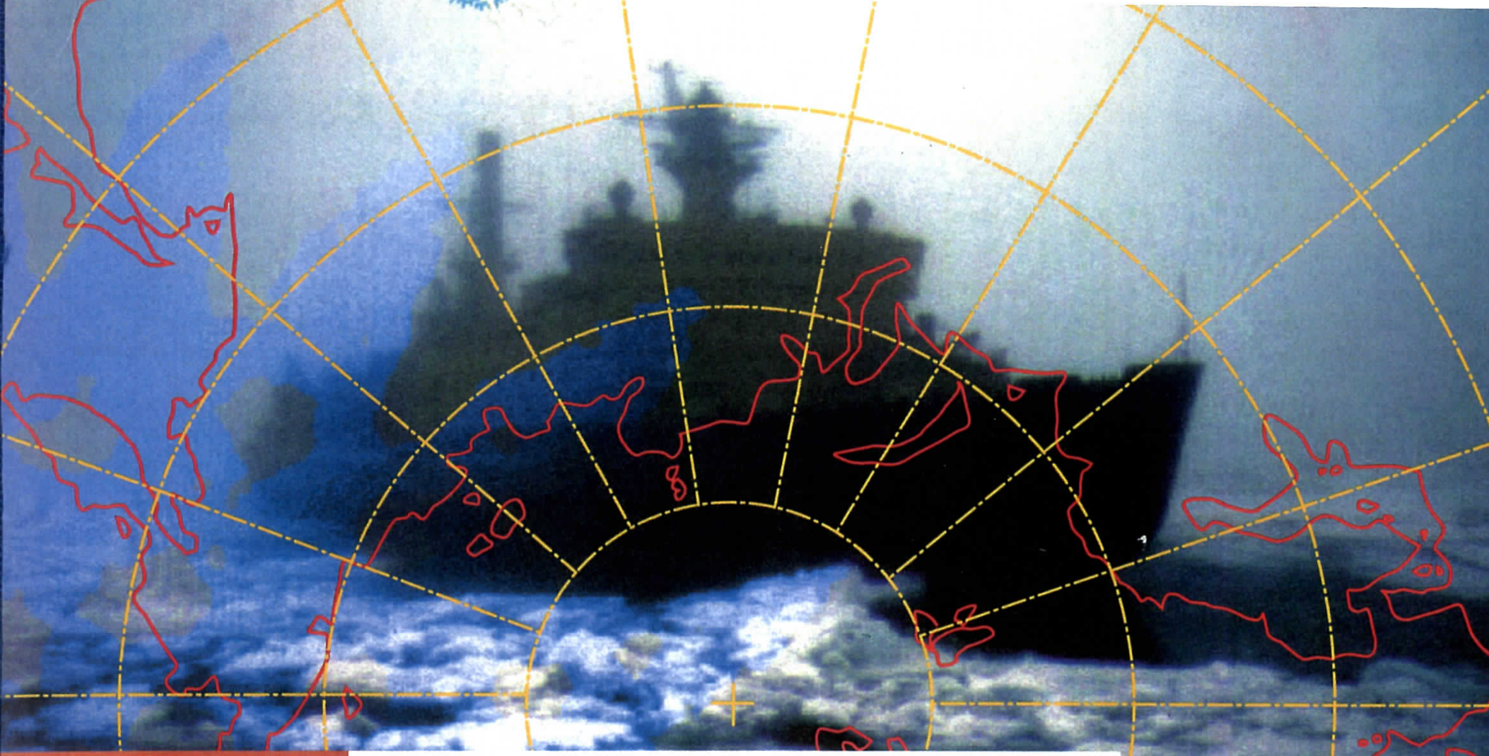
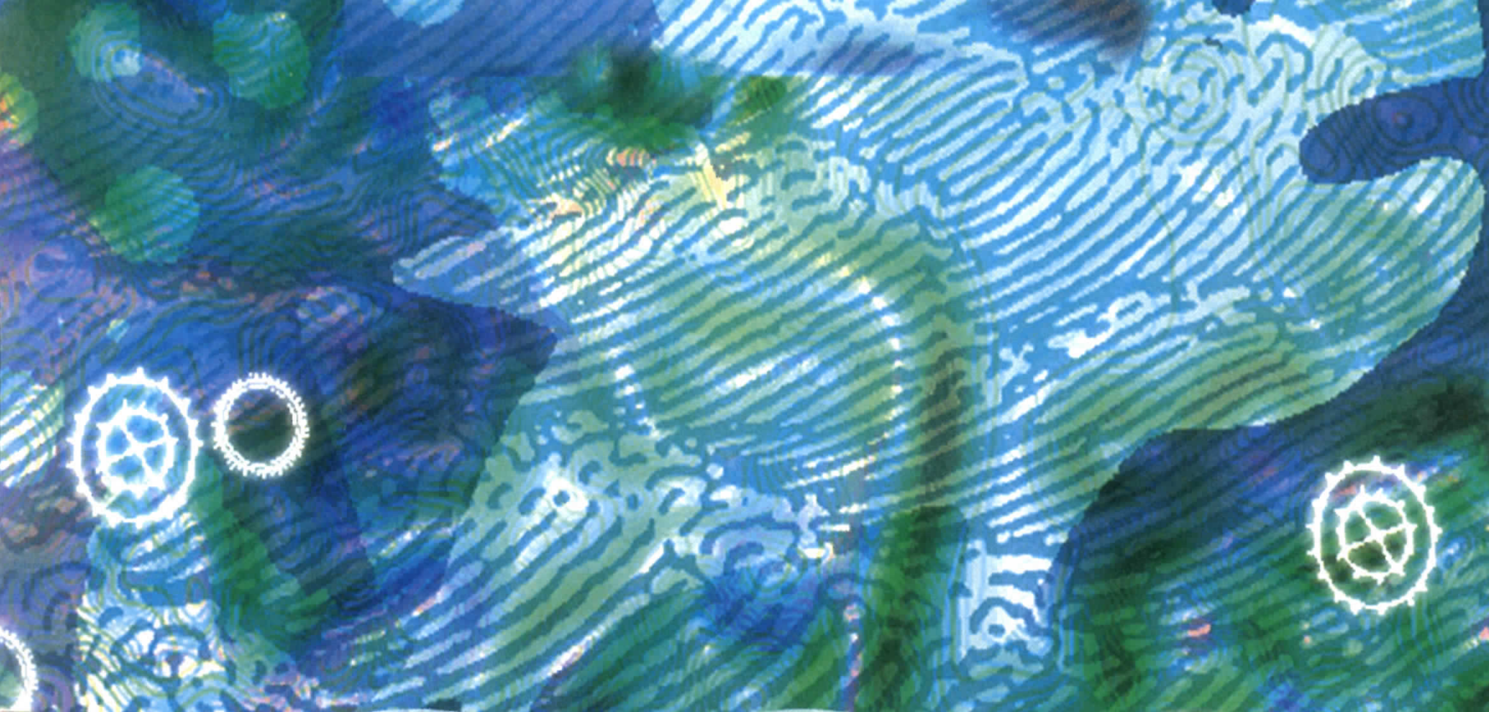


INSROP WORKING PAPER
NO. 70 - 1996, II.6.2

Environmental and Structural Safety of Ships

By L. Tsoy, V. Volkov, S. Karavanov, F. Moreynis
and A. Zubkova



INSROP International Northern Sea Route Programme

Central Marine
Research & Design
Institute, Russia

The Fridtjof
Nansen Institute,
Norway

Ship and Ocean
Foundation,
Japan

International Northern Sea Route Programme (INSROP)

Central Marine
Research & Design
Institute, Russia

The Fridtjof
Nansen Institute,
Norway

Ship & Ocean
Foundation,
Japan

INSROP WORKING PAPER NO. 70-1996

Sub-programme II: Environmental Factors

Project II.6.2: Environmental and Structural Safety of Ships

Supervisor: Loly Tsoy

Title: **Environmental and Structural Safety of Ships**

Authors: **L. Tsoy (1), V. Volkov (2), S. Karavanov (1),**
F. Moreynis (1) and A. Zubkova (1)

Addresses: (1): Central Marine Research and Design Institute
(CNIIMF), Kavalergardskaya Street 6,
193015 St.Petersburg, RUSSIA.
(2): Krylov Research Institute

Date: 27 November 1996

Reviewed by: Mark Fuglem, Ocean Engineering Research Centre,
Memorial University of Newfoundland, St.John's,
Newfoundland, Canada

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

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

FOREWORD - INSROP WORKING PAPER

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

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

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

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

SPONSORS FOR INSROP

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

PROFESSIONAL ORGANISATIONS PERMANENTLY ATTACHED TO INSROP

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

PROGRAMME COORDINATORS

- **Yury Ivanov, CNIIMF**
  Kavalergardskaya Str.6
  St. Petersburg 193015, Russia
  Tel: 7 812 271 5633
  Fax: 7 812 274 3864
  Telex: 12 14 58 CNIMF SU

- **Willy Østreng, FNI**
  P.O. Box 326
  N-1324 Lysaker, Norway
  Tel: 47 67 11 19 00
  Fax: 47 67 11 19 10
  E-mail: sentralbord@fni.no

- **Ken-ichi Maruyama, SOF**
  Senpaku Shinko Building
  15-16 Toranomon 1-chome
  Minato-ku, Tokyo 105, Japan
  Tel: 81 3 3502 2371
  Fax: 81 3 3502 2033
  Telex: J 23704

International Northern Sea Route Programme (INSROP)

Central Marine
Research & Design
Institute, Russia

The Fridtjof
Nansen Institute,
Norway

Ship & Ocean
Foundation,
Japan

SUB-PROGRAM II. Environmental Factors.

II-6. Environmental Safety of Navigation.

II.6.2. Environmental and Structural Safety of Ships

Final Paper

Submitted to
The Joint Research Committee
and
The Steering Committee of Sponsors

Supervisor Dr. Loly Tsoy,
CNIIMF

St.-Petersburg
1996

Project Team

The Project team consisted of the following:

Dr. L.Tsoy	leader of Project, CNIIMF
Dr. V.Volkov	Krylov Research Institute
Dr. S.Karavanov	CNIIMF
Dr. F.Moreynis	CNIIMF
A.Zubkova	CNIIMF

Abstract

Key words: pollution, operational, emergency, ice damage, hull, probable, grounding, collision, requirements, structural safety.

Consideration is given to the sea pollution from tankers of two types: operational pollution in the process of transportation and cargo handling, washing and stripping and accidental pollution resulting from accidents involving loss of the ship's hull integrity.

In the process of this work, the general analysis of ice damages to the hull of tankers navigating in the Arctic along the NSR has been completed.

Accidental oil spills during grounding and collisions of tankers sailing in open water along the NSR are estimated according to the method evolved. The original procedure for probable accidental oil spills during ice damages has been developed and the evaluation of oil outflow from tankers sailing along the NSR has been made.

Requirements for the structural safety of tankers sailing along the NSR from the point of view of preventing pollution are formulated.

INTRODUCTION

This report is a conclusive report on Section II.6.2 “Requirements for Ecological and Structural Ship Safety”. The results of works carried out during 1993-1995 are given in this report. Though annual reports were issued in 1993 and 1994 years the material concerned is presented here too.

The aim of the whole work is the development of requirements for ecological and structural safety of tankers for the substantiation of which a model of probable emergency and operational oil outflows was developed and the proper evaluation of sea pollution from tankers sailing along NSR was carried out.

Sea pollution from tankers may be of two categories: operational pollution in the course of the transportation and during cargo handling, washing and stripping operations and related to loss of the ship′s hull integrity.

The experience of operation of the tanker fleet and investigation of the marine environment show that though accidents with tankers account for a comparatively small portion of the total sea pollution (10 %), the consequences of such accidents happen to be very serious because of the volley-like character of outflows of the transported oil cargo and oil products and are the main cause of the frequently occurring pollution of coastal areas and of the shore proper.

Pollution of arctic waters and shores as a result of accidental oil and oil products outflows from damaged tankers has essential peculiarities:

- greater environmental harm than in the case of pollution of non-arctic regions due to the fact that more time is needed for the natural disappearance of spilled oil, it is more difficult to liquidate the pollution and because of the greater vulnerability of the northern nature;

- addition of one more type of accident which may cause outflow of cargo - ice holes.

The first part of work on theme II.6.2 “Requirements to the environmental and structural safety of ships” performed in 1994 contains the analysis of hull structure ice damages of the tankers sailing in the Arctic and the assessment of the probability of accidental outflows from domestic tankers navigating along the NSR as a result of strandings, collisions and ice damages.

The second part of the work includes the evaluation of operational outflows from tankers sailing at present along the NSR and the development of methods for the calculation of the probabilistic accidental oil outflow during navigation in the Arctic basin.

Methods were put forward and the assessment made of the operational pollution during the outflow of polluted ballast, washing water and the unloading upon the unequipped shore. Under current legislation the outflow of polluted ballast and washing water on the NSR is prohibited.

While carrying out unloading at berth there is practically no sea pollution with oil. However during unloading onto unequipped shore with the use of hoses pollution is possible due to leakage in case of hose damages or leakage in places of connection of separate sections. Volumes of cargo outflows depend on the quantity of pumped cargo, hose length, ice conditions, sea state, weather, etc. and as practice and the assessment made show these outflows are not large.

On the other hand, strandings while navigating in ice are as a rule not accompanied by high sea and this reduces the extent of hull destruction and consequently the oil outflow.

In the development of the method of calculation of the probabilistic accidental outflow of oil from tankers when they sail along the NSR two approaches to the development of requirements to the subdivision of arctic tankers into compartments on the basis of probability procedures are possible:

- regulation of probability characteristics of accidental outflows totally for three types of holes: as a result of the collision of tankers with other ships, stranding and ice damages;

- regulation of probability characteristics of accidental outflows only for ice damages.

The second approach seems preferable because restrictions of probable outflows at collisions and strandings of tankers are already regulated by the MARPOL convention which though not taking into account peculiarities of the operation of ships in the Arctic covers also tankers navigating in ice conditions. However the methods put forward for the assessment of the expected accidental spill have been developed as applied to the first approach because the practical use of common methods without special effort permits the procurement of necessary data for the use of the second approach.

The above methods are the first ones in the world practice of the combined probabilistic estimation of the expected values of accidental spill of oil as a result of three types of accidents. They were developed on the basis of the first similar methods of 1978 [1] taking into consideration two types of accidents: collisions and strandings.

Thanks to the unique experience of the operation of Russian ships in the Arctic Ocean there is a real possibility to get fairly representative statistical data needed for bringing the methods to a numerical algorithm.

The practical procedure for determining mathematical expectation of the emergency oil outflow was developed in 1995 along with the estimation of probable sea pollution from ice damaged existing ships sailing along the NSR.

On the basis of investigations carried out the influence of constructive solutions on probable oil spills from ice tankers was determined and the requirements for structural safety of tankers sailing along the NSR were formulated In conclusion, the works to be carried out during 1996-1997 within INSROP concerning this problem are specified.

The review of the work of 1993 is positive. Certain remarks on figures 1.4, 1.5, 1.9 mainly concern their interpretation and use. Additional explanations and comments to these remarks are attached to the report (Annex 1).

The review of the work of 1995 is positive. Additional explanations and comments to these remarks are attached to the report (Annex 2).

The authors express their gratitude to the reviewer for his attentive, objective and qualified consideration of the work as well as for valuable comments on the content of the report.

I. ANALYSIS OF ICE DAMAGES TO HULL STRUCTURES OF TANKERS OF ARCTIC NAVIGATION

1.1 General analysis of ice hull damages of tankers navigating along the NSR

The major part of the Russian tanker fleet providing for the transportation of liquid supply cargoes along the Northern Sea Route during the last 20 years has consisted of old tankers of "Baskunchak" type (L1), as well as of UL class tankers of "Samotlor" and "Ventspils" types built in Finland in the seventies and eighties accordingly. For the delivery of oil cargoes to the shallow-water ports of the eastern sector of the Northern Sea Route the old L1 class tankers of "Baskunchak" type (DW = 1660 t; L x B x T = 83.4 x 12 x 4.6; N = 2000 h.p.) were used too.

Character of ice damages , their features and frequency are shown in Fig. 1.1 - 1.9.

On "Baskunchak" type tankers of old construction (sixties), which had no double bottom and inner sides in way of cargo tanks, the largest portion of hull damages falls upon the middle of the bow section and the bilge strakes over the whole length of the hull. Damages of the side framing are observed almost over the whole length of the hull, including bilge strakes. On ships of "Baskunchak" type the distribution of damages over the hull length is similar both for corrugation (bulge) and dents for all connecting members.

It should be noted that aggravation of the operating conditions on all the Arctic routes resulted not only in a higher rate of damages to the aged, deteriorated hulls but also in a considerably increased number of heavy ice damages to modern hulls built according to the current Register's Rules at shipyards of the leading European Builders to the highest ice categories UL, ULA.

Thus, numerous damages to the shell plating and framing were recorded on the "Samotlor" type tankers, built to the ice category UL since 1975 to 1978, chiefly to the framing and shell plating in the fore end and also in the bilge area and abutting bottom strakes right to the midship section.

On these ships up to 70% of hull ice damages after arctic navigation fall on these areas (Fig. 1.1 - 1.6) and the amount of replaced shell plating reaches 100 m and more per vessel.

On ships of "Samotlor" type, corrugation of side plating occurs mainly in the forebody and in the "bow intermediate region". The highest frequency of occurrence of corrugation falls upon the area within 0.05-0.1 L distant from the fore perpendicular. The framing damages are mainly observed in bottom grillages and bilge strake over a considerable length of ship (zones A,B) the highest amount of damages occurs in side framing and in the bow intermediate section the place of the highest frequency of framing damages being 0.1 L distant from the fore perpendicular (Fig.1.1,1.4,1.5,1.6).

In the forebody of the first series of "Samotlor" type tankers (Fr. 157-200) the absence of intermediate frames above the ice belt as well as the sharp decrease of thicknesses from 28 to 16,18 mm (for bottom - up to 20 mm) of the bilge strakes abutting upon the ice belt has resulted in a noticeable decrease of the strength of plates of these shell plating areas.

Due to the mass character of hull ice damages of the first series of the "Samotlor" type tankers it was necessary to attach additional ice strengthenings on tankers in process of operation.

Another type of structure mass damages in the area of fore peak and bilge on these ships (common for plate constructions of all arctic ships) are permanent sets ("bulges") of the walls of stringers, diaphragms, platforms, bulkheads abutting upon the shell plating. The extent of such deformations is 300-400 mm from the shell, Fig. 1.2,1.7. It should be noted that after the ice trials of tanker "Igrim" (of the same type) in the Gulf of Bothnia at ice thicknesses up to 70 cm permanent sets of hull structures were not found.

On new UL class tankers of "Ventspils" type the escorting of which during winter supply voyages through ice isthmuses was often carried out in "short" tow, the largest number of damages is concentrated below the ice belt: along the whole length of the ship in bilge strakes and mainly in the forebody in bottom strakes. Attention should be paid to the considerable number of ice damages of the stern bilge portion in way of the bossing as a result of manoeuvring in thick ice while moving astern.

As a whole the distribution of ice damages by the ice classes of the vessels, reflects the composition of the fleet, used in Arctic navigation. The most frequent damages were recorded within the most numerous group of vessels, involved in Arctic traffic - namely vessels of ice lasses UL and L1 including arctic tankers the ice strengthenings of which were inadequate for intensive operation in the Arctic, in particular, in its Eastern sector).

However old deteriorated vessels (older than 15 years) suffered heavy ice damages on almost every voyage in arctic ice (mainly the vessels of ice class L1) provided with no double bottom and inner sides. In this connection it should be noted that for such ships the common cause of the breakage of hull plating tightness and consequently of the pollution of water area, apart from ice damages are “corrosion holes” (honeycombs) and cracking in structures induced by stress concentrators.

These factors stipulate different types of oil leakage and outflow of oil products overboard, namely:

- leakage of oil cargo through the ship side plating in way of side cargo tank due to propagation of cracks arising at the low end of the web frame (bracket) at the point of its connection to the bottom frame (floor)
- overflow (flow) of liquid cargo between adjacent cargo and ballast tanks through the longitudinal bulkheads, which are damaged as a result of plate wear: the liquid cargo flows into the ballast tanks and the mixture of water and oil is pumped out overboard.
- the liquid cargo through cracks in the inner bottom plating mixes with a ballast in the double bottom arranged just under the cargo tanks, and pumped out overboard.

Cracks also occur as a result of material fatigue after some years of tanker service and in consequence of corrosion wear of the structure. The structural fatigue is caused by reversed loads. The fatigue cracks appear first of all in the areas characterized by higher stresses which were not sufficiently compensated at the development of structures. The formation of corrosion craters contributes to cracking especially at low temperatures under dynamic loads. In this respect the imperfect technology of stripping tanks represents a great danger. So in ships without inner bottom the intensive corrosion of bottom plates occurs as a result of frequent stripping of tanks with washing by water jets. By the action of mud, which is washed off during the tank cleaning, the corrosion intensity grows.

1.2. Generalization and analysis of materials on the ice damages to the structures of side and bottom grillages

As mentioned above, the ice damages of arctic ships as a rule occur in the bow third and in the middle part of the hull being located near the forepeak and bilge strakes. The extension of areas of navigation and the prolongation of periods of operation of ships in the Arctic led to an increase both in number and sizes as well as to a change in longitudinal distribution of ice damages to arctic cargo ships, including tankers.

Some typical ice damages of tanker hulls are shown in Fig.1.6 - 1.8. However some differences exist between ice damages to the particular ships. On tankers of the first series of "Samotlor" type considerable dents often occurred due to the excessive distances between side stringers and the insufficient strength of frames in the bow area of Fr.157-200 (r 280*11) up to 2m instead of 1.5 m required by Regulation 81, Ch. 26. The most common side grillage ice damages of this region of the forebody end in the area of waterlines were dents often accompanied by the "tumbling in" of frames. Largest deflections of dents reached 135-200 mm, those of bulges 70 - 90 mm, Fig.1.3 - 1.5. The dents 300 mm in depth observed in the forebody of tanker “Kamenets Uralsky” are evidently connected with operation in swallow water and cannot be attributed to ice damages.

On these ships the main type of ice damages were multiple damages mostly in the form of bulges and corrugation of plates with average deflections of 15-20 mm for bottom and 30-40 mm for bilge.

Maximum plate deflections in the forebody are 90 mm and in the midship portion - 60 mm. Such deflections are commonly accompanied by cracks and leakage.

There were practically no framing and plating damages within the ice belt of "Ventspils" type tankers during the first year of operation.

Average values of the permanent deflection of bottom (bilge) plates (bulges,corrugation) after the first year of operation on these tankers were: in the middle and fore portions f = 15-20 mm, in the aft 8-12 mm; at maximum permanent deflection of the bottom plating: f = 30-40 mm in the fore part and f = 18-25 mm in the aft. Function of probability of permanent deflections of the hull plating and framing of arctic tankers are given in fig. 1.10.

Main Causes of Damages to the Underwater Hull Portion of Arctic Tankers.

The main causes of ice damages to tanker hulls in the Arctic are the severe navigation conditions including ice conditions characterized in the domestic Arctic by a considerable changeability and swallow waters in most sectors of the NSR. The high level of the damageability of ships sailing along the Northern Sea Route may be also attributed to structural pecularities and specific navigation tactics of transport ships under ice conditions.

So a great deal of side damages to “Samotlor” type tankers within 0.1-0.2 L from forward perpendicular is due to their large sizes (relative to channel). When the icebreaker is turning the tankers hit into the turning radius protruding out of the channel ice edge and break it finally by this side area. Due to rapid increase of ice loads on these regions the last ones become the most damaged hull areas of this type of ships.

Errors and deviations from Rule requirements admitted when designing the forward hull structures of such tankers caused mass ice damages in this area. Only the presence of double bottom and inner side on the mentioned tankers prevented significant pollutions of water areas induced by severe ice hull damages in way of cargo tanks.

As a result of the analysis of the dock inspections, permanent sets of the underwater hull portion of tankers of the "Ventspils" type may be divided into four categories:

- dents in way of bow and bilge;
- deformation in the bilge of the afterbody;
- sloping larger size dents in the bottom;
- sharp edge damages.

Damages of the first type are apparently caused by normal ship movement in ice. While being towed in the channel at the end of a long tow a ship may transversely shift in relation to the channel axis (yaw) and owing to this movement strike the ice edge in the channel. So deformations in the after part of tankers are probably caused by the above towing or by the movement astern when large ice blocks get between the ship and the berth or the channel edge and cause shell plating damages. Dents of the third type are probably brought about by the overcoming of an ice isthmus or a hummock or when the ship touches the anchor ice (due to the flux and reflux alterations) sometimes accumulated in arctic regions on the sea bottom. Deformations of this type occur only in the bottom and scratches may be seen along the whole length of the ship. The reason for these damages is the ground touching in shallow areas, because under such conditions this type tankers operate during supply operations.

In the area of variable waterlines there are only insignificant local deformations. Of apparent deviation is the dent in the fore part of tanker "Kashira", port, Fr.142-146, probably caused by getting foul of the icebreaker stern.

There were practically no frame and shell plating damages in the ice belt of tankers of "Ventspils" type within the first ice navigations.

As a whole the analysis of the character of ice damages and qualitative composition of the arctic tankers most susceptible to damages shows that the principal causes of ice hull damages are as follows:

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

Distribution of ice damages to hulls by the ice classes (ice categories) of the vessels usually reflects composition of the fleets used in Arctic navigation. Frequent damages were recorded within the most numerous group of vessels involved in the Arctic, namely traffic-vessels of ice category UL and L1, ice strengthenings of which were inadequate for intensive operation in the Arctic, in particular, in its Eastern sector. Heavily deteriorated vessels (older than 15 years) suffered ice damages on practically every voyage in ice (mainly the vessels of ice category L1). Notwithstanding the measures taken to reduce the accident rate, technical losses entailed by ice damages still remain to be high both in magnitude and in relative figures per vessel.

Apart from ice hull damages the oil pollution of the water basin may be caused by plating and framing cracking induced by cyclic loads and stress concentrators. However the relative number of these cases is small. According to generalized data of the Committee on the prevention of sea pollution (Japan) 30% of cases of oil outflow overboard were brought about by human error and only 2,4% were caused by bad quality of ship hull structure.

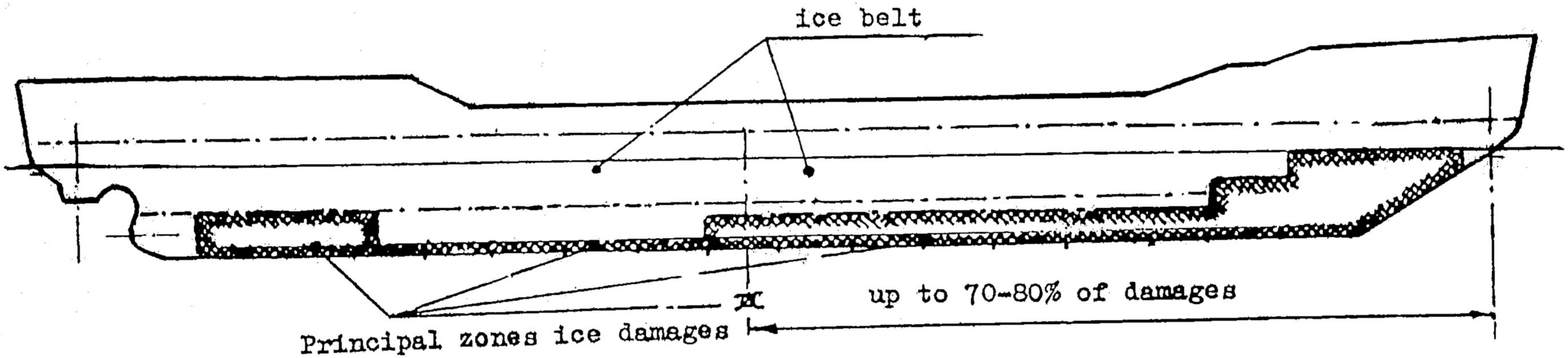


Fig. 1.1. Generalized scheme showing distribution of ice damages over arctic tanker hulls.

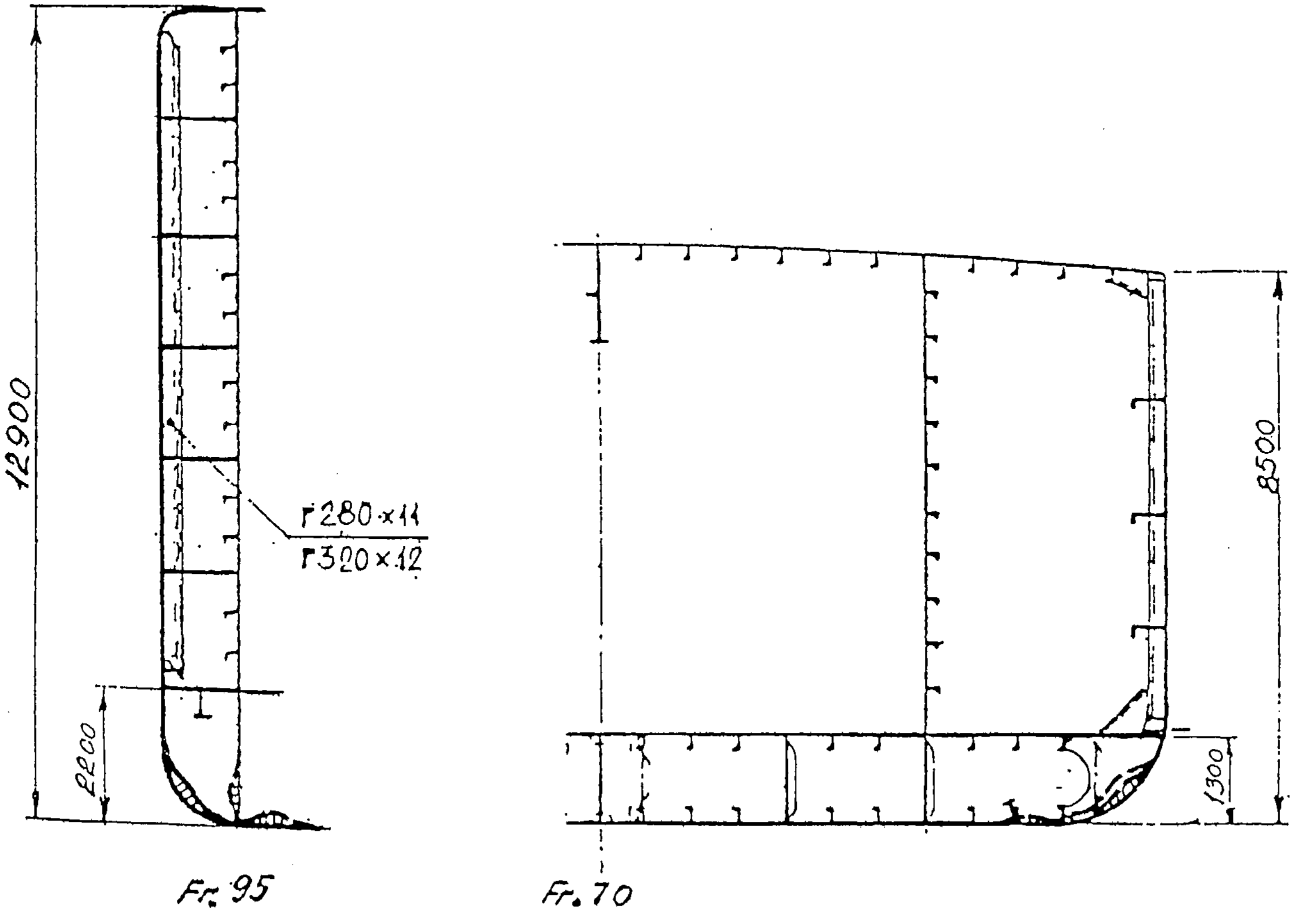
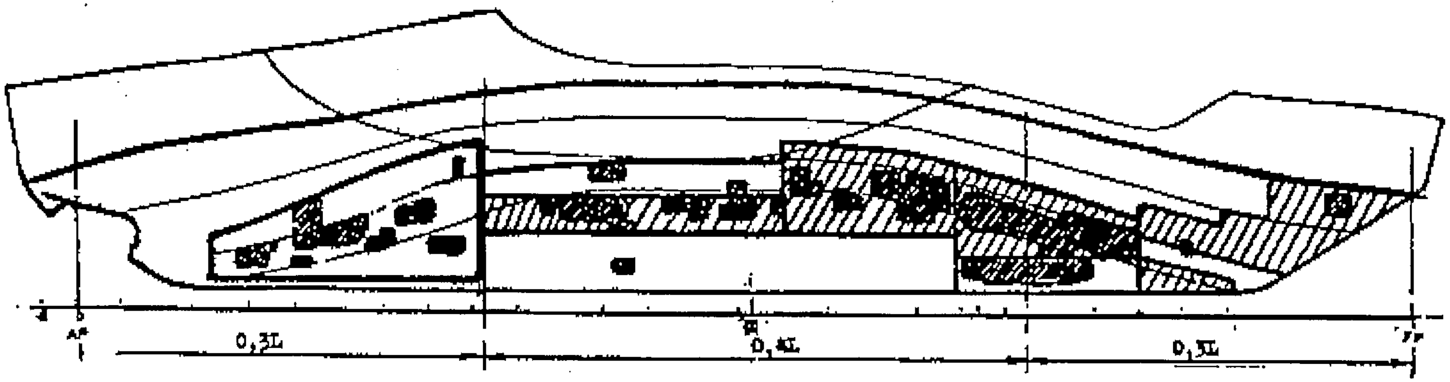


Fig. 1.2. Typical ice dents in midbody on arctic tanker hulls



	strake	Afterbody(C)	Midbody (B)	Forebody (A)
dents	Side	90 *	I00-I20	I60-200
	bilge	80 *	I20-I30	I20-I60
	bottom	70 *	90-I00	90-I00
bulges	side	20 *	60	70-90
	bilge	75 *	25	35-40
	bottom	30 *	30	20

*-separately damages

Fig. 1.3. Areas of the most ice damages and maximum values of frame dents of arctic tankers

☐ ■ - main regions of damages of tanker "Samotlor" and "Ventspils" types

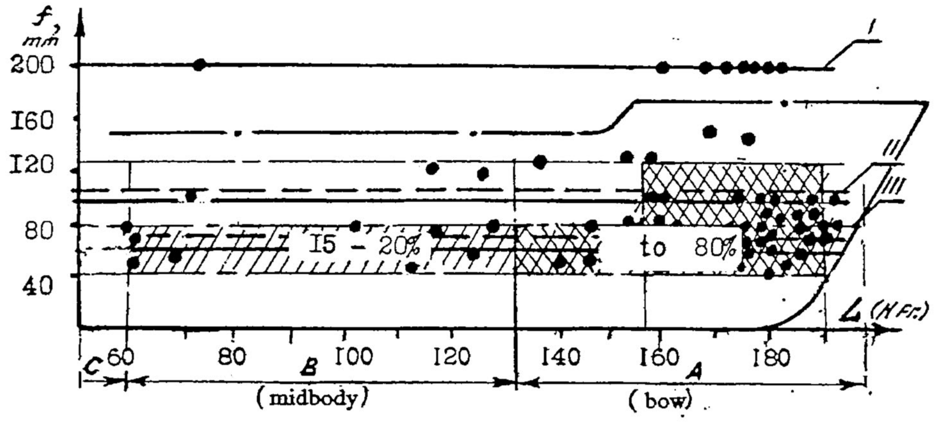


Fig. 1.4. Distribution of permanent deflections of frames along tankers of of "Samotlor" type
1 - side, II - bilge, III - bottom

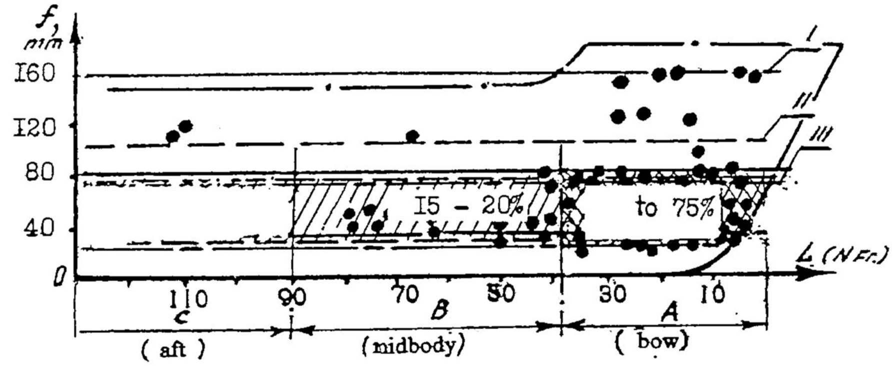
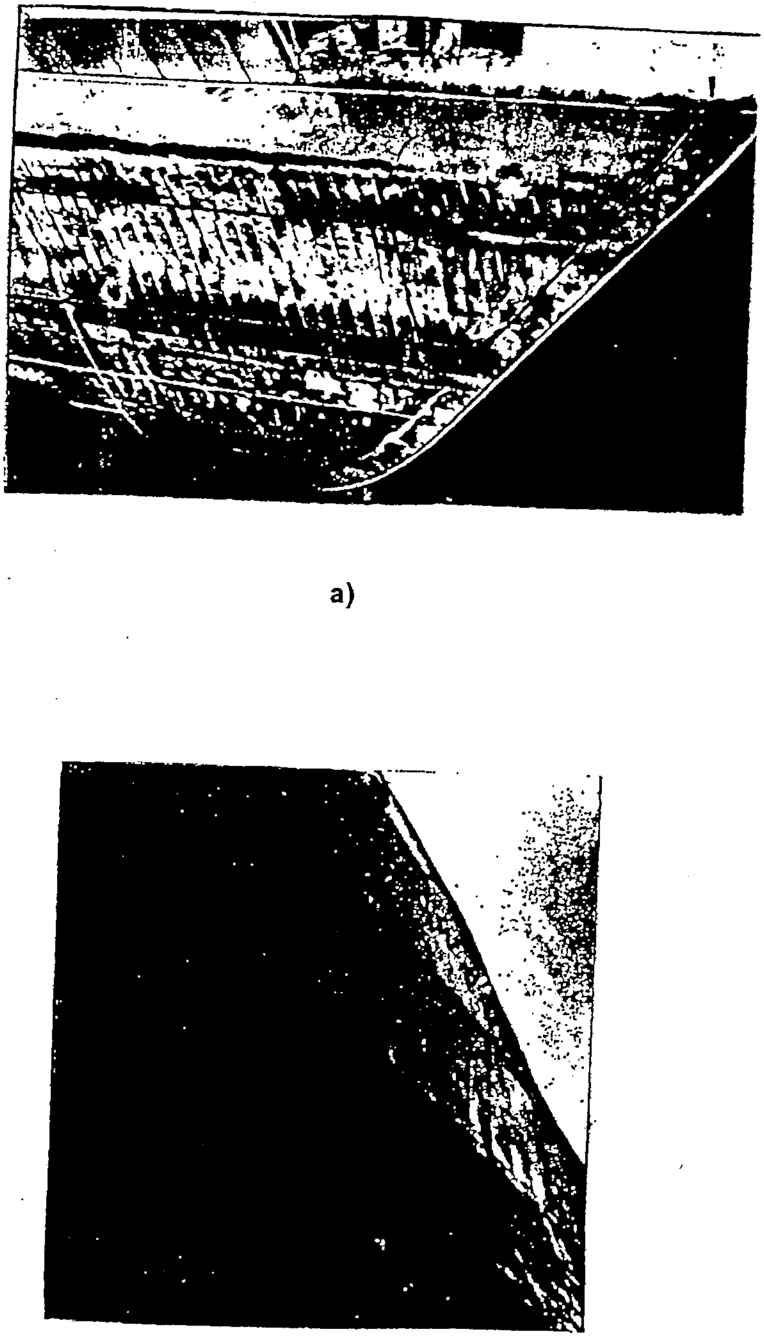


Fig. 1.5. Distribution of permanent deflections of frames along tankers of of "Baskunchak" type
1 - side, II - bilge, III - bottom

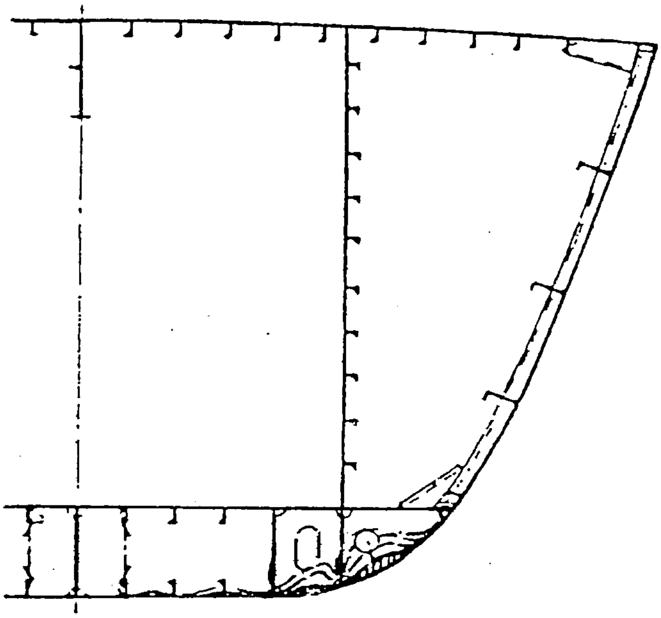


a)

b)

Fig. 1.6. Character of ice damages of arctic tanker bow a), b) - regions of forepeak and side

a)



b)

Fig.1.7. Typical location of ice dents on arctic tanker hulls
a),b) - bottom, bilge strakes

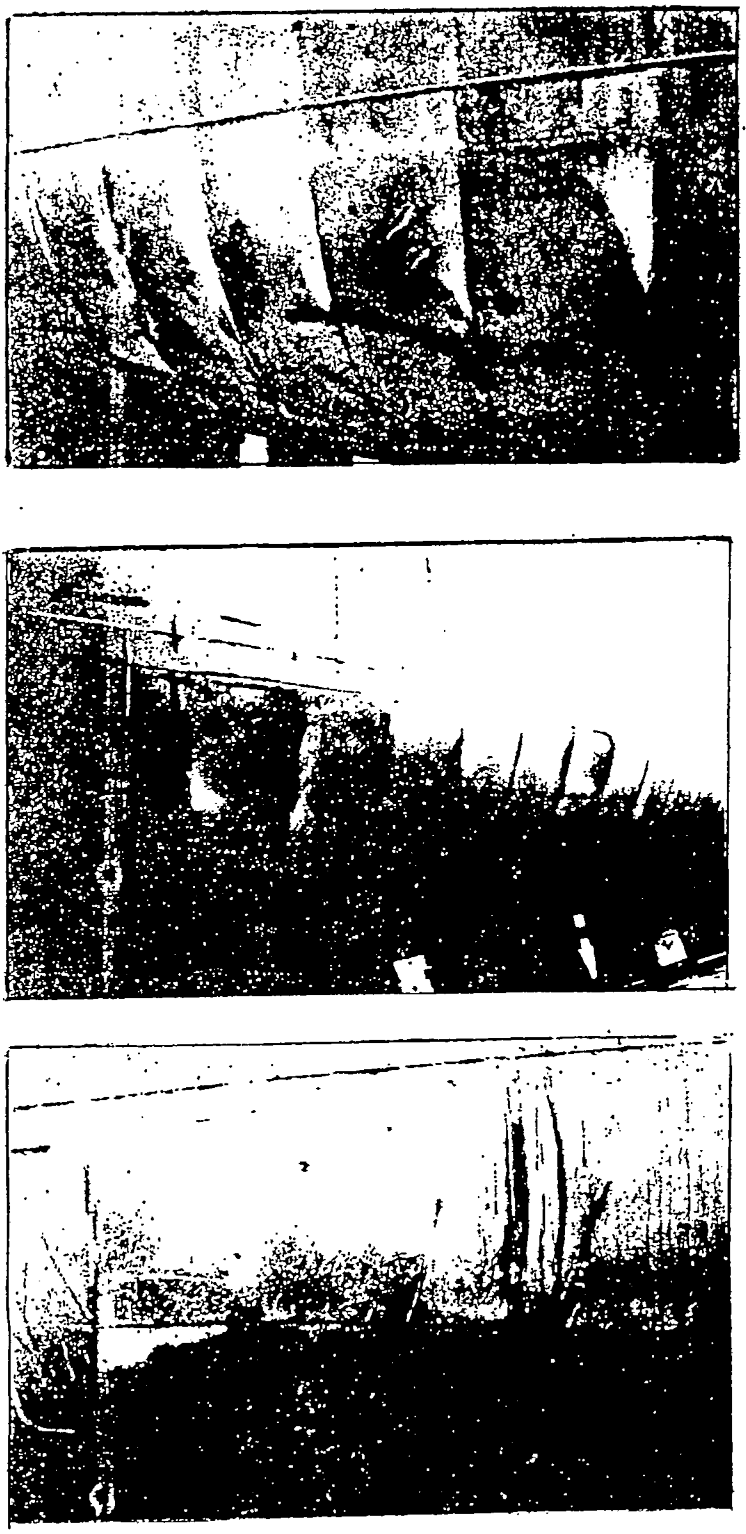


Fig.1.8. Corrugation types of bilge plates

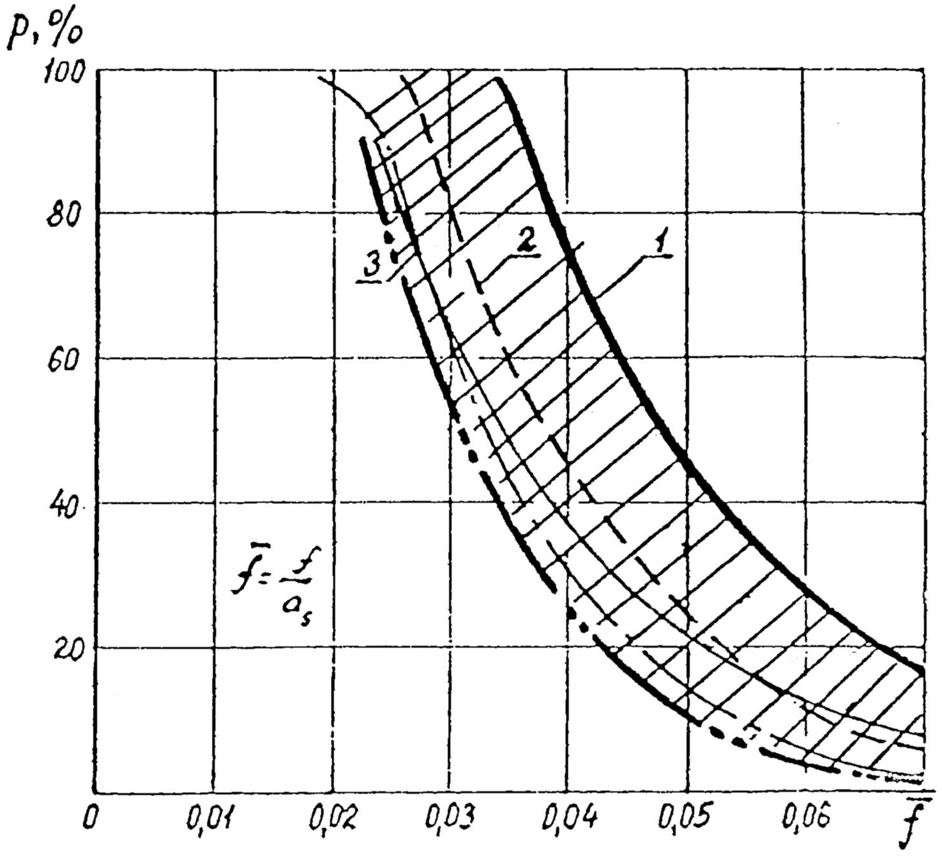


Fig. 1.9. Probability of relative permanent deflections of the bottom plating and bilge strake of icebreaking tankers

1,2 - middle part of the bottom and bilge,
3 - bottom bilge portions in the fore

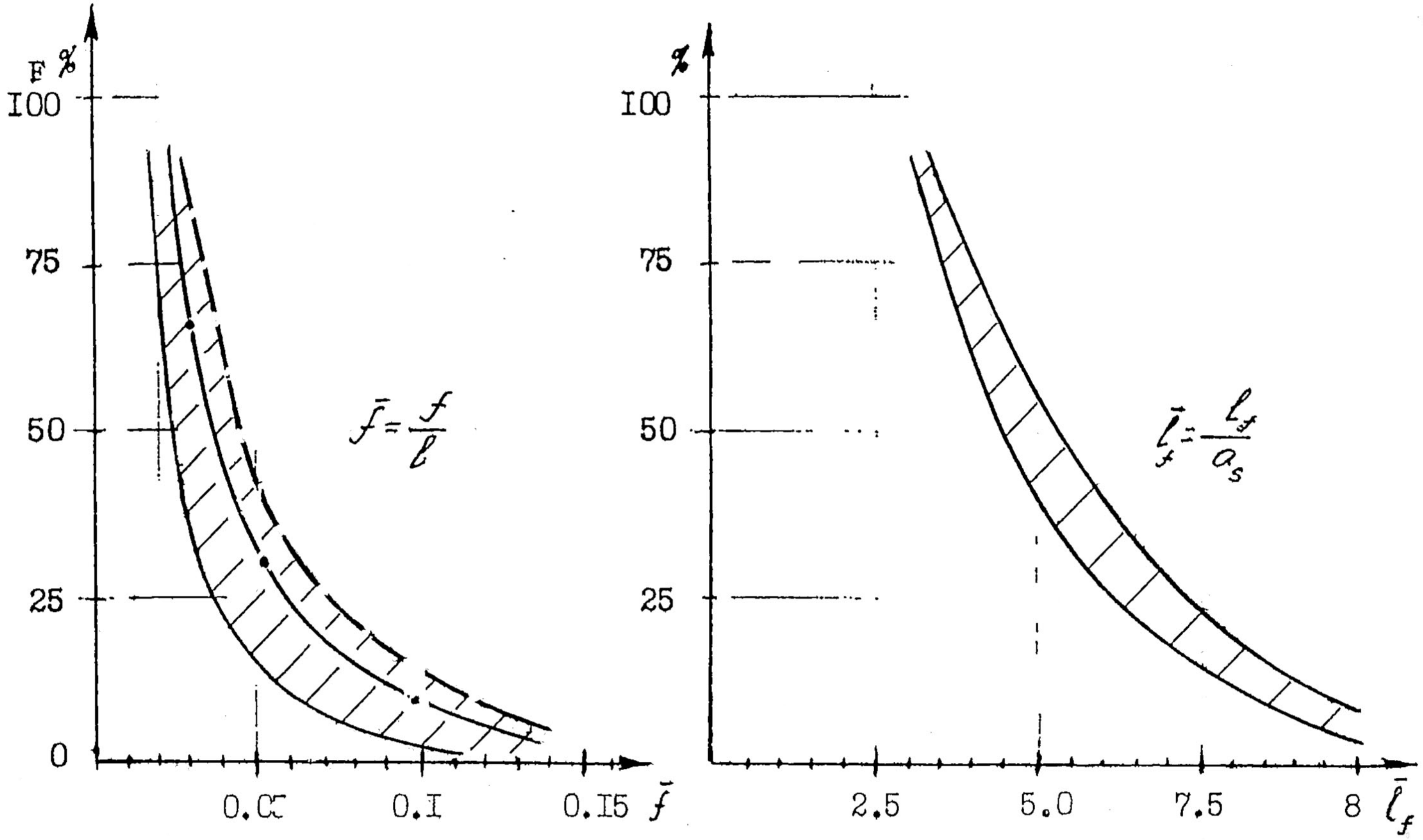


Fig 1.10. Distribution F=1-p for depth (f) and length (lf) of dents in side and bilge areas of the middle and intermediate parts of hull side of "Samotlor" type tankers

2. PROBABILISTIC EVALUATION ASSESSMENT OF THE EMERGENCY OUTFLOW FROM DOMESTIC ICE TANKERS OPERATING IN THE NORTHERN SEA ROUTE

2.1. Assessment of the probabilistic emergency outflow when navigating in ice-free water

Sizes of a hole which the ship gets as a result of damage and the coordinates describing its position by length, width and hull height are random values just as is the volume of cargo spilled out of the damaged ship. Therefore the mathematical expectation of volume Q_a of the cargo spilled as a result of ship being holed was taken as a criterion characterizing probable emergency loss of cargo.

In the determination of Q_a only side damages and holes got at stranding and ramming of the tanker in question by other ship were taken into consideration. Cargo leakages due to fires, explosions and ship breakage are not taken into account because in these cases the loss of cargo practically does not depend on the scheme of subdivision of cargo space into compartments. In the case of ramming by the ship in question of other ships the leakage of cargo usually either does not occur or is insignificant.

Therefore the disregard of holes in such emergency situations should have no effect on the comparability of the assessment of Q_a for tankers of different types.

In the development of methods the materials of the IMO Rules for the division into compartments of passenger ships and Rules of the Russian Register of Shipping were used. As these Rules take into account the distribution laws of the parameters of holes got only by rammed ships the design relationships for the calculation of the compartment damage probabilities at strandings were added.

Power consumption of hull structures was not taken into account in the same way as was the case in the USSR Register Regulations.

In this case the mathematical expectation of cargo outflow is:

$$Q_a = p_c Q_c + p_s Q_s + p_{ic} Q_{ic} \qquad (2.1)$$

where: Q_c - mathematical expectation of the outflow of cargo as a result of getting a hole due to the ramming of tanker by other ship;

Q_s - the same at stranding; Q_{ic} - the same as a result of ice damage; P_c, P_{ic}, P_s - probability of emergency outflow of oil products at rammings, ice damages and strandings.

Values Q_c, Q_s and Q_{ic} are determined by formula:

$$
\begin{aligned}
Q_c &= \Sigma \quad W_c \; q_c \\
Q_s &= \Sigma \quad W_s \; q_s \\
Q_i &= \Sigma \quad W_{ic} \; q_{ic}
\end{aligned}
\qquad (2.2)
$$

where: W_c - damage probability of the compartment in question or of a group of adjacent compartments as a result of getting a hole due to the ramming of tanker by other ship;

W_s - the same at stranding;
W_{ic} - the same in the case of hole caused by ice;
q_c - leakage from the compartment in question or group of adjacent compartments at ramming;
q_s - the same at stranding;
q_{is} - the same in the case of hole caused by ice.

The summation in formulas (2.2) is made by numbers of all compartments or groups of adjacent compartments and that is why $\Sigma W_c = \Sigma W_s = \Sigma W_{ic} = 1$

Probabilities W_c, W_s, W_{ic} and leakages q_c, q_s, q_{ic} are determined under the assumption that the ship gets one continuous hole. In the course of processing of statistic data in the rare cases when simultaneously there were several damages, one conventional hole covering all damages was introduced.

Apparently in collisions the leakage q_c for compartments or groups of adjacent compartments at the damage of which a fully loaded ship sinks or capsizes should be taken as equal to the total volume of the transported cargo. For oil tankers the volume of cargo includes 75% of the full storage of liquid fuel. For other compartments and groups of adjacent compartments at the damage of which the watertight integrity of a fully loaded ship is provided, leakage q_c (if the cargo density is less than 1) is to be determined by formula:

$$q_s = 0.2 \; V^* + 0.8 \; V \qquad (2.3)$$

where: V* - part of the volume of a damaged cargo tank or tanks located above the horizontal plane passing at half of the free board of fully loaded ship with 75% of stock;

V - full volume of the same tanks.

Formula (2.3) was obtained under the assumption that if holes are over the waterline, only the cargo which is above the lower point of hole is spilled. The distribution law of z-axis of this point was taken as being uniform. If holes are situated below the waterline and got as a result of ramming it was assumed that the outside water replaces all the cargo. According to statistical data gathered by IMCO the frequency of the occurrence of holes above the waterline is 0.2 and this value has been taken into account in formula (2.3).

At $\gamma > 1$ (γ - cargo density) and provided watertight integrity the value q_c apparently will be equal to volume of a damaged cargo tank over the horizontal plane being Z_d distant from the principal one. This distance is equal to the mathematical expectation of z-axis of the lower point of the hole.

$$q_c = V (T - 3.1 \ Kv \ Kd) \qquad (2.4)$$

where: T - draft of fully loaded ship with 75% of stock.

Coefficients K_v and K_d taking account of the influence of the specification speed (in knots) and full displacement of ship D (in tons) upon the sizes of damages may be determined by formulas;

$$k_v = 0.4 \ (1 + v_s / 14) \quad \text{at} \quad 0.67 < k_v \leq 1 \qquad (2.5)$$

$$k_d = \sqrt{} (2 + 0.001 D) / (1 + 0.001 D)$$

Formulas (2.5) were obtained with the use of IMO statistical data about sizes of holes at ship's collision.

At stranding the leakage q_s is to be determined by formula:

$$q_s = 1.15 \ V + (15 \ T - B) \ V / (\gamma \ (15 \ H - B) \qquad (2.6)$$
$$\text{at} \quad 0.25 \ V < q_s \leq V$$

This relationship was obtained under assumption that at $\gamma > 1$ the whole cargo is spilled and at $\gamma = 0.67$ about 1/3 of the tank content flows out. The last value (1/3) in the same way as the limitation of minimum outflow by 25% of the volume of damaged tanks is taken with due account of provisions of Rule 23 of the Annex 1 to the 1973 MARPOL Convention.

In the present work for taking into account the influence of the seas it was assumed that because of the damping effect of the double bottom in the course of the flow of oil and water over it the leakage in the presence of double bottom is determined by formula (2.6) and without double bottom (at $\gamma < 1$) $q_s = 0.25V$, that is irrespective of other factors at stranding of a tanker without double bottom half of the whole content of oil of cargo tanks is spilled out.

Probability W_c of ramming may be determined by the product of three factors

$$W_c = a_c \, p_c \, r_c \qquad (2.7)$$

a_c value takes into account the distribution law of a relative abcissa x_d/L of the middle of hole of the rammed ship and for the compartment in question or group of adjacent compartments is equal to the value of distribution density $f_c(x_d/L)$.

p_c value takes into account relative extent of flooded compartment l/L and the distribution law of a relative extent of hole taking into consideration the influence of a specification speed. Value p_c is practically equal to the probability of damage of the compartment restricted only to transversal bulkheads at $a_c = 1$.

Value r_c for side compartments is equal to the probability of non-damage of the longitudinal bulkhead of a rammed ship and at combined damage of side and adjacent compartments to the probability that the bulkhead dividing these compartments is damaged and next longitudinal bulkhead is not damaged. Design relationships for the determination of these values obtained by the approximation of statistical distributions are given below.

$$a_c = 0.4 \, (1 + \xi_1 + \xi_2 + \xi_{1,2}) \qquad (2.8)$$

where $\xi_1 = x_1 / L$, $\xi_2 = x_2 / L$ if $x \le 0.5 \, L$

$\xi_1 = \xi_2 = 0.5$ if $x > 0.5$

$\xi_{1,2} = (x_1 + x_2) / L$ if $x_1 + x_2 \le L$

$\xi_{1,2} = 1.0$ if $x_1 + x_2 < L$

where:

x_1 - distance from the aft perpendicular to the after bulkhead of the compartment in question;

x_2 - distance from the aft perpendicular to the fore bulkhead of the compartment in question;

L - length of ship between perpendiculars.

Values p_c at $L < 200$ m

$$p_c = k_v\ (4.46\ A^2 - 6.2\ A^3) \qquad (2.9)$$
$$\text{if}\ \ A \le 0.24$$
$$p_c = 1.072\ A - 0.086 - (1 - k_v)\ (A - 0.24)\ /13$$
$$\text{if}\ \ A > 0.24$$
$$\text{where}\ \ A = 1\ /\ k_v\ L$$

at $L > 200$ m

$$p_c = k_v\ (4.46\ A1^2 - 6.2\ A1^3) \qquad (2.10)$$
$$\text{if}\ \ A \le 0.24$$
$$p_c = 1.072\ A1 - 0.086 - (1 - k_v)\ (A1 - 0.24)\ /13$$
$$\text{if}\ \ A > 0.24$$
$$\text{where}\ \ A1 = 1\ /\ 200\ kv\ L$$

where: l - length of the tank in question .

For pairs of adjacent compartments p_c value used in the calculation is to be determined by formula:

$$p = p_{1,2} - p_1 - p_2 \qquad (2.11)$$
$$\text{or}$$
$$p = p_{2,3} - p_2 - p_3$$

etc.,

where: p_1, p_2 etc. - values of p_c determined by formulas (2.9) and (2.10) for single compartments with length l_1; l_2 etc.

$p_{1,2}$ - value of p(c) determined in the same way as applied to a pair of compartments with a total length $l_{1,2} = l_1 + l_2$;

l_1; l_2 etc. - lengths of single compartments.

While calculating values a_c and p_c the following conditions should be met:

$$(1\ /\ n)\ \Sigma\ a_i = 1 \qquad (2.12)$$

$$\Sigma p_i = 1$$

where: n - number of compartments considered

Value

$$\mathbf{r_c = 0.58\ C\ /\ (\ A + 0.02\ ) \quad if \quad C \leq 0.2} \qquad (2.13)$$

$$\mathbf{r_c = 0.0016\ /\ (\ A + 0.02\ ) + C + 0.36 \quad if \quad C > 0.2}$$

$$\mathbf{at \quad C = b\ /\ k_v\ B}$$

and at A < 0.2 B value r_c may be determined by linear interpolation between unity (at A = 0) and value r_c determined by formula (2.13),

where: B - breadth of ship;

l - distance between transversal bulkheads corresponding to lengths of compartments by calculation of a_c and p_c;

b - distance of longitudinal bulkhead from shell plating measured in the plane of load waterline for the area where values a_c and p_c are determined.

At stranding, as the analysis of IMO statistical data about sizes of ship holes has shown:

- sizes of damage: length l_d height hd and depth bd of the hole are practically not inter-correlated;
- value ld can be taken as directly proportional to the length of ship as for a hole of rammed ships;
- value b_d can be assumed as being directly proportional to the breadth of ship as for a hole of rammed ships;
- value h_d is not correlated with ship's dimensions.

These results of analysis were used to obtain design relationships for the determination of probability W_s of the compartment damages at stranding:

$$\mathbf{W = p_s\ r_h\ r_s} \qquad (2.14)$$

Value p_s is equal to the probability of damage of the compartment in question or of a group of adjacent compartments at getting a hole caused by stranding if compartments are restricted only to transversal bulkheads.

Value r_h is equal for inner-bottom compartments to the probability of non-damage of the second bottom and at combined flooding of inner-bottom compartments and those over the double bottom to the probability of damage of the second bottom.

Value r_S is actually similar to value r_C, but due to the difference of the distribution laws of the random value r_S at ramming and stranding, formulas for the calculation of r_C should be different.

While deriving formulas for the calculation of p_S, r_h and r_S values it was assumed that high speed vessels at stranding get larger holes, but height and depth of hole do not depend on speed. The influence of the speed of movement upon l_d/L value at stranding was taken the same as at ramming.

To simplify the calculation of Q_a density f_S of the distribution of the system of random values l_d/L and x_d/L at stranding was represented as:

$$f_s(l_d/L, x_d/L) = 0.8 f_c(l_d/L, x_d) + 0.4 f_h(l_d/L) \tag{2.15}$$

where:

f_S - distribution density of values l_d/L and x_d/L ,determined as for rammed ships;

f_h - distribution density of values l_d/L and x_d/L for holes extended from the bow proper towards the stern got as a result of stranding.

The portion of each type of holes was selected so that the obtained distribution density would be in agreement with the bar graph of relative hole lengths at stranding produced in the analysis of IMO statistics on ship damages.

$$p_S = 0.6\ a_c\ p_c + p_h \tag{2.16}$$

As value p_h takes account only of holes extending from the bow proper towards the stern, for all single compartments except forepeak and for all adjacent compartments including forepeak p_h value is zero.

The probability of combined damage of several adjacent compartments including forepeak at getting a hole extending from the bow proper to the stern is equal to the probability that the hole extent will be less than the total length of these compartments l_Σ but more than the total length of compartments l^* excluding the last stern one.

Probability of such event:

$$P(l^* < l_d < l_\Sigma) = F_h(l_\Sigma) - F_h(l^*)$$

where: F_h - integral function of the distribution of length of holes extending from the bow proper to the stern.

On the basis of that and taking into account the assumptions adopted the following formula was derived:

$$P_h=0.4\{(4-3\,k_V)(x_2-x_1)/L+3(1-k_V)[(L-x_2)^2-(L-x_1)^2\,]\,/\,L\} \qquad (2.17)$$

where values X_1 and X_2* are distance of after bulkheads.

Number of adjacent compartments in the determination of p_h is not restricted to three-fold compartments.

Besides, as a result of approximation of the integral function of distribution $F_S(h_d)$ by linear relationship the following formulas for the calculation of r_h were obtained:

$$r_h = 0.5\,\sqrt{\ } h_d \qquad \text{at } h_d \leq 3\text{ m} \qquad (2.18)$$

$$r_h = 0.02\,h_d + 0.8 \qquad r_h \leq 1 \text{ at } h_d > 3\text{m}$$

- for combined damage of inner-bottom compartments and of those arranged above the second bottom:

$$r_h = 1 - 0.5\,\sqrt{\ } h_d \qquad \text{at } h_d \leq 3\text{ m} \qquad (2.19)$$

$$r_h = 0.2 - 0.02\,h_d + 0.8 \qquad r_h \leq 0 \text{ at } h_d > 3\text{m}$$

Also by approximation of the integral function of distribution $F_S(C)$ by linear relationship, formulas for the determination of value r_S (j = 1) were obtained

- as applied to single outer (side) compartment:

$$r_{1,S} = 1.085\,\sqrt{\ }(b_1/B) + 0.633\,(b_1/B)^{1.5} \qquad \text{at} \quad b_1/B \leq 0.2 \qquad (2.20)$$

$$r_{1,S} = 0.519\,b_1/B + 0.05\,(b_1/B)^2 + 0.437 \qquad \text{at} \quad b_1/B > 0.2$$

- as applied to single not outer (any middle) compartment (j≠1):

$$r_{j,S} = 0.633\,(b_1/B)^{1.5} \qquad \text{at} \quad b_1/B \leq 0.2 \qquad (2.21)$$

$$r_{j,S} = 0.405\,b_1/B + 0.05\,(b_1/B)^2 + 0.026 \qquad \text{at} \quad b_1/B > 0.2$$

- for couples of compartments adjacent in width ($b_{1,2} = b_1 + b_2$) one of which is outer side compartment ($j = 1$)

$$r_{1,2,s} = r_{(1+2)s} - r_{1s} - r_{2s} \qquad (2.22)$$

where:

r_{1s} - hole width factor at stranding for a single outer (side) compartment [with width b_1];

r_{2s} - the same for the second compartment out of two adjacent in width (not side) ones [with width b_2];

$r_{(1+2)}$- the same for a single (side) compartment with width b , equal to the total width of two adjacent compartments b_1 and b_2 ($j = 1$).

- as applied to couples of adjacent in width not outer compartments:

$$r_{j,j+1,s} = r_{(j+(j+1)),s} - r_{j,s} - r_{j+1,s} \qquad (2.23)$$

where: r_{js} - hole width factor at stranding for a single not outer compartment (first from the starboard out of adjacent ones) with width b_j;

$r_{j+1,s}$ - the same for the second not outer compartment (with width b_{j+1}) out of adjacent ones in width;

$r_{(j+(j+1))s}$ - the same for a single not outer compartment with a width equal to total width of two adjacent compartments b_j and b_{j+1} ($j \neq 1$);

also as applied to three-fold adjacent in width compartments [$b_{1,2,3} = b_1 + b_2 + b_3$), the first of which is the outer side one ($j=1$)

$$r_{1.2.3\,s} = r_{(1+2+3)\,s} - r_{(1+2)s} - r_{(2+3)s} + r_{2s} \qquad (2.24)$$

- for three-fold adjacent in width not outer compartments ($j \neq 1$)

$$r_{j+1,j+.2s} = r_{(j+(j+1)+(j+2))s} - r_{(j+(j+1))s} - r_{((j+1)+(j+2))s} + r_{(j+1)s} \qquad (2.25)$$

accordingly for four-fold adjacent in width [$b_{1,2,3,4} = b_1 + b_2 + b_3 + b_4$ compartments, first of which is outer (from the starboard) side one ($j=1$):

$$r_{1.2.3,4\,s} = r_{(1+2+3+4)\,s} - r_{(1+2+3)s} - r_{(2+3+4)s} + r_{(2+3)s} \qquad (2.26)$$

The above methods are suitable for the investigation of the efficiency of different systems of structural protection of tankers with a number of longitudinal bulkheads not exceeding three.

For the determination of a supposed volume of emergency outflow from tankers the mathematical expectation value of probable spillage Q_a should be multiplied by the probability of ship's getting into emergency.

Methods for the determination of mathematical expectation of the outflow Q_{ic} at getting an ice hole are now being developed.

By means of methods being developed of the probabilistic assessment now being developed the eventual outflows at collision and stranding for 3 tankers were calculated:

"Samotlor" - deadweight 16800 t, $Q_c = 0$, $Q_s = 400m^3$,
"Ventspils" - deadweight 6300 t, $Q_c = 130\ m^3$, $Q_s = 90m^3$,
"Partizansk" - deadweight 2900 t, $Q_c = 60\ m^3$, $Q_s = 50m^3$.

2.2. Procedure for determining the expected value $\overline{Q}_n$ of oil outflow from a damaged tanker when navigating in ice of the Arctic Ocean

-1. The expected value $\overline{Q}_n$ of oil outflow from a damaged tanker when navigating in ice should be determined by the formula:

$$Q_n = C_{is}\ \overline{Q}_{is} + C_c\ \overline{Q}_c + C_{st}\ \overline{Q}_{st} + C_{cn}\ \overline{Q}_{cn} \qquad (2.27)$$

where

C_{is}, C_c, C_{st}, C_{cn} - are respectively the relative frequencies of damages sustained due to contact with ice, collision with another ship, stranding, getting of the ship foul of another as applied to accidents during navigation in the Arctic Ocean.

$\overline{Q}_{is}$, $\overline{Q}_c$, $\overline{Q}_{st}$, $\overline{Q}_{cn}$ - are respectively the expected values of oil outflow caused by a damage sustained due to contact with ice, collision with another ship, stranding, the ship getting foul of another.

It is self-evident that

$$C_{is} + C_c + C_{st} + C_{cn} = 1 \qquad (2.28)$$

Inasmuch as the experience gained in ice navigation shows, in cases when the ship fouls another ships failures are usually caused to peaks containing no oil, basically:

$$\bar{Q}_{cn} = 0$$

Therefore, it would be advisable to transform the formula (1) into:

$$\bar{Q}_n = C_{is} \bar{Q}_{is} + C_c \bar{Q}_c + C_{st} \bar{Q}_{st} \qquad (2.29)$$

Because of comparability of the $\bar{Q}_n$ evaluations the following expression can be assumed as applied to the formula (2.29):

$$C_{is} + C_c + C_{st} = 1 \qquad (2.30)$$

-2. The quantities $\bar{Q}_c$ (collision with another ship) and $\bar{Q}_{st}$ (stranding) can be determined either by an algorithm proposed by V.N.Volkov and S.F.Glazov [1] or by an algorithm being currently developed by Committee MEPC of IMO.

-3. The expected value $\bar{Q}_{is}$ of oil outflow resulting from an ice damage will be determined from a formula similar to the complete probability formula:

$$\bar{Q}_{is} = \sum_{i=1}^{n} W_{is;\,i}\ q_i + \sum_{i=1}^{n-1} W_{is;\,i,\ i+1}\ q_{i,\ i+1} \qquad (2.31)$$

where

$W_{is,\ i}$ - is the probability that in case when the ship hull sustained an ice damage the latter is situated between the transverse bulkheads of the i-th compartment;

$W_{is,\ i,\ i+1}$ - is the probability that under the same conditions the damage impairs the bulkhead separating the i-th and i + 1-th adjacent compartments;

q_i - is the outflow from the i-th compartment;

$q_{i,i+1}$ - is the total outflow from the i-th and i + 1-th adjacent compartments (if the compartment concerned is intended for oil cargo or fuel then the quantity q is equal to the compartment volume otherwise q=0);

n - the number of watertight compartments.

The formula (2.31) holds true for the cases where there are no longitudinal bulkheads and horizontal platforms. Then the components of the formula (2.31) will be modified to fit subdivision of the ship by transverse and longitudinal bulkheads and horizontal platform.

-4. The quantity $W_{is,\ i,\ i+_1}$ is determined by the formula:

$$W_{is,\ i,\ i+_1} = W_{is,\ i+(i+1)} - W_{is,\ i} - W_{is,\ i+_1} \qquad (2.32)$$

where

$W_{is,\ i+\ (I+1)}$ - is the probability that the ice damage occurs between the two end bulkheads bounding the i-th and i + 1-th adjacent compartments (as applied to the case where one hypothetical compartment of $(l_i + l_{i+_1})$ long is damaged).

-5. The probability $W_{is,\ i}$ will be determined according to the work of K.Wendel [2] by the formula:

$$W_{is,\ i} = \iint\limits_{Gi} f_{is}\ (l_d/L,\ x_d/L)\ d\,(l_d/L)\ d\,(x_d/L) \qquad (2.33)$$

where

$f_{is}\ (l_d/L,\ x_d/L)$ is the probability distribution density of the relative extent l_d/L (longitudinal), and relative abscissa of the middle x_d/L of the ice damage.

G_i - the domain of integration in conformity with Fig.1.

THE DOMAIN OF INTEGRATION

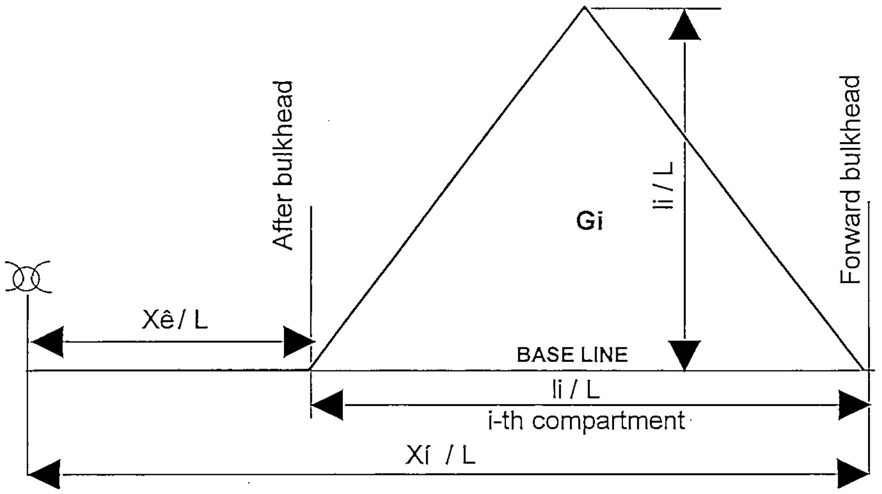


Fig. 2.1.

-6. Based on the works of V.N.Volkov [3] and M.St.Denis [4] it will most likely be possible to transport the formula (2.33) into the following form:

$$W_{is} = a_{is} \; P_{is} \qquad (2.34)$$

where

$$a_{is} = F_{is}\,(x_d/L = x_n/L) - F_{is}\,(x_d/L = x_{\hat{e}}/L) \,/\, (x_n/L - x_{\hat{e}}/L) \qquad (2.35)$$

$$P_{is} = \int_0^{li/L} F_{is}\;(l_d/L)\; d\;(l_d/L) \qquad (2.36)$$

where

l_i/L - the relative length of the i-th compartment;

F_{is} (x_d/L) - is the distribution function of the abscissa of the middle of the ice damage;

F_{is} (l_d/L) - is the distribution function of the relative extent (longitudinal) of the ice damage.

In the present case the length L should be considered to be equal to ship's length on summer waterline.

-7. If there is a longitudinal subdivision the probability $W^{b}_{is,\,i}$ that the ice damage occurs between the transverse bulkheads of the i-th compartment and does not impair the second inboard side will be determined by the formula:

$$W^{b}_{is,\,i} = W_{is,\,i}\; r_b \qquad (2.37)$$

$$r_b = F_{is}\,(b_d = b) \qquad (2.38)$$

where

$F_{is}\,(b_d)$ - is the distribution function of the transverse extent b_d of the ice damage;

b - is the breadth of the double side.

Accordingly, the probability $W^{b,b+1}_{is,\,i}$ that under the same condition the second inboard side will be damaged, is:

$$W^{b,b+1}_{is,\,i} = W_{is,\,i}\;[1 - F_{is}\,(b_d = b)] \qquad (2.39)$$

-8. If there is a horizontal platform the probability $W^{u}_{is,\,i}$ that the ice damage occurs between the bulkhead of the i-th compartment and above the platform, is:

$$W^{u}_{is,\,i} = W_{is,\,i}\; r^{u}_{h} \qquad (2.40)$$

$$r^{u}_{h} = 1 - F^{d}_{is}\,(z^{d}_{d} / T_s = z_{pl} / T_s) \qquad (2.41)$$

where:

$F_{is}^{d}(z_{d}^{d}/T_{s})$ - is the distribution function of the relative vertical position of the ice damage bottom;

T_{s} - is the summer draft;

z_{pl} - is the height of the platform above the base line.

The probability $W_{is,\ i}^{d}$ that under the same conditions the damage occurs below the platform, is:

$$W_{is,\ i}^{d} = W_{is,\ i}^{d}\ r_{h} \tag{2.42}$$

$$r_{h}^{d} = F_{is}^{u}\ (z_{d}^{u}/T_{s} = z_{pl}/T_{s}) \tag{2.43}$$

where:

z_{d}^{u} - is the vertical position of the ice damage top.

The probability $W_{is,\ i}^{d+u}$ that under the same conditions the platform is damaged, is:

$$W_{is,\ i}^{d+u} = W_{is,\ i}^{d+u}\ r_{h} \tag{2.44}$$

$$r_{h}^{d+u} = F_{is}^{d}\ (z_{d}^{d}/T_{s} = z_{pl}/T_{s}) - F_{is}^{u}\ (z_{d}^{u}/T_{s} = z_{pl}/T_{s}) \tag{2.45}$$

-9. If there are transverse and longitudinal bulkheads and a horizontal platform the probabilities W^{*}_{is} will be accordingly determined by formulae like:

$$W^{*}_{is} = W_{is}\ r_{b}\ r_{h} \tag{2.46}$$

10. To solve numerically the problem formulated it will be necessary to have initial statistic data on:

- the relation between the quantities C_{is}, C_{c} and C_{st} (Sea item 1);
- the extent (longitudinal) of the ice damages (Sea item 6);

- the longitudinal position of the ice damages (Sea item 6);
- the transverse extent of the ice damages (Sea item 7);
- the height of the lower edges of the ice damages above the base line (Sea item 8);
- the height of the upper edges of the ice damages above the base line (Sea item 8).

2.3. Practical procedure for determining the expected value Q_{is} of oil outflow from a damaged tanker when navigating in ice of the Arctic Ocean

-1.The expected value Q_{is} of oil outflow from a damaged tanker when navigating in ice should be determined by the formula of complete probability.

$$Q_{is} = \Sigma\, r_{is}\, W_{is;i}\, q_i + \Sigma\, r_{is}\, W_{is;i;i+1}\, q_{i,i+1} \qquad (2.47)$$

Where Q_{is} - is the probability that in case if the ships hull ice damages the hole is situated between transverse bulkheads of the i-th compartment;

$W_{is, I, I+1}$ - is the probability than under the same conditions the ice hole impairs the bulkheads separating i-th and i+1th adjacent compartments;

r_{is} - is the reduction factor making allowance for longitudinal bulkheads and/or horizontal platforms;

q_i - is the outflow from the i-th compartment being equal to the compartment volume;

$q_{i\ 0+1}$ - is the total outflow from the i-th and i + 1-th adjacent compartments (if the compartment is not intended for oil cargo or fuel, then q = 0);

n - the number of watertight compartments.

-2. The probability W_{is} for the compartment restricted only by two transverse bulkheads is determined by formulae:

$$W_{is} = 0.57\,[\,F(X_2 / L_{is}) - F\,(X_1 / L_{is})\,] + 0.43\, a_{is}\, P_{is} \qquad (2\text{-}48)$$

$$F(X/L_{is}) = 0.196(X / L_{is} + 0.5), \text{ if } \tilde{O}/L_{is} < 0.092;$$
$$F(X/ L_{is}) = 6.35(X/L_{is})^2 - 0.97\, X / L_{is} + 0.1515, \text{ if } 0.092 < X / L_{is} < 0.3; \qquad (2\text{-}49)$$
$$F\,(X / L_{is}) = 2.84\, X / L_{is} - 0.42, \text{ if } \tilde{O} / L_{is} > 0.3$$

$$A_{is} = [\,F\,(X_2 / L_{is}) - F(X_1 / L_{is})\,]\, L_{is} / X_2 - X_1 \qquad (2\text{-}50)$$

$$P_{is} = 5\,(l / L_{is})^2 + 0.255\;\; l / L_{is},\ \text{if}\ l / L_{is} < 0.08$$

(2-51)

$$P_{is} = 1.03\,(l / L_{is}) - 0.03,\ \text{if}\ l / L_{is} > 0.08$$

where L - is the ship length on waterline corresponding to the maximum draught d_{is} admitted when navigating in the Arctic Ocean;

x_1 - is a distance from the middle of the length L_{is} to the stern bulkhead of the compartment;

x_2 - is a distance from the middle of the length L_{is} to the forward bulkhead of the compartment;

I - is a compartment length equal to $x_2 - x_1$.

If the compartment is bounded by the stepped bulkheads then the values x_1 and x_2 correspond to the transverse planes passing through the nearest parts of bulkheads considered.

Formulae (2.48), (2.50) and (2.51) are obtained by K.Wendel's method with allowance for statistical laws of distribution of relative extent of the ice water leakage holes and relative abscissa of the middle of them (along the ship length).

-3. In case when there are longitudinal bulkheads the probability w_{is} for the compartments adjacent to the shell plating is determined according to formulae in par.2, and the probability of damage to the longitudinal bulkhead is assumed to be equal to zero, because the maximum depth of the ice holes does not exceed 0,6 m.

-4. In case when there is a watertight horizontal platform in the compartment the probabilities r_{is} of damage (hole) relative to the platform are determined by the formulae:

Above the platform:

$$r_{is,1} = 1 - F_d\,(Z / d) \qquad (2.52)$$

Under the platform:

$$r_{is,2} = F_u\,(Z / d) \qquad (2.53)$$

In way of platform:

$$r_{is,3} = F_d(Z/d_{\ddot{e}}) - F_u(Z/d_{\ddot{e}}) \tag{2.54}$$

$$F_d(Z/d_{\ddot{e}}) = 2\,Z/d_{\ddot{e}}\,,\ \text{if}\ Z/d_{\ddot{e}} < 0.3$$

$$F_d(Z/d_{\ddot{e}}) = 0.6\,Z/d_{\ddot{e}} + 0.42,\ \ \text{if}\ 0.3 < Z/d_{\ddot{e}} < 0.97 \tag{2.55}$$

$$F_d(Z/d_{\ddot{e}}) = 1,\ \ \text{if}\ Z/d_{\ddot{e}} > 0.97$$

$$F_u(Z/d_{\ddot{e}}) = 4\,(Z/d_{\ddot{e}})^2,\ \text{if}\ Z/d_{\ddot{e}} < 0.3$$

$$F_u(Z/d_{\ddot{e}}) = 1.74Z/d_{\ddot{e}} - 0.69(Z/d_{\ddot{e}})^2 - 0.1,\ \text{if}\ 0.3 < Z/d_{\ddot{e}} < 1.25 \tag{2.56}$$

$$F_d(Z/d_{\ddot{e}}) = 1,\ \text{if}\ Z/d_{\ddot{e}} > 1.25$$

where Z - is the height of the platform above the base plane.

Formulae (2.55) and (2.56) are obtained from processing of statistic data on the relative applications of upper and lower edges of the ice holes.

-5. Value $W_{is,\,i,\,i+1}$ is determined by the formula

$$W_{is,\,i,\,i+1} = W_{is,\,i+(i+1)} - W_{is,\,i} - W_{is,\,i+1} \tag{2.57}$$

where $W_{is,\,i+(i+1)}$ is a probability calculated by formulae (2.52) - (2.55) as applied to one conventional compartment in length $l_I + l_{i+1}$, equal to the total extent of i-th and i + 1th compartments.

By means of methods being developed of the probabilistic assessment of the eventual outflow Q_{ic} of cargo from tanker after getting an ice hole the mathematical expectation of Q_{ic} value for 3 tankers of UL class was determined:

"Samotlor" - deadweight 16800 t, $Q_{ic} = 0$,
"Ventspils" - deadweight 6300 t, $Q_{ic} = 200\ m^3$ (100 Q_{ic}/ DW = 3.1%),
"Partizansk" - deadweight 2900 t, $Q_{ic} = 40\ m^3$ (100 Q_{ic}/ DW = 1.3%) .

The zero outflow $Q_{i,c}$ of tanker "Samotlor" may be attributed to the fact that the ship has double sides not used for the transportation of cargo and that ice holes are of small depth.

The advantage of tanker "Partizansk" from the point of view of reducing Q(n), in comparison with tanker "Ventspils", is that on the first ship there are side ballast tanks over a considerable length of hull in the forebody.

3. ESTIMATION OF VOLUMES OF THE OPERATIONAL OIL OUTFLOW FROM TANKERS NAVIGATING CURRENTLY ALONG THE NSR

At present the Northern Sea Route is navigated by tankers owned by the Russian Shipping Companies and tankers leased by Latvia and Finland, whose principal particulars are shown in Table 3.1.

Time delivery of oil products to the Arctic has lately been considerably reduced. For the purpose of this work annual delivery of oils, taking into account volumes of annual oil delivery before 1990 and delivery forecast available for years after 2000, may be taken to be about 1m t. About 20% of the oils delivered are unloaded onto the unequipped shore.

Sea pollution from tankers may be of two types: operational pollution incidents in the process of transportation and cargo handling, tank washing and stripping operations; accidental incidents resulting from accidents involving loss of the hull integrity.

Over the past 30 years no accidental pollution incidents were recorded either in the western or eastern sector of the Arctic. Among the operational pollution incidents, sewage pollutions (outlined in other works under II.6.2.) are not considered below, only those pollutions associated with cargo handling and ballast operations are dealt with.

These operational pollutions from tankers may be subdivided into three components:

- spills resulting from cargo handling operations;
- pollutions resulting from pumping out overboard of dirty ballast;
- pollutions resulting from pumping out overboard of washing water.

The oil content in dirty ballast discharged from ships whilst outside the special areas, as specified in Regulation 9, MARPOL 73/78, shall not exceed 1/30000 of the total quantity of the cargo carried, that is:

$$\mathbf{P_{disch} = P_{c.c.} / 30000, t}$$

where

$P_{c.c.}$ is cargo capacity of the ship, t.

Table 3.1.

MAIN CHARACTERISTICS OF ICE TANKERS

CHARACTERISTIC	Partizansk	Oleg Koshevoi	Ventspils	Lunni	Samotlor
Year of construction	1988	1980	1983	1976	1975
Country of construction	Finland	USSR	Finland	FRG	Finland
Ice class	UL	L3	UL	1A Super	UL
Length of ship, m: maximum Lmax	97.35	124.97	113.00	164.40	160.00
between perpendiculars Lbp	90.10	120.56	105.33	150.00	148.00
Breadth of ship B, m	14.20	16.63	18.30	21.50	23.00
Depth H, m	6.50	6.90	8.50	12.00	12.90
Draft T ,m	4.90	4.15	7.20	9.50	9.20
Deadweight DW, t	2853	4987	6297	15955	16670
Light displacement Dl, t	2002	2518	3103	-	7900
Capacity of cargo tanks Wc, cu.m	3100	5903	5943	16885	17580
Capacity of ballast tanks Wb.t., cu.m	1338	2784	3553	-	5850
Wb.t./DW	0.469	0.558	0.564	-	0.351
Type of propulsion plant	Med.-sp.eng.	Med.-sp.eng.	Slow-sp.eng.	Slow-sp.eng.	Slow-sp.eng.
Propulsion plant power Npp, kW	1*2870	2*1104	1*4350	-	8538
Operational power No, kW	-	-	-	-	7794
Type of propulsion device	1 CPP	2 FPP	1 FPP	CPP	FPP
Loaded speed, kn	13.5	12.3	15.2	-	16.2
Ballast draft speed, kn	14.0	-	16.0	15.0	15.7
Cargo pumps: type of drive	electrical	electrical	el.-hydraulic	el.-hydraulic	electrical
number and capacity, un.*m3/hr	4*130	2*850	8*145	8*320	6*350
			3*190	-	-
pressure head, m.w.c	80	55	82	135	100
Features of arch. and struct. type	double bottom	double shell	double bottom	double shell	double shell
Thruster, kW	-	bow thruster-	-	bow thruster,736	-
	-	-130	-	air-bubbl.system	-
Steaming range, mil.:as to specification	2500	4000	5000	-	10000
max.(on account of cargo-carr. capacity)	-	-	-	-	15000.0
Crew number, pers.	23	23	28	-	25.0

In this case, when tankers not provided with segregated ballast tanks carry the whole quantity of oils the total discharge in the Arctic shall not exceed

$$\sum P_{disch} = \sum Q / 30000,\ t,$$

where

$\sum Q$ is the annual quantity of oil delivery to the Arctic.

Thus, when delivering oils, the total possible discharge shall not exceed 33 t per year. However, nowadays the Arctic oil traffic is supported solely by tankers provided with double hull structures and segregated ballast tanks. When the segregated ballast is discharged no oil pollution occurs.

Capacity of the segregated ballast tanks on the tankers in operation is sufficient for navigation in the Arctic. Ballast is not loaded into the cargo tanks and hence no dirty ballast is discharged. The more so as under the present domestic law any discharge of dirty ballast in the Arctic is prohibited.

When performing tank washing operations the contamination level of the washing water may be estimated as a percentage of the cargo capacity of the tanker. When the tanker is provided with double bottom and double side the contamination level of the washing water will be about 0.1% of the cargo capacity of the tanker. This corresponds to the total possible oil discharge:

$$P_{disch.w.w.} = 0.001 \sum Q \cong 100\ t.$$

Any discharge of contaminated water from ships sailing along the NSR is prohibited, the washing water shall be retained on board and discharged to shore reception facilities. Therefore any pollution involving discharge of the washing water does not practically occur.

Operational pollution resulting from cargo handling operations may be considered as accidental pollution.

When a ship is unloaded on the berth any oil pollution does not practically occur. But when a ship is unloaded onto unequipped shore using hoses, pollution may be possible owing to leakage from damaged hoses or leakage from individual section joints.

Length of the floating hoses when ships are unloaded onto the unequipped shore in the Arctic amounts to 2.5 km. Use is made of hose sections of 38 m in length and 100 mm dia.

The hose is usually brought ashore with the help of a launch. During unloading the regular check on the hose condition is run. In case of detection of leakage, unloading is stopped and the hose repaired usually replacing sections. Accidental oil outflow can amount in such case to several tens of liters and depends on the quantity of cargo transferred, and on conditions of ice, sea, weather etc.

If we assume that the accidental oil outflow during one unloading amounts to an average of 50 l, then with an average consignment of oils discharged onto the unequipped shore of abt. 250 t and total traffic volume of abt. 0.2*1m.t=0.2 m.t the possible accidental oil outflow during unloading onto the unequipped shore will amount in this case to abt. 33 t per year.

4. INFLUENCE OF CONSTRUCTIVE SOLUTIONS ON PROBABLE OUTFLOW FROM ICE TANKERS

As shown in Part 1, the largest portion of ice hull damages is concentrated in forepeak, bilge strakes and hull bottom. As the forepeak is separated from cargo tanks by a cofferdam, the presence of double structures (bottom and side) plays a special role in providing for ecological cleanness of tanks.

Since ice damages do not exceed 300 mm in depth the availability of double structures in bottom and side practically decreases the danger of oil outflow overboard from cargo tanks, but does not exclude certain pollution of water area while pumping out the ballast, if there were cracks in inner structures through which the leakage of cargoes into ballast tanks occurred.

Though the presence of only double bottom overlapping the bilge, as it was in «Venspils» type tankers, decreases sharply a probability of oil outflow at the ice impact, it does not exclude such a possibility when the ship side is heavily damaged above the bilge in way of cargo tanks. When there is no second side, only strict fulfilment by captain of the interdiction on the carriage of dangerous liquid cargoes in side tanks will be a guarantee of ecological purity of the ship.

The complete absence of bottom and side double structures in way of cargo tanks as in the case of old «Baskunchac» type tankers makes the ship ecologically dangerous when carrying oil products and other dangerous cargoes.

The probability of oil outflow as a result of the ice hull damage of tankers provided with different tank structures may be estimated by the method developed in Sections 2 using the distribution functions of damage sizes obtained in Section 1.

5. DEVELOPMENT REQUIREMENTS FOR STRUCTURAL SAFETY OF TANKERS OPERATING IN THE NORTHERN SEA ROUTE FROM THE POINT OF VIEW OF PREVENTING OIL POLLUTION OF WATER BASIN

The requirements for structural safety of tankers operating along the NSR based on the analysis of operational experience may be divided into the following main groups:

- classification requirements for the ice class of ship with regard for navigation region according to the Rules for Navigation along the NSR;
- requirements for hull structures, securing ecological ship safety;
- requirements for cargo systems (cargo-handling gears) and equipment.

5.1. Classification Requirements

According to the current Register Rules, L1 class ships may be used for independent sailing in the Arctic only during the summer navigation period under easy ice conditions. In other navigation periods and under heavy ice conditions they may operate only under icebreaker support.

In domestic practice the transport ships of this class sail along the Northern Sea Route only during the summer-autumn period of navigation. The main volume of marine sector of the Arctic basin in the seventies and eighties fell within «Samotlor» (UL) and «Ventspils» (UL) type tankers. L1 class tankers were used on supply voyages in the Arctic during the summer-autumn period. The vessels operating in the Arctic include different type timber carriers, support ships of «Pioneer» type as well as «Baskunchak» type tankers (L1, L x B x T = 83.4 x 12 x 4.65 m; Dw = 1660 t; N = 1470 kWt), having no double bottom and side in way of cargo tanks. "Baskunchak" type tankers operate mainly in the eastern sector of the NSR.

Operational experience in the Arctic has shown that the requirements of the current Registers Rules for the ice strengthening of L1 type ships are insufficient for safe ice navigation along the NSR, because when sailing early in the summer navigation period and in the period of extended navigation the ships of this type suffered heavy ice damages and some ships sank. It was clear that for steady operation under ice conditions of the NSR the higher class ships must be used.

So, according to the "Requirements for structure, equipment and outfitting of ships sailing along the Northern Sea Route" accepted by the Administration of NSR, L1 category ice strengthened ships of the Register Rules may be permitted to operate under the icebreaker escort in the western sector of the NSR (to 125 E) during summer the period in favorable navigation conditions.

During all-the-year-round navigation under icebreaker escort along the NSR ULA class tankers may be used in all the regions, and UL class ice strengthened tankers may operate in the western region.

5.2. Requirements for tanker hull structures directed to guarantee their ecological safety

The peculiarity of emergency oil outflows in the NSR is the lack of cases of oil outflow in a great quantity during the ships' collisions under ice conditions. It is due to relatively low ship speeds in ice, tactics of ships' movement in convoy (when falling foul the ships have damages in forward and aft ends and in the secondary deck structures) and also the sufficiently high strength of Arctic ships (their high class).

At the same time the analysis of data on ice hull damages of ships sailing along the NSR has shown that the probability of failure of the shell plating and framing in way of cargo tanks at ice impact or compressions is rather great (with dents 100 mm in depth the probability is 30-40%, with 200 mm dents - 10 - 15%, fig. 1.10).

Therefore for safe ecological protection of the water area along the NSR it is necessary to use double bottom and side structures in oil tankers, carrying oil and other dangerous cargoes.

Thus, all oil tankers of gross tonnage 300 tons and more should have double bottom over the whole ship breadth, between forepeak and afterpeak bulkheads and double sides in way of cargo tanks. Double bottom height and double side width should be in accordance with the requirements of the convention MARPOL 73/78 as amended.

Tanks in double bottom and double sides should not be used for carriage of oil products and other harmful substances. These containers may be used as segregated ballast tanks or should be empty.

The use of tanks in the double bottom within the engine room location of fuel store and lubricating materials is permitted in existing oil tankers.

The fuel tanks and other containers of capacity of 50 m^3 and more intended for carriage of harmful substances should not abut with the shell plating of the ship hull. The tank or container wall turned to the ship side should be placed at a distance no more than 0.76 m from the shell plating.

To continue sailing along the NSR of tankers of Arctic Fleet being already in service and having no double bottom it is necessary to exclude the application of side tanks for transportation of oil products and other harmful liquids.

A number of requirements contained in the "Requirements for structure, equipment and outfitting of ships sailing along the NSR" should be fulfilled.

5.3. Requirements for cargo systems and equipment

It should be noted that rather often oil pollution of harbour waters occurs during cargo handling operations due to the break of hose sealing and the appearance of honeycomb and punctures in the hoses. It is therefore necessary to develop special requirements for the transfer of oil products between roaders and floating cargo hoses, including the improvement of the connecting lock.

Thus to guarantee structural ecological safety of tankers sailing along NSR the following requirements may be formulated:

- class of tankers intended for navigation along the NSR should be not lower than UL of MRS. L1 class ice strengthened tankers under icebreaker escort may operate in the western region of the NSR in easy ice conditions during summer navigation;
- only tankers provided with double bottom and side structures in way of cargo tanks should be employed for works on the Northern Sea Route;
- application of side tanks intended for carriage of oil cargoes and harmful substances is not permitted on tankers in service which have no double sides;
- double bottom and side tanks are not to be used for placing of oil products and other harmful substances. Ships in service are permitted to use double bottom tanks only in way of the engine room for the placement of fuel stores and lubricating materials;
- in ships provided with icebreaking stem and short forepeak the double bottom may not extend up to the forepeak bulkhead in way of the raked stem provided that the watertight compartments situated between the forepeak bulkheads and the bulkhead arranged in place of a stem abutting with a keel line are used only for storage and transportation of non-contaminating liquids.

Cargo tanks in tankers of gross tonnage of 300 tons and more intended for transportation of oil products as well as fuel and cargo tanks in all the chemical tankers and liquid gas vessels shall always be situated at a distance not less than 0.76 m from the hull shell plating. The containers in tanker double sides may be used as segregated ballast tanks or should be empty.

To guarantee the safe navigation of ships sailing along the NSR with regard for their strength it is recommended to have on board the “ship’s ice passport” or, in the absence of such, “Temporary recommendations on safe ship speeds . These documents allow shipowners to determine the safe ship speed in ice depending on operation region and season, ice conditions on the particular route and technical state of the ship hull.

When solving a problem on the possibility of navigation along the NSR of domestic ships built according to the USSR Registers Rules which were in force till 1981, the technical state, structure and strength of ship hulls should be a subject of special consideration by the NSR Administration.

To assure the ship towing, the additional ice-strengthening of plating and framing in the forebody in way of hawse pipes and stem as well as the possibility of attachment of towing rope in the ship bow are to be provided for.

The equipment for removing and placement of ship bower anchors, if necessary, should be fitted.

6. POSSIBLE DIRECTION OF WORKS TO BE CONTINUED (within INSROP)

The investigations have shown that the most perspective type of tankers which in the nearest future will be used for the tranportation of oil products in the Arctic will be supertankers of 50-100 thousand deadweight tons and more.

Mass and sizes (in particular breadth) of these tankers will be considerably larger than that of existing icebreakers.

These peculiarities lead to a change in ship inertia characteristics and also make more strict the conditions of their operation in ice.

Besides in some cases the deep draughts will require additional transshipment operations the use being made of light and medium draught tankers. This circumstance will require the development and improvement of systems and facilities for the transfer of oil afloat.

For the protection of ecological purity along the NSR given the current trend of growth of the oil tanker Arctic Fleet it will be necessary to develop special requirements for hull structures and systems of cargo transfer from one tanker to another at sea (or lying out). We can do this work during 1997-98.

So during 1997-98 it is intended:

to develop requirements for structures, cargo systems and equipment of supertankers of perspective construction (including tankers - icebreakers) in order to prevent pollution of water areas along the NSR from tankers.

These recommendations will be developed bearing in mind the practical use of the domestic Arctic Fleet and on the basis of the analysis of changes in operation tactics under ice conditions and the character of structure loading in connection with unusual ship dimensions.

REFERENCES

1. Volkov V.N., Glazov S.F. “Probabilistic evaluation of the amount of cargo outflow in the case of collisions and stranding of tankers”. Sudostroenie, 1978, No 4, pp. 11-15.

2. Wendel, K.Die Wahrscheinlichkeit des Uberstehens von Verletzungen Schiffstechnik, Vol. 36, No7, 1960.

3. Volkov V.N. "Determination of the probability of ship's insubmersibility when getting a hole", Sudostroenie, 1963, No.5.

4. M.St.Denis. A Note on the Probabilistic Method of Assessing Survivability to Collision Damage", Schiffstechnik, 1962, No.48, t.9.

ANNEX 1

1. Fig. 1.4, 1.5 represents a qualitative pattern of the damage frequency distribution in a form of dents over the hull length of tankers having until now carried out the bulk of the transportation of liquid cargo along the NSR.

The same figure shows maximum values of the bending permanent set deflections of dents detected on these tankers in different hull areas for the whole period of operation.

This is one of the most important characteristics of the environmental safety of the operation of tankers in the Arctic.

Therefore we cannot agree with the opinion that there is no information in figures 1.4, 1.5.

Comparative evaluation of the probability of the occurrence of dents in hulls of icebreakers and icebreaking cargo ships will be given in the second part of the report.

2. Fig. 1.9, as it was noted in text, shows graphs of functions $F = 1 - p$, where p - probability of the occurrence of relative deflections $< f/a_s$ (a_s - practical spacing). The curves presented are constructed for ships with UL and ULA ice strengthening categories. Curves for different hull areas are spaced rather close to each other within the section-lined zone between curves.

Cracks in the shell plating are usually brought about at relative deflection values f/a_s exceeding 0,08-0,1 being realized for shell plates of arctic navigation ships with very low probability.

Connection between chapters 1 and 2 is defined by the probability of cargo or fuel spillage through cracks or holes in hull caused by ice damages of the hull structure plating. Results of the analysis of ships ice damages obtained in the first chapter are partly taken into account in the assessment of emergency spillages and are used while developing methods to determine emergency spillages from tankers during their operation in the Arctic.

More detailed information on damages is essential, but as it follows from the title of the work only ships of arctic navigation (that is of UL, ULA and higher categories) were analysed because ships of lower ice classes are not admitted for sailing along the NSR.

ANNEX 2

Review of the INSROP 11.6.2 Discussion Paper
«Environmental and Structural Safety of Ships»
by L.Tsoy, V.Volkov, S.Karavanov, F.Moreynis and A.Zubkova.

The stated objective of the study is to develop requirements for the ecological and structural safety of tankers travelling along the Northern Sea Route. In part 1, statistics on observed damages on different locations and distributions for the sizes and defections of these damages. Damages include dents and corrugation. The largest defections observed were 300 mm; it was suggested these were from strandings. The largest observed defections from ice interaction was 200 mm. Problems resulting from corrosion and fatigue cracks are discussed, including possible migration of cargo fuel into outer ballast tanks.

In part 2, equations are developed for estimating the expected amount of oil outflow given a ship collision event Qc, a stranding (or grounding) event Qs, or an ice interaction event Qi. Examples of outputs are provided for three vessel types as follows:

Vessel type	Vessel dwt (t)	Qc (m^3)	Qs (m^3)	Qi (m^3)
Samotlor	16800	0	400	0
Ventspils	6300	130	90	200
Partizansk	2900	60	50	40

The reason given for 0 outflow for the Samotlor vessel is that it has double sides, and in the case of collisions, the vessels are moving relatively slowly.

In part 3 of the report, estimates of volumes of operational outflows are given. This includes outflow due to discharging ballasts, discharging washing water, and off loading oil through hoses where there are no berthing facilities. Discharging of ballast water and washing water is prohibited along the Northern Sea Route.

In part 4, the use of double hulls is suggested as a solution for reducing the risk of accidental pollution, as the maximum deflections observed were less than 300 mm.

In part 5, existing requirements are reviewed and possible revisions suggested. It is suggested that the absence of large spills results because of low speeds combined with ice strengthening. It is recommended that double hulls be used in accordance with the MARPOL 73/78 convention, with outer tanks not used for carrying oil. It is also recommended that methods for transferring crude to shore be improved.

In part 6, possible directions for future work are outlined. This includes specific consideration of larger tankers (50-100 thousand dwt) which are likely to be used in the future.

The report indicates that if double hulled tankers are used and if these are ice strengthened, properly maintained and operated only in conditions for which they were designed, then the risk of pollution due to ice damage or ship collision is very small. In the case of ice damage, this appears largely reasonable and the management of traffic to ensure only adequate and maintained vessels are used is crucial. It would be helpful for the reader if the types of conditions vessels traveling on the route will be subjected to are more clearly identified. In low ice concentrations, the vessels may move at nearly full speed, so impacts with multiyear or glacial ice could potentially cause heavy damage. How much multiyear ice and glacial ice is found along the route? What conditions were the vessels analyzed subjected to? A probabilistic analysis of ship-ice interaction would be useful. The authors have noted the small size of the vessels analyzed and the need to consider loads on larger vessels in more detail. Analytic modelling of vessel-ice interaction and the resulting global and local ice pressures would be useful both in understanding results and in predicting loads for newer large vessels.

The assumption of minimal pollution risk in the case of collisions is questionable in the case of open water or near open water conditions. Can information on the observed number of collisions and groundings worldwide be applied to the Northern Sea Route? Though damages would be reduced because of ice strengthening, risks could not be entirely removed. It would seem that studies of the stability of damaged vessels and methods to optimize configuration of storage compartments to reduce the chance of capsizing are important.

The section on dents and corrugation is very informative. In figure 1.5, do the lines for side, bilge, and bottom represent average values? Is it possible to identify for how many of these cases there was discharge of cargo fuel? It would be helpful further when the extent of damage is related to construction and steel type, and when it is related to loading conditions. On page 45 it is mentioned that some L1 type vessels sank. Is there data on why they sank or on the amount of oil spilled and the consequences? Have any UL or ULA vessels sunk? It is stated that losses due to breaking up of ships is not studied because this does not depend on subdivision of cargo space. This could be regulated to some extent through inspection of vessels and requirements for adequate hull girder strength. References to all of the regulations and reports mentioned would be helpful. Also, the term γ on page 24 is not identified.

Review by: Mark Fuglem,
Ocean Engineering Research Centre,
Faculty of Engineering and Applied Science
Memorial University of Newfoundland,
St.John's, Newfoundland AIB 3X5,
Canada

Response to comments in Mr. Mark Fuglem's review

Authors express their gratitude to the reviewer for the attentive, objective and qualified consideration of work as well as for valuable comments on the content of the report.

As to separate observations the following could be stated:

1. The reviewer notes the advisability of setting conditions along the routes of operation and also of giving information on the presence and amount of multi-year and glacial ice in the track.
   It was intended to provide data mentioned and consider ships of larger sizes as well as analytical modelling of ship/ice interaction later on during the continuation of work.

2. The reviewer notes the advisability to examine the ship's damaged stability.
   It should be noted that this work considers the sea pollution with oil and not the structural safety not directly related to the pollution.

3. Authors apologize for the lack of the identification symbol γ on page 24 and are introducing corresponding corrections into the text of report.
   γ- density of the transported cargo, t/m^3.

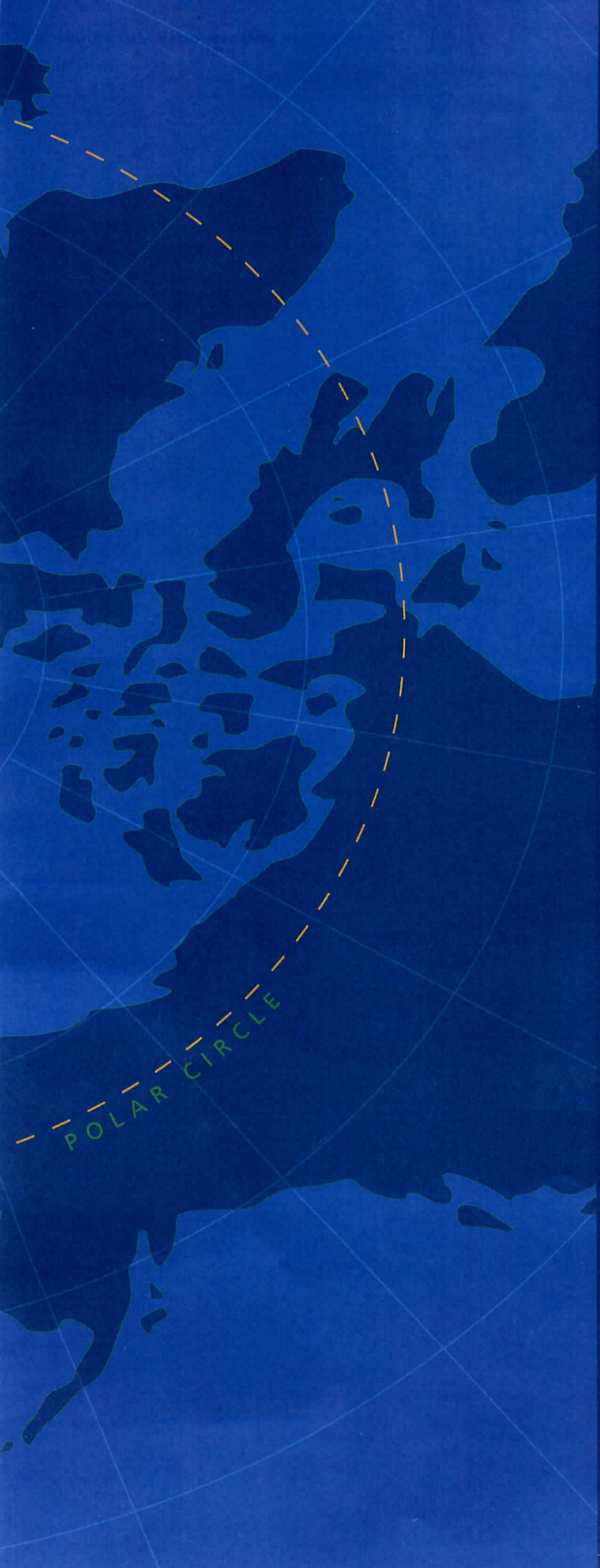
4. Fig.5 represents not average values of permanent deflections, as it is noted in the review, but the range of their changes in different hull areas.

5. In the next comment the reviewer apparently means not the discharge, but the spillage of oil products in the event of damage. In this connection we would like to note that in our domestic practice the fuel spillage in the event of ice hull damage of ships in the Arctic was not observed except cases of the losses of ships.

6. Later on, while continuing works on the project it is intended to analyse the relation between the extent of ice damages and type of the structure (including characteristics of the material) of hull.

7. Cases of losses in the Arctic of L1 class ships concern dry cargo ships. No ships of UL and ULA classes were lost in ice.

Wishes of the reviewer for deeper study of causes of the losses of cargo ships in the Arctic will be taken into account in our subsequent work.



The three main cooperating institutions of INSROP

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

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

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