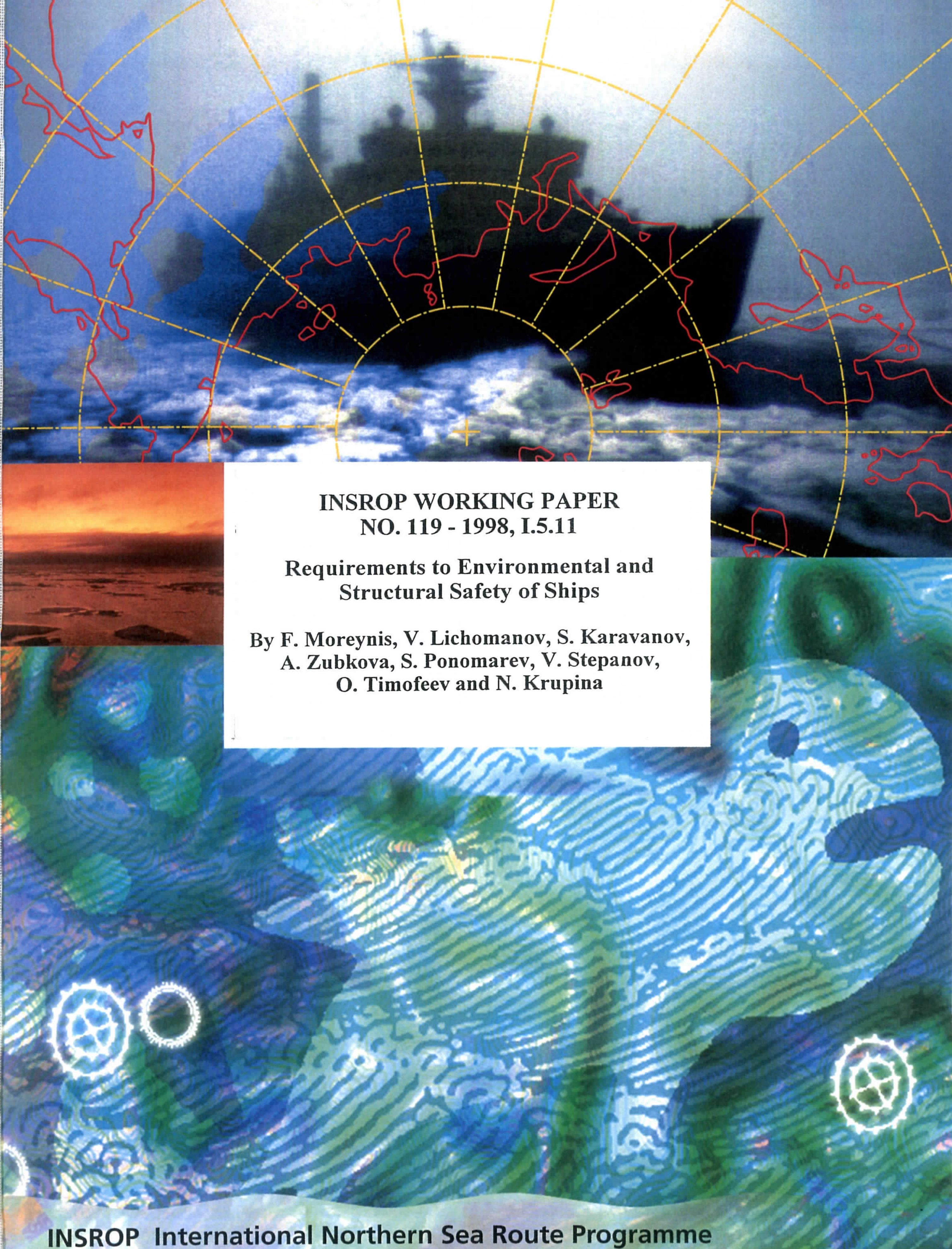

INSROP WORKING PAPER
NO. 119 - 1998, I.5.11

Requirements to Environmental and Structural Safety of Ships

By F. Moreynis, V. Lichomanov, S. Karavanov,
A. Zubkova, S. Ponomarev, V. Stepanov,
O. Timofeev and N. Krupina

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. 119-1998

Sub-programme I: Natural Conditions and Ice Navigation

Project I.5.11: Structural Safety of Ships Operating in Ice

Supervisors: Felix Moreynis (CNIIMF) and Vladimir Lichomanov(AARI)

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

Authors: **F. Moreynis(1), V. Lichomanov(2), S. Karavanov(1), A. Zubkova(1), S. Ponomarev(1), V. Stepanov, O. Timofeev(2), and N. Krupina(2).**

Addresses:
(1) Central Marine Research and Design Institute (CNIIMF),
6 Kavalergardskaya Street, 193 015 St. Petersburg, Russia
(2) Arctic and Antarctic Research Institute, 38 Bering Street,
199 226 St. Petersburg, Russia

Date: 6 October 1998

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

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.

SPONSORS OF 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
- The Central and Eastern Europe programme
- State Industry and Regional Development Fund, Norway
- Phillips Petroleum Company, Norway
- Kværner a.s.
- Norwegian Federation of Shipowners
- Norsk Hydro
- Fridtjof Nansen Institute

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
- Norwegian Polar Research Institute
- SINTEF (Foundation for Scientific and Industrial Research - Civil and Environmental Engineering), Norway.

PROGRAMME COORDINATORS

- **Yuri Ivanov, CNIIMF**
Kavalergardskaya Str.6
St. Petersburg 193015, Russia
Tel: 7 812 271 5633
Fax: 7 812 274 3864
E-mail: cniimf@neva.spb.ru

- **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

- **Hiroyasu Kawai, SOF**
Senpaku Shinko Building
15-16 Toranomon 1-chome
Minato-ku, Tokyo 105-0001, Japan
Tel: 81 3 3502 2371
Fax: 81 3 3502 2033
E-mail: sofkawa@blue.ocn.ne.jp

Project Team

The Project team consisted of the following:

Dr.	F.Moreynis	leader of Project, CNIIMF
Dr.	V.Lichomanov	leader of Project, AARI
Dr.	S.Karavanov	CNIIMF
	A.Zubkova	CNIIMF
	S.Ponomarev	CNIIMF
Dr.	V.Stepanov	AARI
Dr.	O.Timofeev	AARI
	N.Krupina	AARI

Abstract

Key words: ice damages, cargo ships, distribution of damages, marine pipelines, environmental safety, numerical simulation, side grillages, test calculations, ice passport, recommendations, ice class, structural recommendations.

Consideration is given to the hull ice damages of cargo ships, distributions of the most serious damages are provided and causes of ice damages analysed. Structural safety of the marine pipelines as a part of the environmental safety of tankers was dealt with. Numerical simulation of the operation of the side grillages of ice tankers has been carried out. Results of the test calculations are presented. Assessment was made of the effect of the ice passport on the reduction of the environmental pollution. Recommendations for the selection of ice classes to improve the ships' safety were drawn up.

INTRODUCTION

Reliability of operation of arctic ships to a considerable extent depends on their structural safety. The structural safety is of special importance for arctic tankers as it is closely associated with the probability of emergency spills of oil described in details in report N 70-1996. I.6.2. Environmental and Structural Safety of Ships. The structural safety of ships involves structural safety of hull and safety of equipment. The safety of hull is defined by the scheme of subdivision and by the strength of hull grillages.

The present report considers data on the ice ship's hull damages, their statistical processing and analysis. It also deals with problems of the unloading of tankers onto the unequipped shore, numerical simulation of the disruption of oil tanker structures under the impact of ice taking into account the wear, use of the ice passport and its effect on the reduction of the environmental pollution. Recommendations as well are given to the construction and equipment of arctic tankers.

Certain changes into the scope of works fulfilled were introduced because of the cut of the working time from 2 years to 1 year.

The present work has been performed within the scope of the Project I – Natural Conditions and Navigation in Ice. Sections 1,2,4 are made by CNIIMF, section 3 – by AARI.

1. Ice damages of hulls of ice ships

1.1. Peculiarities of hull ice damages of cargo ships on the Northern Sea Route.

Ice damageability of arctic ships and the distribution of damages over the hull areas depends on a number of factors including the complexity of ice conditions during the navigation period, tactics of sailing through ice, structural features, extent of the ship's hull wear, ice class of ship. Generally the distribution of ice damages between the ice classes of ships reflects the number of ship groups of each class drawn to the arctic transportation service - mainly ships of UL and L1 classes including arctic tankers the ice strengthenings of which did not completely corresponded to the intensive operation of fleet in the Arctic. In the middle and end of eighties the share of ULA class ships in the group of most frequently damaged ships considerably increased.

While analysing the damageability of cargo ships in the arctic ice it is necessary to take into account the fact that in the Russian transport fleet only ULA class ships are directly adapted for the work in the Arctic. UL class ships (analogous to the highest Baltic class in the Russian Register Rules as to the level of requirements imposed on them) are intended for use on the NSR only during the summer-autumn period of the navigation under assistance of an icebreaker. L1 class ships may be admitted for the navigation in the Arctic in summer, in the absence of ice or under very easy ice conditions (in open floating ice decayed by melting). Ships of lower ice classes may be used on certain route sections in summer only if there is a long-range forecast of open water on the way of movement of ship.

The above stated is formulated in the "Rules of navigation along the NSR" and proved by the half a century experience of navigation in the Arctic of the domestic fleet - L1 class ships account for up to 50-75% of all ice damages of ships during the arctic navigation. Ships of the L1 category are mostly old ships of the former UL class reclassified in the process of the improvement of the Register Rules. They have no appropriate strengthenings for the navigation through the arctic ice and their hulls are considerably worn out with time. Their use in the arctic navigation was bound up with the necessity to provide for the heavy cargo traffic characteristic of the Arctic in the seventies and eighties. Only recently due to the obsolescence of these ships and their replacement with those more adapted for sailing in the Arctic their share in the total extent of the ice damageability began to diminish. Comparative figures of the damageability of ships of different ice classes are given below.

Statistics of the distribution of ships' damageability by ice classes was annually analysed by CNIIMF. Character of the distribution of ice damageability by classes depends greatly on the quality composition of the fleet participating in arctic navigations and therefore changes from year to year. Dynamics of this change for 30 years of the operation of fleet in the Arctic is shown in table 1.1.

Table 1.1

Dynamics of the damageability of hulls of ships of principal classes

Years	sixties	74-76	1978	80	81	83	84*)	87	88	89
ULA	3%	2%	2%	0	1.3%	9%	~1.5%	8%	13%	16%
UL	28%	5.5%	6.5%	16.7%	19%	19%	3%	41%	34%	42%
L1	40%	73%	74%	67%	68%	54%	~ 9%	37%	33%	16%

*) Far East Shipping Companies Only

The greatest number of ice damages (up to 70% - 1983) and their large sizes are observed in the East of the Northern Sea Route, mainly in the East Siberian and Chuckchee Seas characterized by the heaviest ice conditions on the NSR. Heavy ice damages are especially frequent in the southern part of the East Siberian Sea from the Medvezhiy Islands to the Wrangel Island including the Longa Strait.

During heavy (as to ice conditions) navigation periods up to 50-60% of all ice damages of the arctic fleet occurred just on the ships, which were operating on this section of the route.

Absolute sizes of ice damages of the shell plating and framing considerably differ. So, the major part of bulges and corrugations of the shell plating has deflections of 15-50 mm and only separate bulges reach 70-80 mm. Dents (hull framing damages) are principally from 30-40 up to 80-100 mm deep. Maximum sizes of damages for ships of different ice classes are also different. So, a maximum depth of dents obtained at the impact against ice of the L1 class ships (*Baskunchak, Pioner*) the hull of which is not sufficiently strengthened for the navigation through arctic ice reaches 400 mm, of the UL class ships (*Samotlor,Dmitriy Donskoy*) - 250-

300 mm, of the ULA ships specially constructed for the operation in the Arctic does not exceed 200-250 mm.

Dents are the most hazardous hull ice damages. The experience shows, that even large deflections of the plating between framing (bulges, corrugations), as a rule, do not cause the water leakage of plates. With undamaged framing deep bulges are accompanied by cracks in the plating, the water leakage is extremely seldom and only on ships with the wear of plating exceeding admissible standards.

It should be noted that water leakage cracks usually arise when dents are deeper than 80 - 100 mm, in joints of the framing with plating. With deflections ≤ 200 mm the disclosing of cracks, as a rule, does not exceed 30 - 40 mm and their extent may reach 1.5 - 3 m. At considerable depths of dents these crack parameters may increase more than twice (L1) and cause danger of the loss of ship. Directly within the area of plates (between frames) at bulges, even with large deflections, cracks are formed extremely seldom, mainly in highly (more than by 50%) worn plates having extensive channeling corrosion. Salient feature of ice holes is their small area. The majority of such holes arise within dents and represent slit cracks formed in weld seams or in the near-seam zone. Such cracks-holes extend usually along the ship, more seldom – across, with a length (l_{cr}) from 50 up to 1000 mm and edge disclosure (b_{cr}) from 2 up to 50 - 60 mm. In rare cases of heavy damages the extent of ice cracks may reach 2 - 3 m and the width of their disclosure - 100-200 mm. Such damages cause the emergency situation and are subject to the immediate repair.

As a whole, the number of water leakage damages varies from 20 - 30% to 45 - 50% (ships of the L1 class) of their total amount. During heavy (as to the ice conditions) navigation periods (1982, 1987) the number of such damages may reach 50 - 70% of the total number of hull damages. In the abnormally heavy navigation of 1983 the share of water leakage hull damages reached the highest level - 84%.

Peculiarity of mass ice structure damages in the form of dents are permanent sets ("bulging") of stringer walls, diaphragms, platforms, bulkheads adjoining the shell plating near the forepeak and bilge in the forebody half of the hull. The zone of such deformation of plate structures extends, counting from the plating, by 300 - 400 mm.

On ships the icebreaker escorting of which through ice isthmuses is often carried out by "close" towing the greatest number of ice damages is concentrated below the ice strake: in bilge strakes - along the entire length of the ship, in bottom strakes - mainly in the forebody. Bottom grillages and bilge in such way of escorting are under the effect of higher ice loads caused by the impact of ice floe fragments thrown out from under the ship' screws. Apparently this circumstance may be the reason of high damageability (up to 70% of all ice damages) of the bottom grillages of ships of the *Amguema* type (class ULA) and tankers of the *Ventspils* type (UL) frequently escorted through heavy ice isthmuses by icebreakers by "close" towing. It is worth mentioning that on some UL and ULA class ships there is a considerable number of moderate ice damages of the bilge stern portion and the ship's side near the screw shaft bossing being a consequence of the reverse manoeuvring in the thick ice.

The overwhelming majority (70 ÷ 80%) of ice damages of cargo ships occur when ships follow the icebreaker. In independent navigation and under conditions of compacting not more than 10-12 % of ice damages occur. Distribution of the number of ice damages between separate parts of the hull over the ship' s length is as follows: 60-80 % of ice damages is concentrated in the forebody half of the ship, not more than 20% - amidships. Only on ships of the ULA category the conditions of the operation of which approach those of icebreakers the area of the heaviest damages is somewhat shifted towards the stern and embraces the midship.

1.2. Quantitative estimates of the mechanism of the distribution of the heaviest ice damages of plating and framing over the underwater hull portion.

The overwhelming majority of ice damages (about 90%) is located in the underwater part of the hull the side damages amidships of the ULA and UL classes of ships being recorded rather seldom. L1 class ships are in this respect the exception. Principal amount of ice damages is concentrated in the area of the forepeak, in the forebody sections of the flat bottom as well as in bilge strakes (strictly speaking, in bilge structures and adjoining bottom and side strakes). Up to 70-80% of the ice damages of the above constructions is located in the forebody half of ship extending from the stem to the midship.

Location of the most frequently damaged hull sections is bound with ship's operational conditions in ice and consequently with the ice class of ship. Character of the distribution of the most damaged areas over the ships' hull is summarized in table 1.2, fig. 1.1 – 1.3.

Table 1.2

Damageability of hull areas as shares of the total number of damages

Area/class	ULA	UL	L1
side	30% (21% - B *) 8% - A)	63% (33% - A 28% - F)	50% (25% - A 13% - F)
bilge	19% (14% - A 6% - B)	19% (11% - A 6% - B)	23% (18% - A 4% - B)
bottom	51% (35% - A 10% - B 6% - C)	14% (4% - A 6% - B 4% - C)	26% (18% - A 7% - B 1% - C)

*) In brackets - distribution of ice damages by local areas over the length of ship

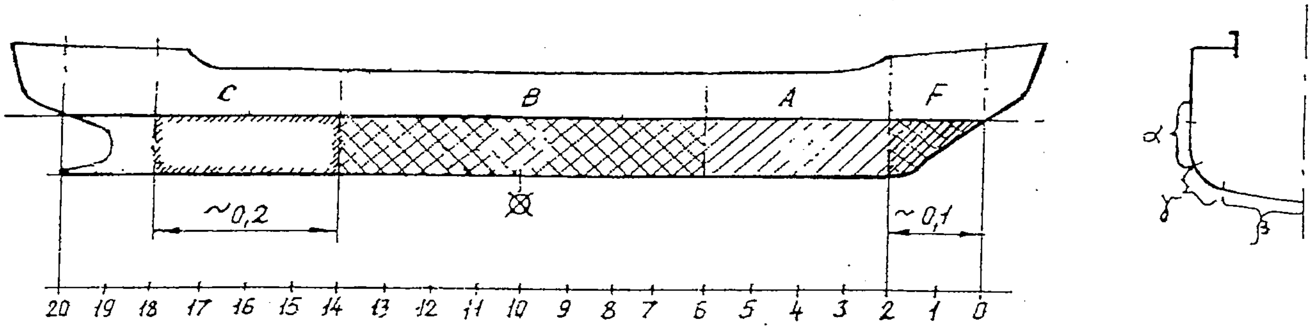

Fig. 1.1 General scheme of the underwater portion of hull

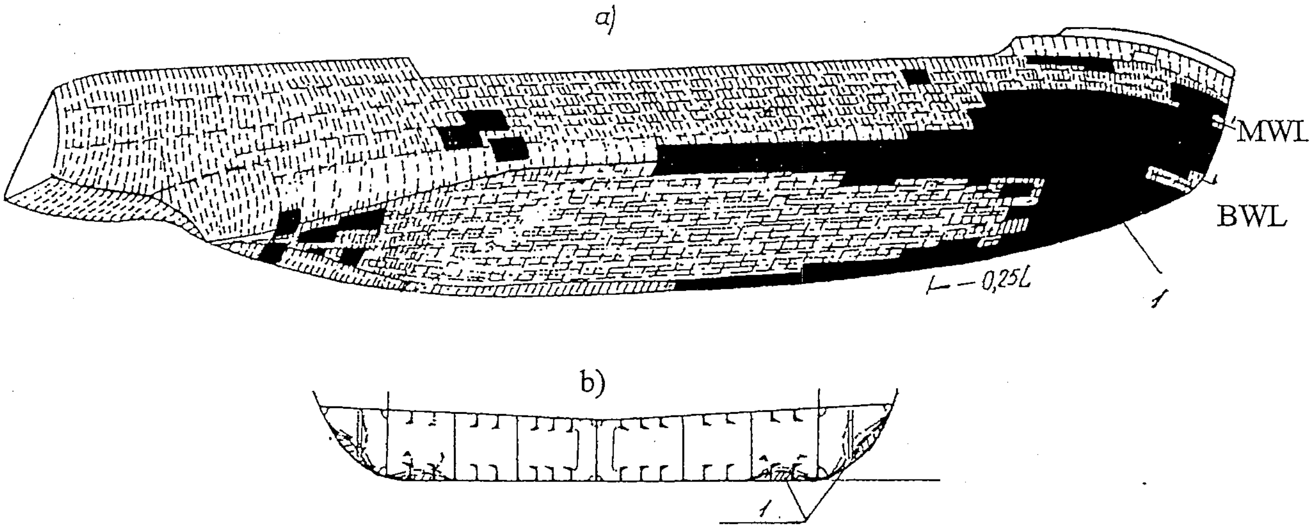

Fig. 1.2 Typical location of ice damages area of arctic ships.
1 – *ice damages*

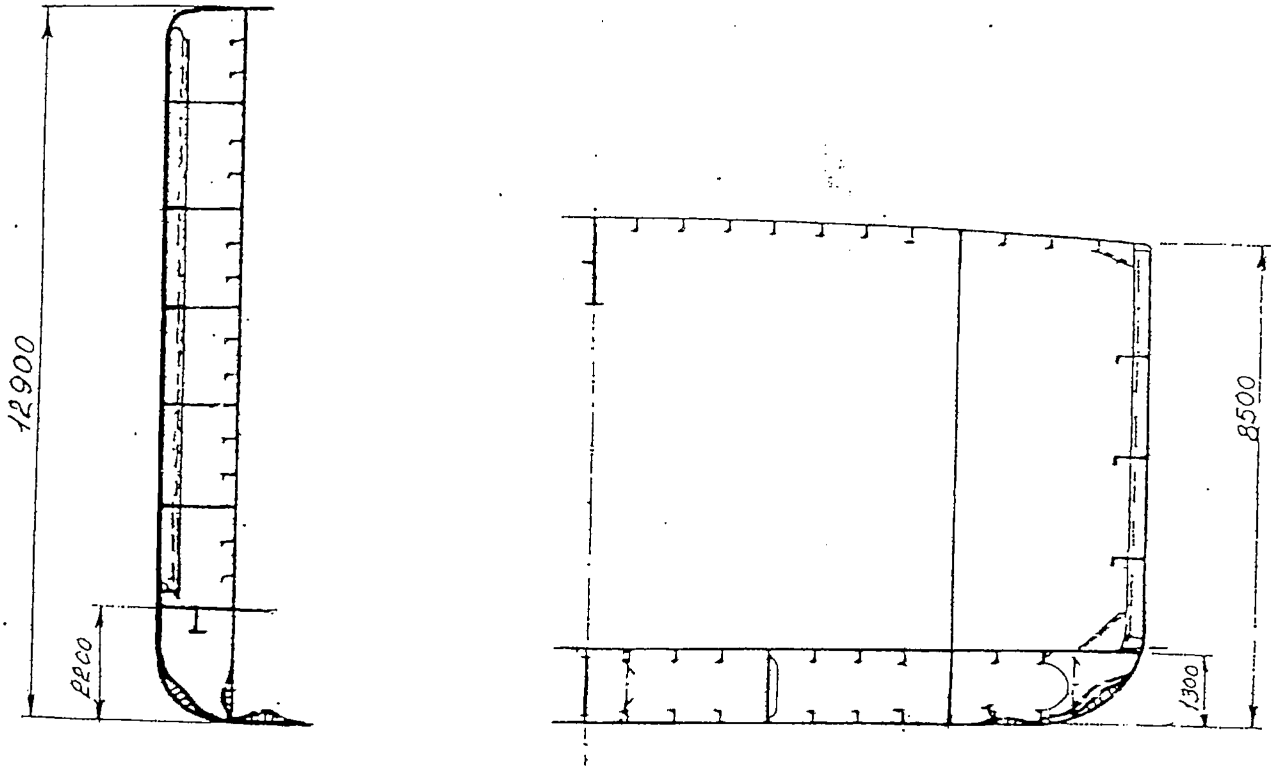

Fig. 1.3 Typical ice dents in the midbody of arctic tanker hulls

It should be noted that the probability distribution of the occurrence of ice damages in sides, bilge and bottom shown in table 1.2 is rather approximate as during the inspection for defects at a ship repair facility the bilge is not considered separately, but related either to bottom members, or to the side grillage. From the results of the analysis of the operation of ships on the NSR the vertical structural member damage distribution in a generalized way is illustrated graphically in fig. 1.4.

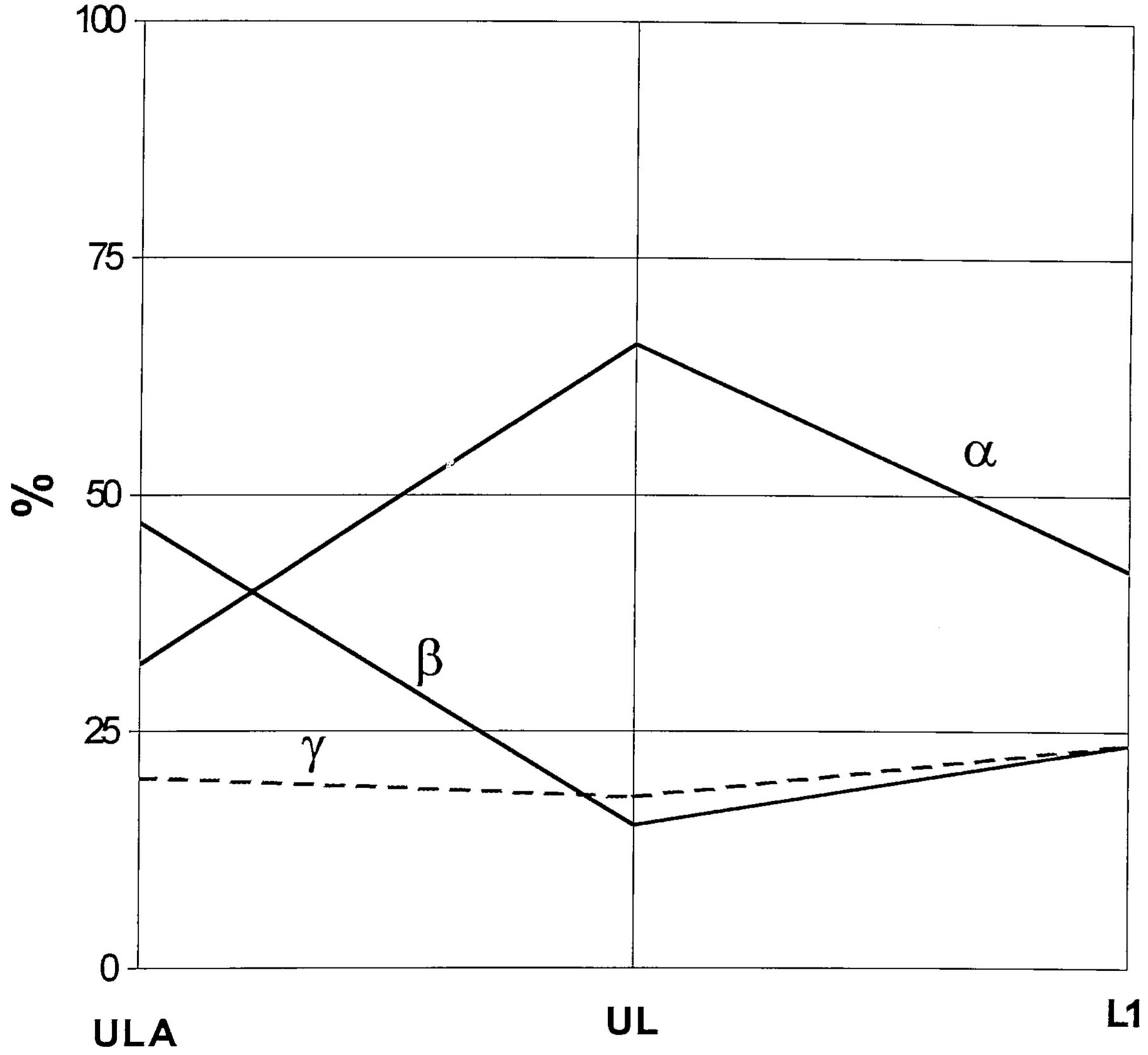

Fig. 1.4 Relative ice damageability of side (α), bilge (γ) and bottom (β) in the hull of ships of different ice classes

Probability of the occurrence in a certain construction of damage in the form of a dent of definite depth (P_{if}) is presented in fig.1.5, 1.6 by the distribution function of the dent depth - F (≥ f) %. While constructing the graphs the use was made of the primarily processed materials of FEPI, CNIIMF and other organizations published in [1] - [3]. As the experience of the inspection for defects has shown, if dents are 80-100 mm deep and deeper, cracks are formed in the shell plating in places where the framing is welded on. As a rule, dents with such characteristics cause the water leakage. For ULA class ships, 20 - 30% of ice dents turn out in practice to have the water leakage, for L1 class ships ~ 50%.

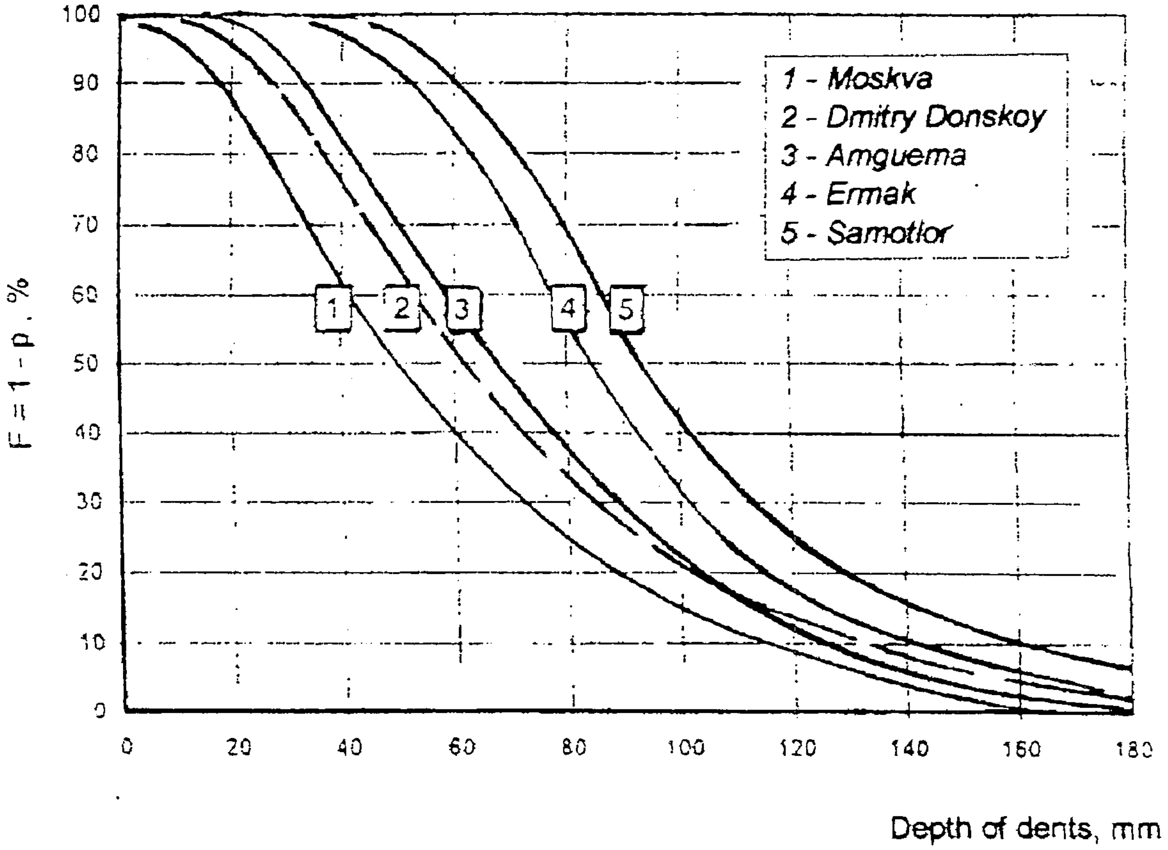

Fig. 1.5. Plots of distribution function F = (1 – p) of dents depth (p – is the probability of the occurrence of dent of a given depth in the bottom and bilge strakes of the middle and intermediate hull areas)

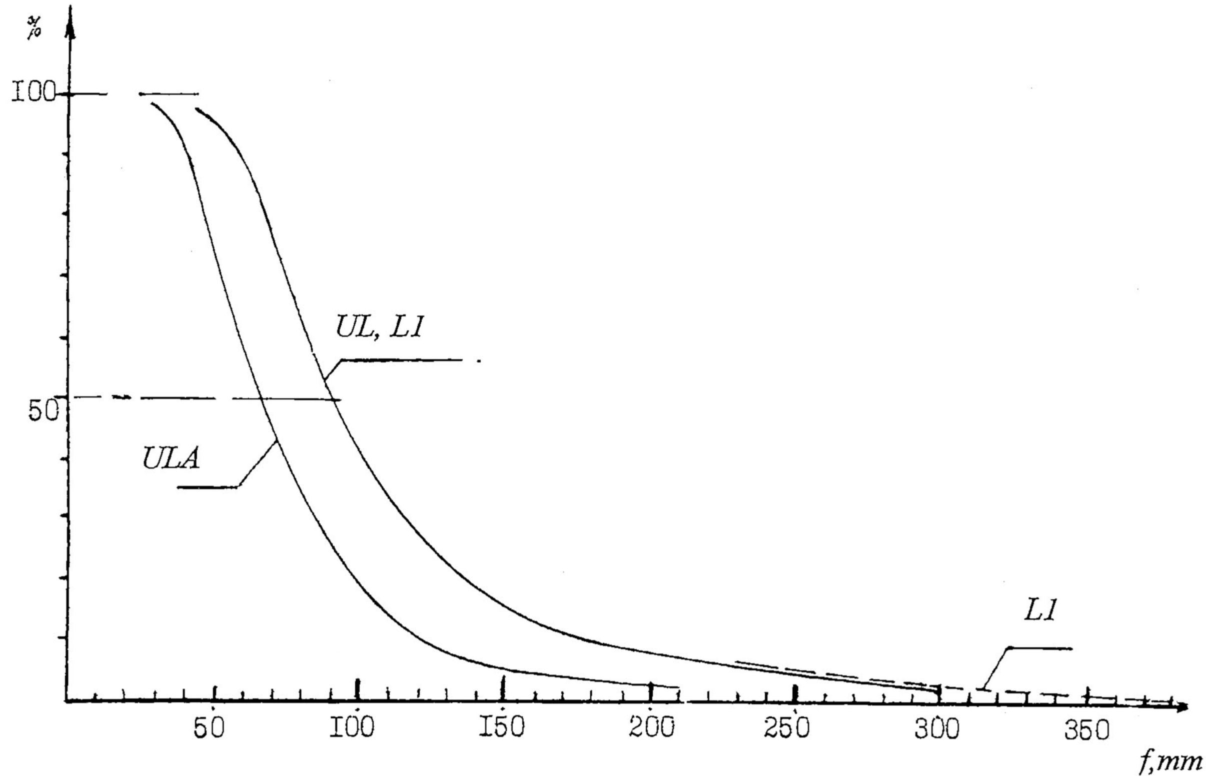

Fig.1.6. Distribution of the ice permanent deflection values of arctic ships

As a whole for the design of ships of all classes the probability curves of water leakage deflections also fall closely to each other making possible to use generalized curves Fig.1.6, 1.7. Substantial difference is seen only in the tail portions of curves, in the zone of the maximum values of dents; here the influence of the ice class of ship is in evidence. The ice class maximum dent depths dependence is presented in table 1.3.

Table 1.3

Maximum dent depths, mm

Area/class	ULA	UL	L1
Side	150 - 200	300	400
Bilge	100 – 120	200	100 – 150
Bottom	100 – 150	150 – 200	250

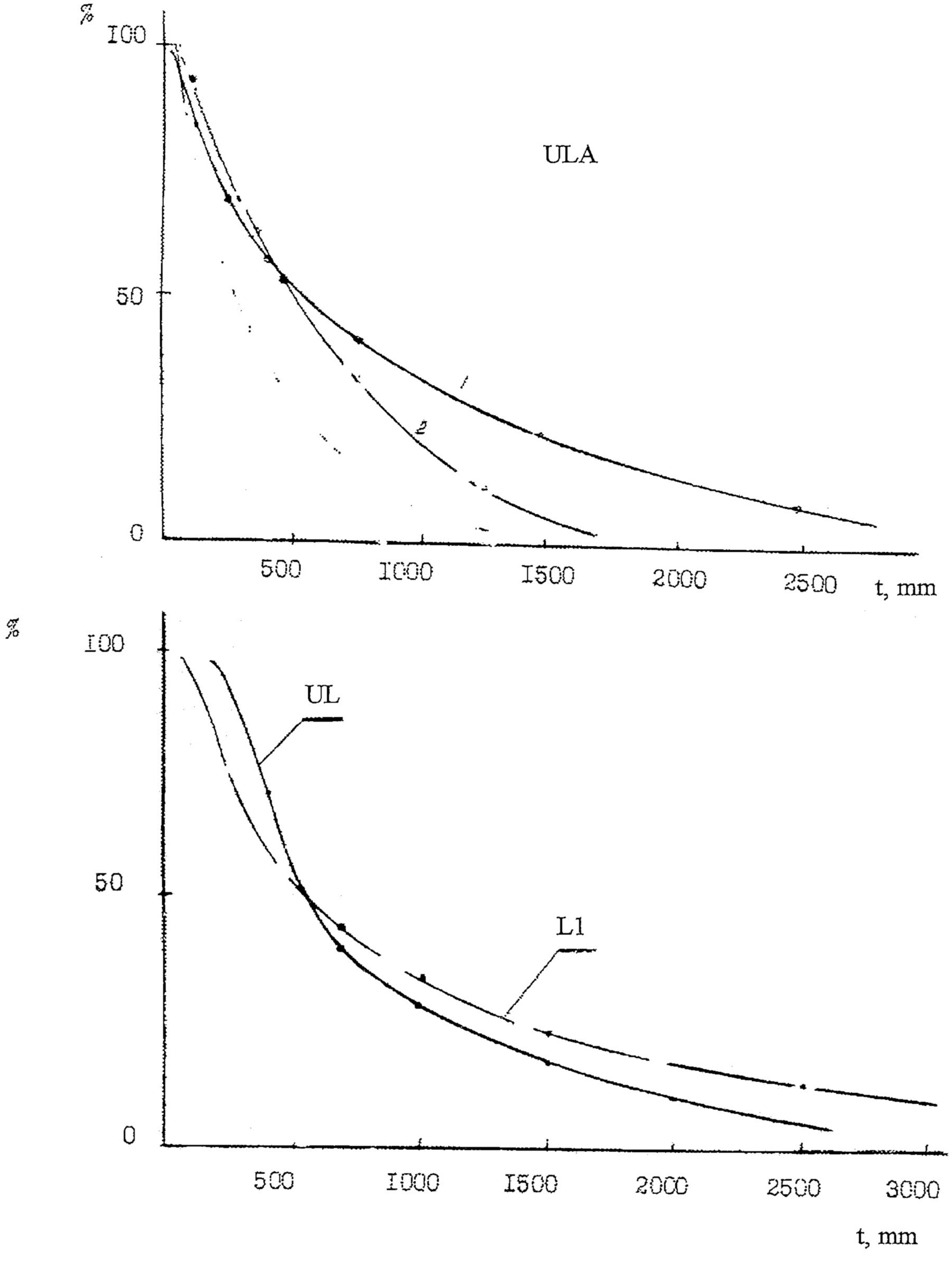

Fig. 1.7. Distribution of hole (crack) lengths in the hulls of arctic ships
1, 2 – bow, midbody

Curves shown in figs. 1.5 and 1.6 represent probabilities of the excess by permanent framing deflections (depth of dents) of the depth of ice dents plotted on the abscissa. Under the ice damage (dent) we understand a permanent deflection of frame or of plate structure supporting the shell in the zone of the impact against ice. Fig. 1.5 shows probabilistic curves for a number of icebreakers and cargo ships. In fig. 1.6, generalized curves for ships of the UL and ULA classes being the major portion of the domestic arctic fleet are plotted.

As one can see from these graphs, the probability of the excess by permanent deflections of high values of the depth of dents (f ### 150 - 350 mm) is very low and is 1-7% for different classes of ships. For domestic ships operating on the Northern Sea Route these probabilities are the following:

ULA f ### 150 mm ### 5%
200 mm ### 1%

UL f ### 200 mm ### 6%
250 mm ### 2%
300 mm ### 1%

L1 f ### 200 mm ### 7%
250 mm ### 3 %
300 mm ### 2%

Number of the analysed events of framing damages for ships of the UL and ULA classes was 200 and 250 accordingly, for the L1 class - 380.

Distribution of zones of the most serious ice damages over the surface of the underwater part of hull depends not only on the class of ship, but also on structural characteristics of a specific ship. So, for example, tankers of the *Samotlor* type of the first series had serious structural drawbacks in ice strengthenings of side in the forebody where there was a comparatively weak side framing and the drastically reduced plating thickness over the bilge strakes (to 16, 18 mm in comparison with the thickness of the ice strake - 28 mm). Due to the distances between side stringers being too great and the insufficiency of the moment of resistance of bow frames near fr 157 - 200 (r 280 x 11) on tankers of the *Samotlor* type of the first series the most commonly encountered type of the ice damages of the side grillage framing of this area were dents. These damages in the area of variable waterlines were frequently accompanied by "tumbling in" of frames. The largest deflections of dents reached 130 - 200 mm, of bulges – 70 - 90 mm (on tanker *Kamenets Uralskiy* in the forebody the dents were even 300 mm deep). Surface areas of the shell plating to be replaced because of ice damages on these ships reached 100 - 200 square m per one ship for a navigation and not infrequently more. Consequence of a sudden reduction of the bilge thickness (at the double increase of a frame spacing) were mass damages of bilge strake plates in the form of bulges and corrugations. Such structural deficiency characterizes many ships which were operating in the seventies-eighties on the NSR - timber carriers of different types (class L1), tankers (UL, L1), supply vessels of the "Pioner" type (L1) as well as multipurpose ULA class ships of the "Norilsk" type. As a result of the ice impact on bilge strakes of these ships, after arctic navigations mass corrugations and bulges were detected.

1.3 Analysis of the reasons of heavy ice damages of arctic ship hulls.

Complicated navigational conditions including the ice situation characterized in the domestic Arctic by the high variability are the main reasons of ice damageability.

Quite a number of reasons are responsible for the high level of the ice damageability of cargo ships in the arctic basin. If structural ice damages are meant (that is those which are caused by the impact of ice against the hull), the main reasons may be the following:

1. Shallow water in most sectors of the NSR.
2. Errors and deviations from the Rule requirements admitted when designing forward hull structures of ships.
   In particular, such violation of Rules in the case of tankers of the "Samotlor" type caused mass ice damages in the above ship sections. Only the presence of double bottom and inner side on these tankers prevented significant pollution of water areas due to heavy ice hull damages in way of cargo tanks.
3. Use in the areas of heavy ice conditions of ships with insufficient ice strengthenings as applied to this region of the NSR and the navigation period (for instance, the use of the UL class ships during the early period of navigation in the east of the NSR).
4. Poorly selected tactics of the icebreaker support.
   It concerns first of all the "close" escorting and towing of ships in the channel at short stay.

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 strike the ice edge in the channel.

Dents in the flat bottom are due not only to the "close" towing while pressing forward through an ice isthmus or a hummock, but arise also when the ship touches the anchor ice (because of the flux and reflux alterations) sometimes accumulated in arctic regions on the sea bottom. Dents with crooked edges occur only in the bottom, scratches are often found almost over the whole length of the ship. The cause of these damages is contact with the ground in shallow water as under such conditions the ships often work during supply operations.

The analysis of the character of ice damages and of the structural quality of arctic ships most susceptible to ice damages shows that the principal technical causes of the ice hull damages are the following:

- use of a ship of the ice class inadequate for the area and season of its operation (for instance, L1 for the NSR);
- considerable wear (including corrosion) of hull structures in the zone affected by ice loads;
- errors in the design of structures including unjustified deviations from the requirements of the Register Rules.

As a rule, just heavy ice conditions along the entire route or on its separate sections result in serious ice hull damages. At the end of the 70 - ies - beginning of the 80-ies every second navigation on the NSR was complicated or heavy. At present only every third or fourth navigation may be classified as a heavy one.

Realization of the most dangerous scenario of the occurrence of an ice damage is conditioned also by the compliance of the ship's category of ice strengthenings (class) with the complexity of ice conditions on a specific section of the route.

As a rule, the strength of the ULA class ships allows them to independently sail through thick ice if power of their propulsion unit is sufficient for surmounting a stretch of such ice with a certain concentration. Meanwhile the L1 class ships are able to navigate only on separate sections of the route supported by icebreakers and under the easiest ice conditions.

Results of the analysis of the probability to realize scenarios (conditions) of the occurrence of ice damages on the NSR are in a generalized way tabulated in table 1.4.

Table 1.4

Probability of the realization scenarios

Mode of movement through ice	Average frequency, %
Independent movement	5 – 10%
Movement behind icebreaker	50 – 60%
Close towing	15 – 20%
Breaking down of ice near the ship, compacting	5 – 10%
Ground touching in shallow water	1 – 2%

2. Structural safety of ships' pipelines

Of special importance in the Arctic is the safety of tankers in connection with higher detrimental effect of the oil pollution in this area. Safety of tankers from this point of view may be called environmental.

Structural safety of ships implies structural safety of hull and safety of the equipment. The hull safety is defined by the subdivision system and strength of hull grillages.

Integral part of the environmental safety is safety of systems and pipelines.

While considering the environmental safety (see report No 70 - 1996, item 6.2) emergency spills at strandings, collision, ice damages and operational spillages were examined. Operational spillages, in turn, are divided into spillages during cargo handling operations, pollution in the process of pumping out of the contaminated ballast and outboard pumping of the wash water.

Emergency spills, as it was shown in the above mentioned report, drastically decrease in connection with the coming in force in 1990 of rule 13 F of the International Convention for the Prevention of Pollution from Ships 1973/78 IMO (MARPOL 73/78). In accordance with this rule the cargo spaces have to be protected by double structures: double bottom and double sides.

The availability of double structures with segregated ballast tanks located there excludes the contamination while pumping out dirty ballast and the consideration of arctic areas as special ones leads to the prohibition of the discharge of dirty washing waters during the voyage.

In this connection the most probable pollution of sea is during the cargo handling operations.

With unloading at berth the oil pollution of sea is practically improbable, but during the unloading onto the unequipped shore with the use of hoses or pipelines the pollution is possible in case of the damage of hoses or pipes or leakage through joints between individual sections. Unloading onto the unequipped shore is carried out when there is stable ice cover or through ice free water. Pipes or hoses are laid through ice or float over water.

During the roadstead unloading in open water and in the fast ice the use is made of the sectional hose (sections are 38 m long with a diameter of 100 mm). Hoses with a length of about 4 km are stowed in the aftercastle.

The laying of hose in open water is carried out by a launch, recovery - by the shipboard facilities, oil residues being discharged into a cargo tank. Hose operations involve also pressure testing at the beginning of loading and the blow-through at the end of loading. In the process of loading it is periodically necessary to pass along the hose checking for leakage. If leakage is detected, the loading is stopped, clips are applied, sections replaced etc.

The pollution can be considerably reduced using specially supplied hoses consisting of sections 400 m long with a diameter of 150 mm. Hoses are reeled up round special drums located on ship. In winter during the cargo handling under the roadstead conditions either hoses or pipes are laid down over the ice.

So, during unloading operations near the cape Kharasavey hoses were laid, but while loading gas condensate of the Tambey fields in the Ob Gulf a pipeline about 4 km long with a diameter of 150 mm was laid over the river ice.

Tubes of the temporary pipelines laid over the ice may be connected by welding or screwed on if drilling pipes are used.

To improve the reliability of joints of temporary and marine pipelines, at the Central Research Institute of Shipbuilding Technology, bellmouth connections and expansion branches have been developed [4].

The connection of pipes, hooking up of fittings to pipes and of pipes to branches of mechanisms is made through flanging (fig. 2.1).

The manufacturing of tube tees is made by the welding on of a branch, simple in design, to the pipe "collar" produced out of the pipe body (fig. 2.2).

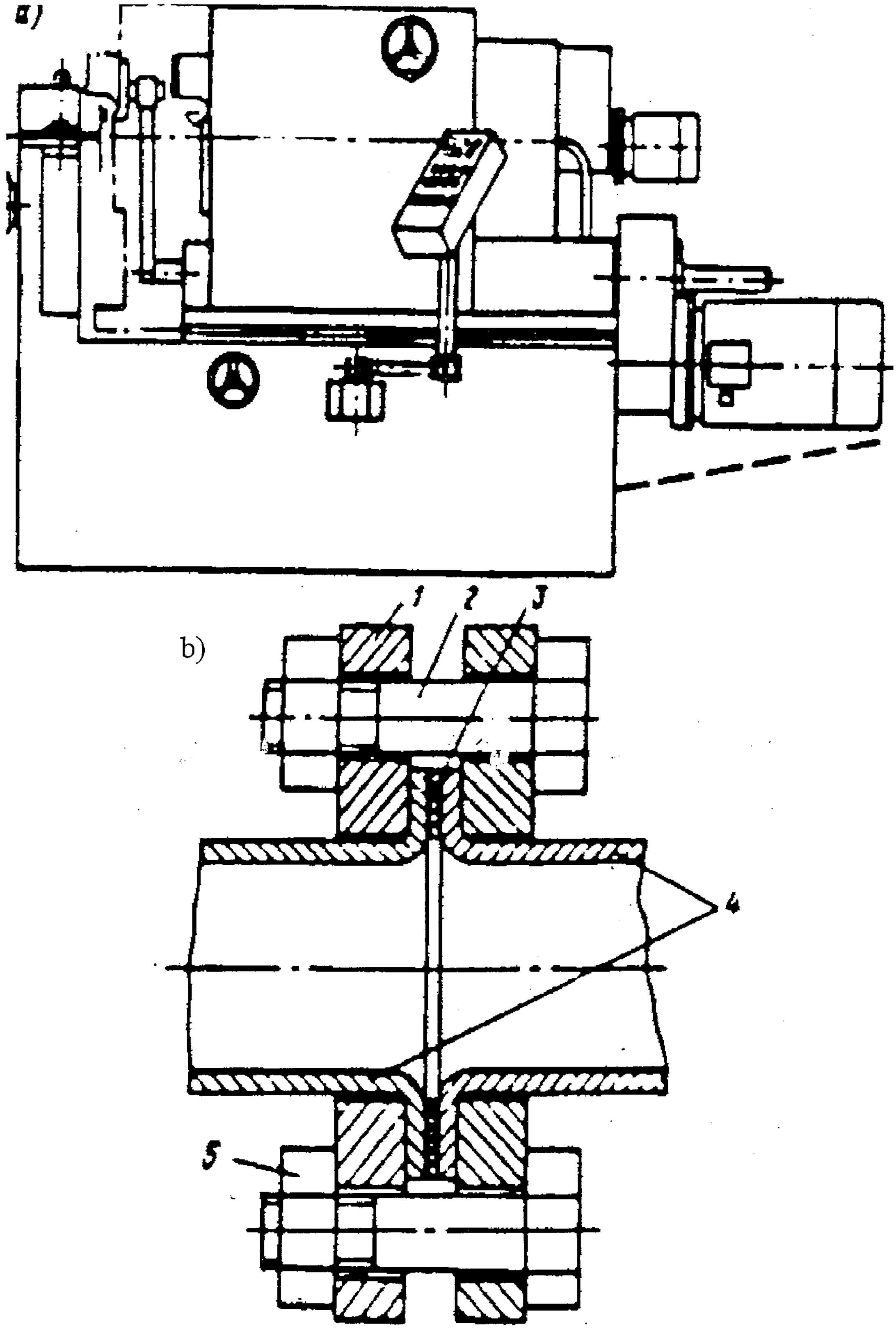

Fig. 2.1 Connection of pipes with flanging: a – tool; b – connection with flanging; 1 – flange; 2 – bolt; 3 – washer; 4 – pipe with flanging; 5 - nut

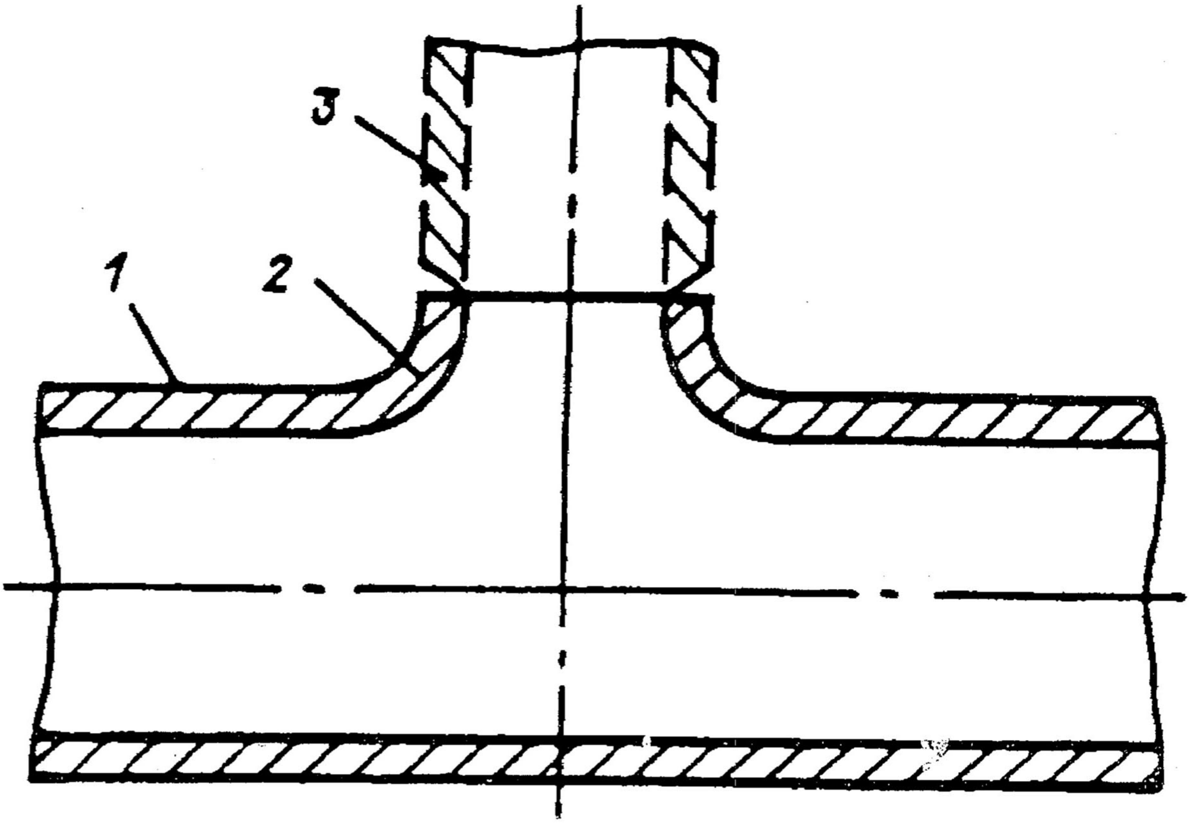

Fig. 2.2. "Collar" type connection of the branch with pipe:
1 – pipe; 2 – collar; 3 – branch

Fig. 2.3 shows the comparison of the conventional technology of the fabrication of pipelines with the new one.

Fig. 2.4 shows bellmouth connections and expansion branches.

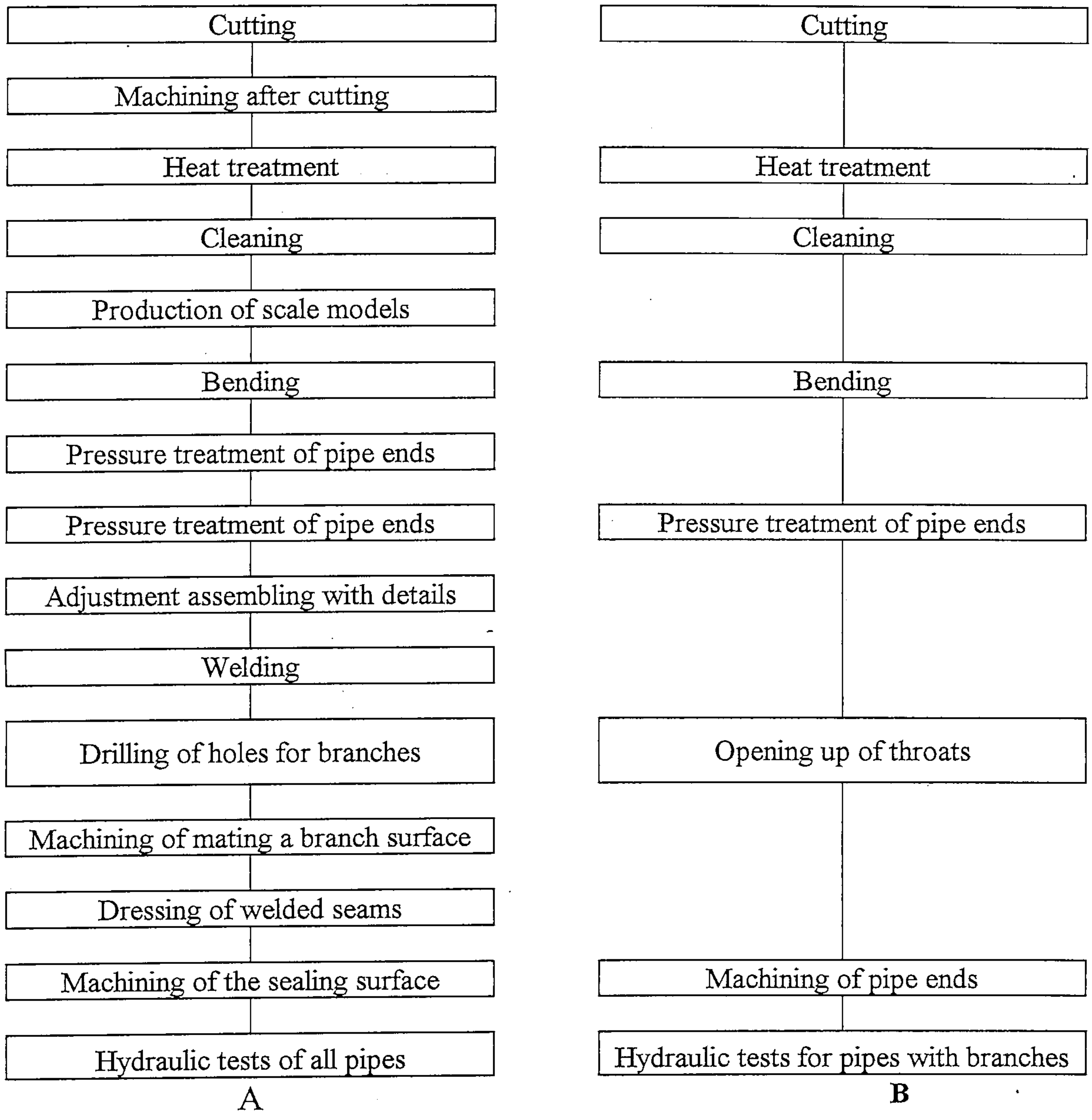

Fig.2.3. Block diagram of comparison of traditional (A) and new (B) technology of the manufacture of pipelines

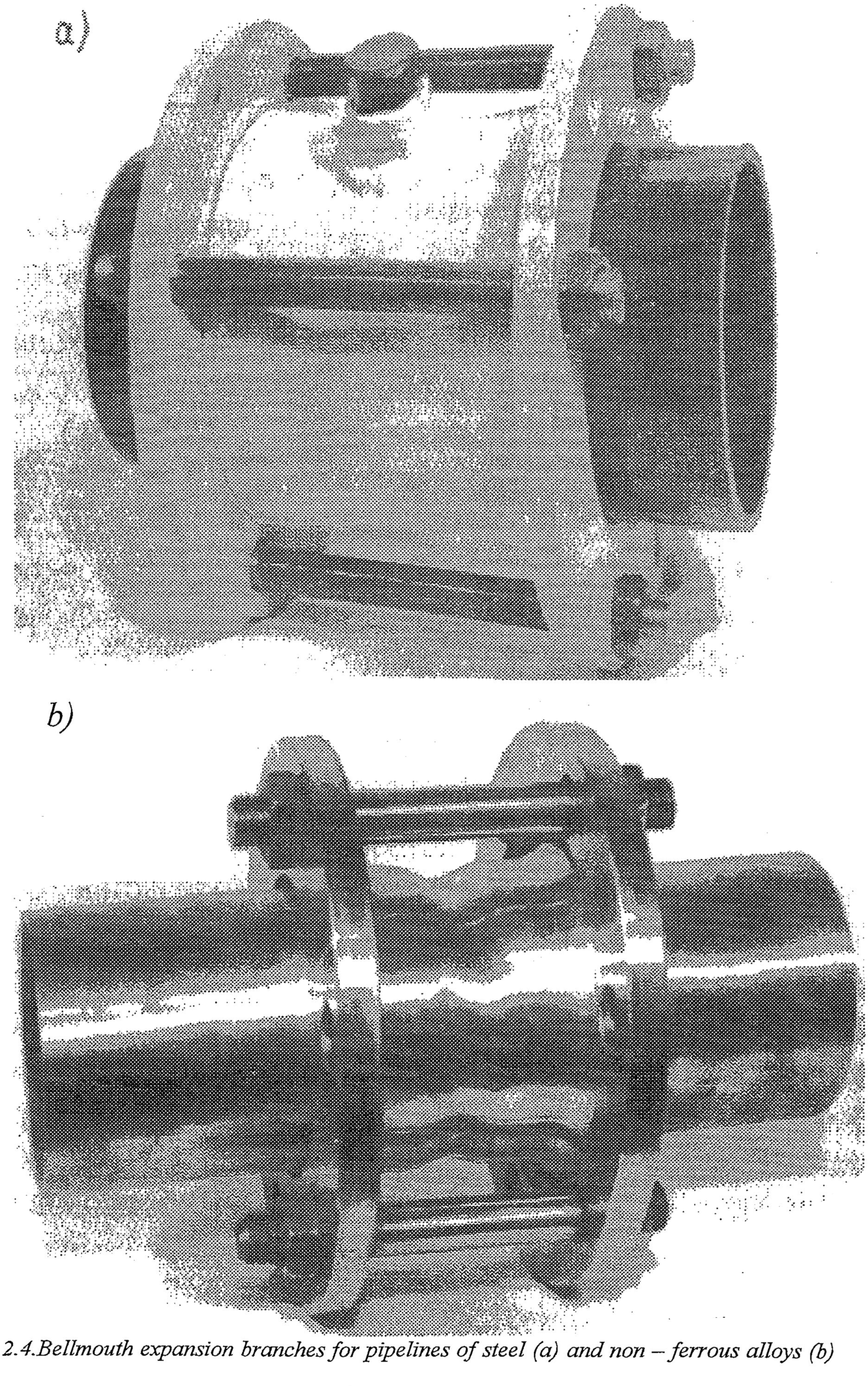

Fig. 2.4.Bellmouth expansion branches for pipelines of steel (a) and non – ferrous alloys (b)

Bellmouths at pipe ends and connecting bushes for branches are manufactured mechanically at the horizontal hydraulic presses with the help of simple devices.

The pipeline composed of the above elements may take axial and angular movements, release its components of the effect of different strains and drastically reduce tension and deformation at the ship's heeling in seaways. With the help of bellmouth connections a pipeline may be constructed which would take tearing forces as well. It is possible to build a pipeline practically without welded elements thus increasing the serviceability and reducing the number of failures.

Piping with bellmouth connections and expansion branches increases the reliability and makes the overhaul period twice as long.

Bellmouth connections and expansion branches with a diameter of 25 - 1000 mm are applicable for the marine pipelines, transporting fresh and sea water, gases, oil and oil products at a temperature within the range of (- 40) - (+100)°C and at a conventional pressure of up to 1.6 MPa. They can operate at an axial shifting of pipes of up to ±20 mm and at an angular pipe shifting of up to 8°.

Connections and branches have a certificate of the Russian Marine Register and Det Norske Veritas (Norway) and are successfully in service aboard tankers, fishing vessels, dry cargo ships, on semisubmersed drilling rigs etc.

3. Numerical simulation of the operation of structures of the ice tanker side grillages

3.1. State of art

Two framing systems are used in practice in Russia to design the ice belt structures: the cross uniform framing system and the cross web framing system. The use of intermediate framing set by height of the ice belt is also common. The grillage structure built up by the cross framing system (fig. 3.1) on ice ships has usually a practical spacing of 400-600 mm and a frame span of 2 - 4 m.

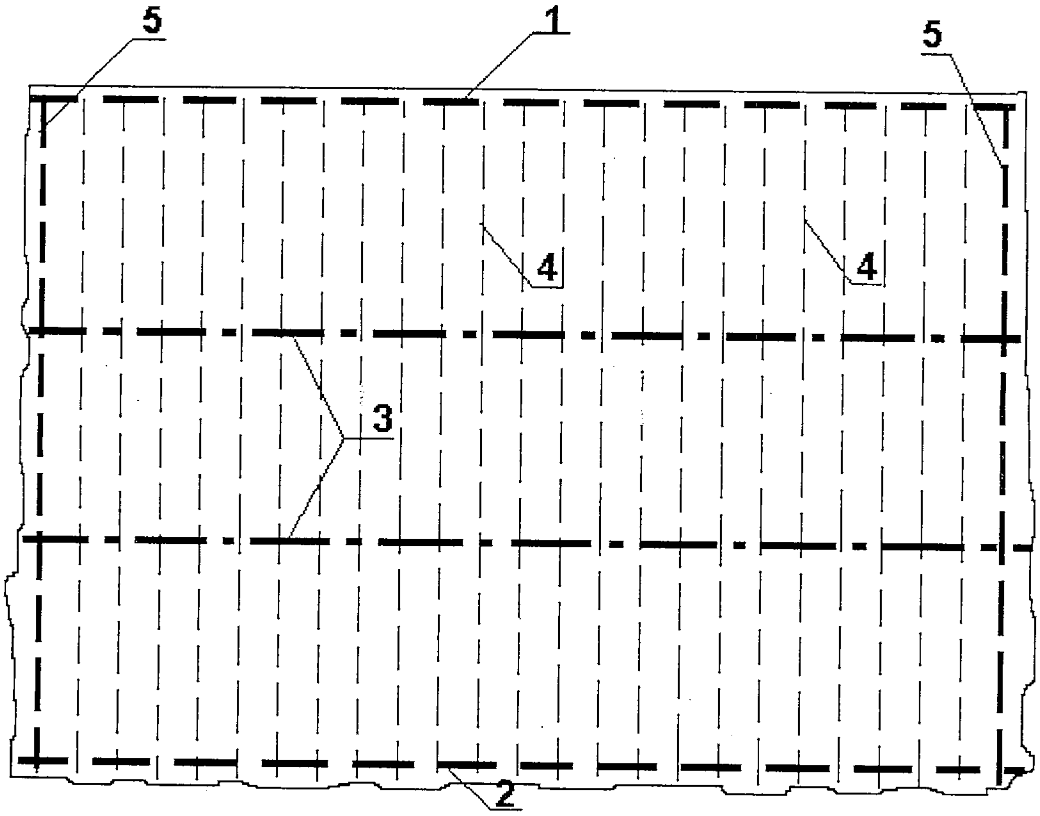

Fig.1. Diagram of the ice belt grillage built up by the cross framing system: 1 - deck; 2 - double bottom; 3 - side stringer; 4 - frame; 5 - transverse bulkhead

The ice belt grillage built up by the cross web framing system (fig. 3.2) has the following parameters: spacing – 400 - 600 mm, frame span - 2-3 m, web framing spacing - 2.4 - 3.2 m. The web frame has larger scantlings than the ordinary one.

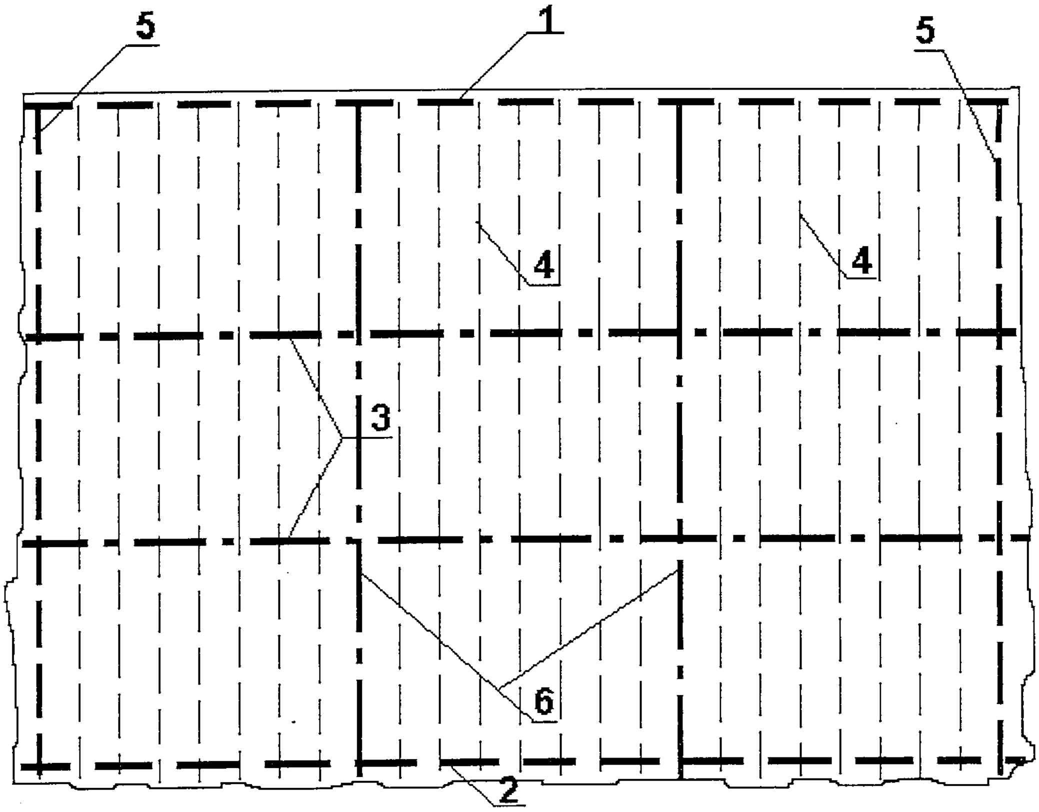

Fig. 3.2 Ice belt grillage designed by the cross web framing system: 1 - deck; 2 – inner - bottom plating; 3 - side stringer; 4 - ordinary frame; 5 - transverse bulkhead; 6 - web frame

The requirements of the leading classification societies to the general arrangement and structures of ice tankers which were published at the beginning of 90-ies aim first of all at the improvement of the environmental safety of ships of this type. Among such requirements there are the following:

- restriction of the cargo tank volume;
- double bottom (appeared at the beginning of 70-ies);
- availability of purely ballast tanks;
- obligatory fitting out of the double side.

The last requirement results in the reduction of volume assigned for cargo spaces and in the increase of the mass of hull at the expense of the installation of longitudinal bulkheads parallel to sides this substantially reducing the efficiency of tanker as a transportation vehicle. It is especially appreciable for ice tankers which while having the same dimensions as conventional tankers should possess higher power and hence a larger mass of the propulsion plant and additional mass of the ice belt structures. The above circumstances make urgent the problem of reducing losses of the efficiency of ice tankers through the optimization of the ice belt structure by the reliability criterion to be achieved at the design stage. The reliability as probability of the nonfailure by a given critical state criterion was selected as a universal factor of the safe operation of construction from the environmental point of view.

Standard service life of a tanker depending on national rules is 15-25 years. During this time the structutral elements of side grillages are subject to the corrosive and abrasive wear the permanent plastic deformations being accumulated. Both factors reduce the original strength of construction. For this reason it is of importance to assess the effect of wear and of accumulated plastic deformations upon the operational strength of construction.

The object of work in 1997 is the development of methods for the comparison of the reliability of the ice belt grillages of ice tankers having different framing systems. The comparison is made on the basis of the numerical simulation of the structural response on the effect of ice loading under the most different scenarios of its application. Probabilistic distribution of the outer loading parameters is assumed to be given. The reliability is determined by the yield and permanent plastic deformation criteria using the methods developed at the first phase of INSROP. The reliability is to be determined at different scantlings. The second step (stage) of investigations is the choice of structural dimensions of the double side grillage elements under the condition of equal reliability to the grillages with uniform and web cross framing systems. This will enable determining the compliance of the conventional ice belt structures with double side structure the anticipated damageability of which would be not worse than the traditional one. The different wear intensity of structural members of the inner longitudinal bulkhead and of the outer ice belt of double side grillages may by the end of the operational period considerably change the rate of the reduction of reliability for this type of construction in comparison with conventional grillages. For this reason it is necessary to additionally carry out numerical investigations of the wear effect and damages upon the reliability of different structures by the end of operational period.

At the final stage of investigations in 1998 it was intended to draw up the first edition of the methodology of the assessment of risk of oil tankers being damaged during their sailing through ice. While developing the procedure it was planned to use data on the ice damages of ships and to investigate the effect of the recommended speeds of movement under various ice conditions calculated for each type of ship in ice passports.

3.2. Calculational schemes of grillages

This section contains the structural grillage schemes according to which the finite element models for the calculation in the ANSYS systems are produced.

The structural drawing of the grillage built up by the uniform cross framing system is shown in fig. 3.3. The structural drawing of ice belt grillages built up by the web cross framing system is shown in fig. 3.4. Structural drawing of the double side is shown in fig. 3.5. The double side has a width of 2 m. The arrangement of vertical and horizontal diaphragms corresponds to the arrangement of web frames and side stringers of the grillage in fig. 3.4.

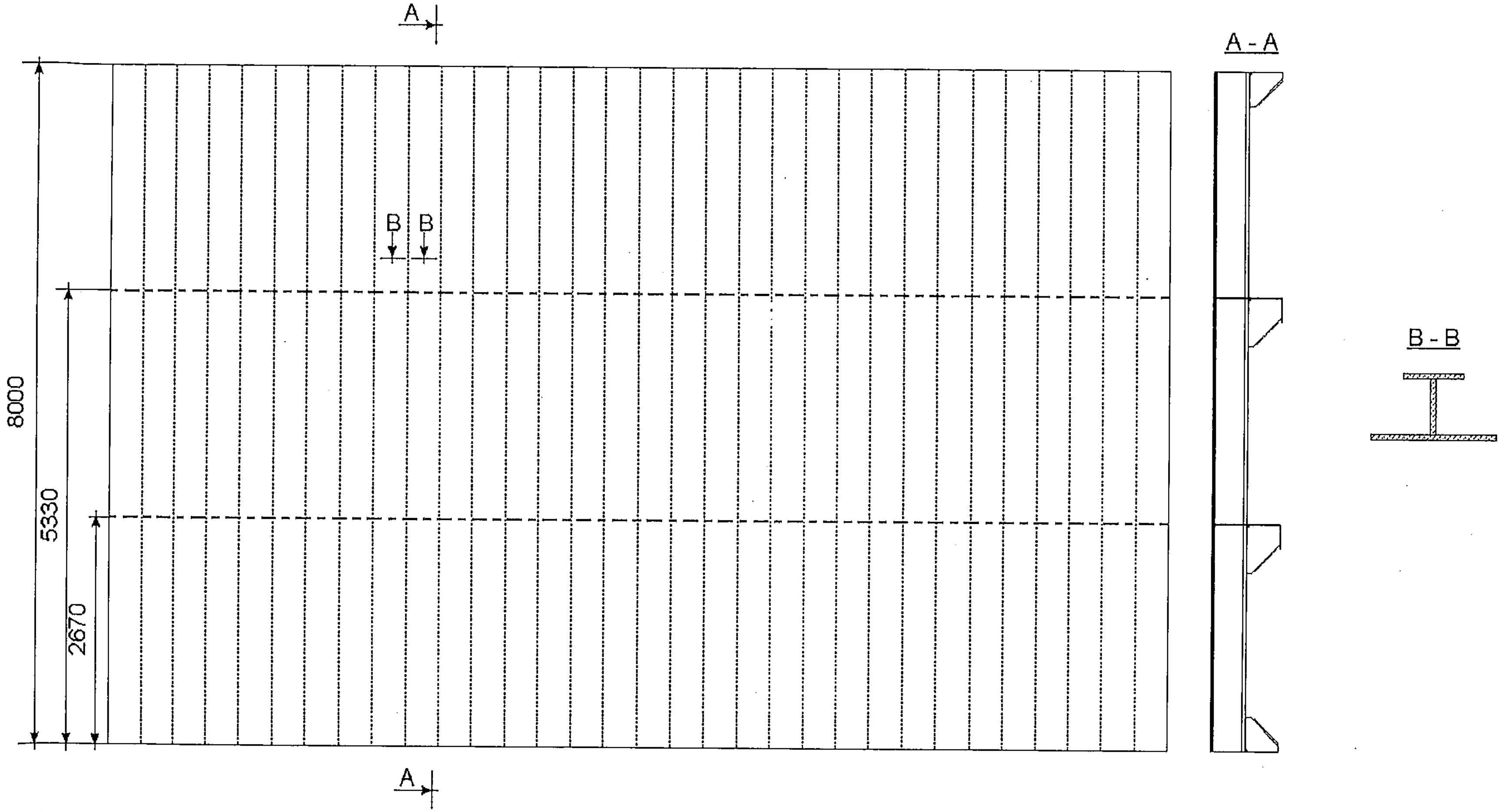

Fig.3.3. Structural drawing of the calculated grillage built up by the uniform cross framing system. A-A –section through the ordinary frame; B-B - frame cross section

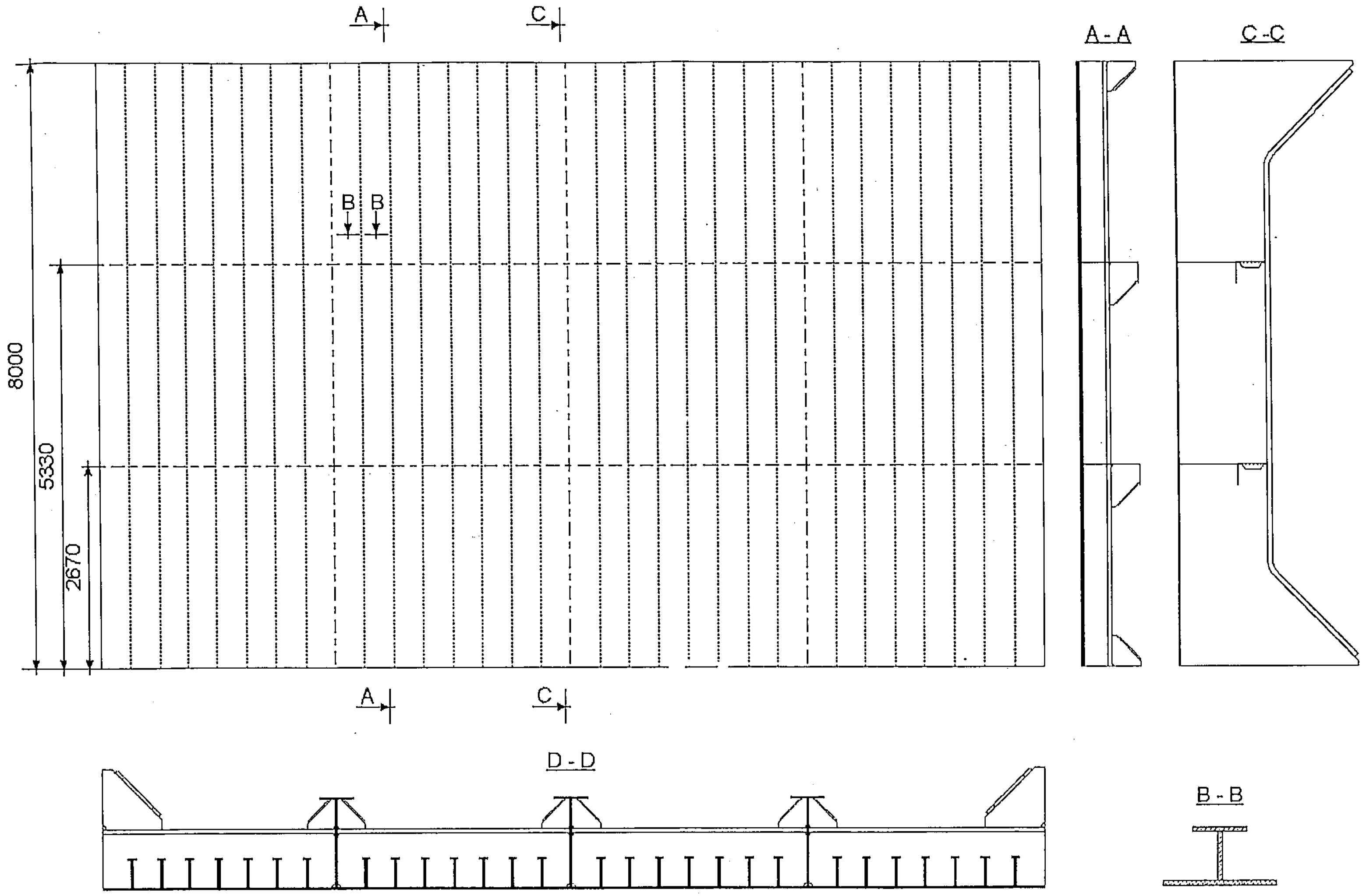

Fig.3.4. Calculated grillage, cross web framing system. A-A section through the ordinary frame; B-B - cross section of the ordinary frame; C-C - section through the web frame; D-D - longitudinal section for the side stringer

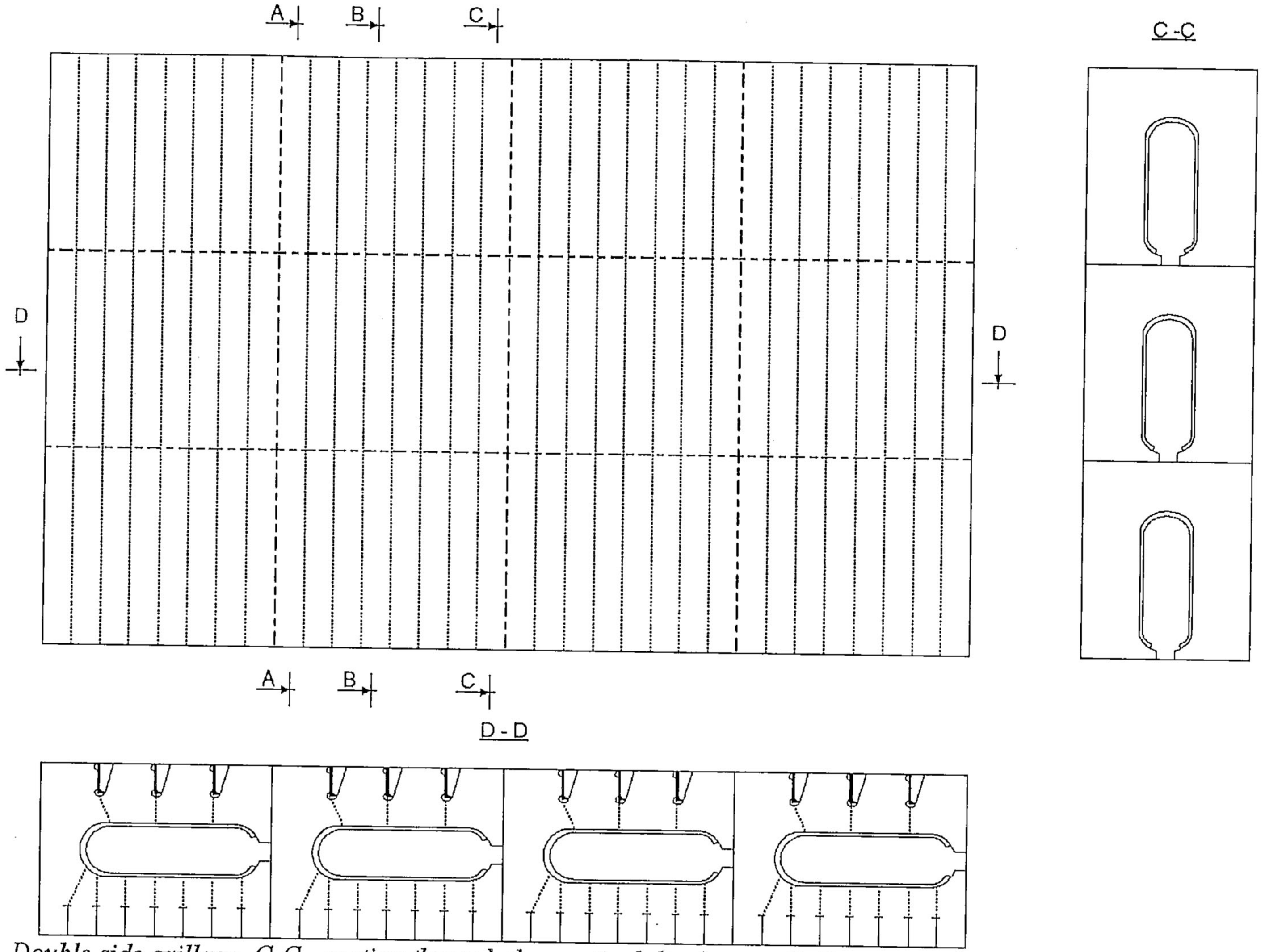

Fig.3.5. Double side grillage. C-C - section through the vertical diaphragm; D-D - section through the horizontal diaphragm

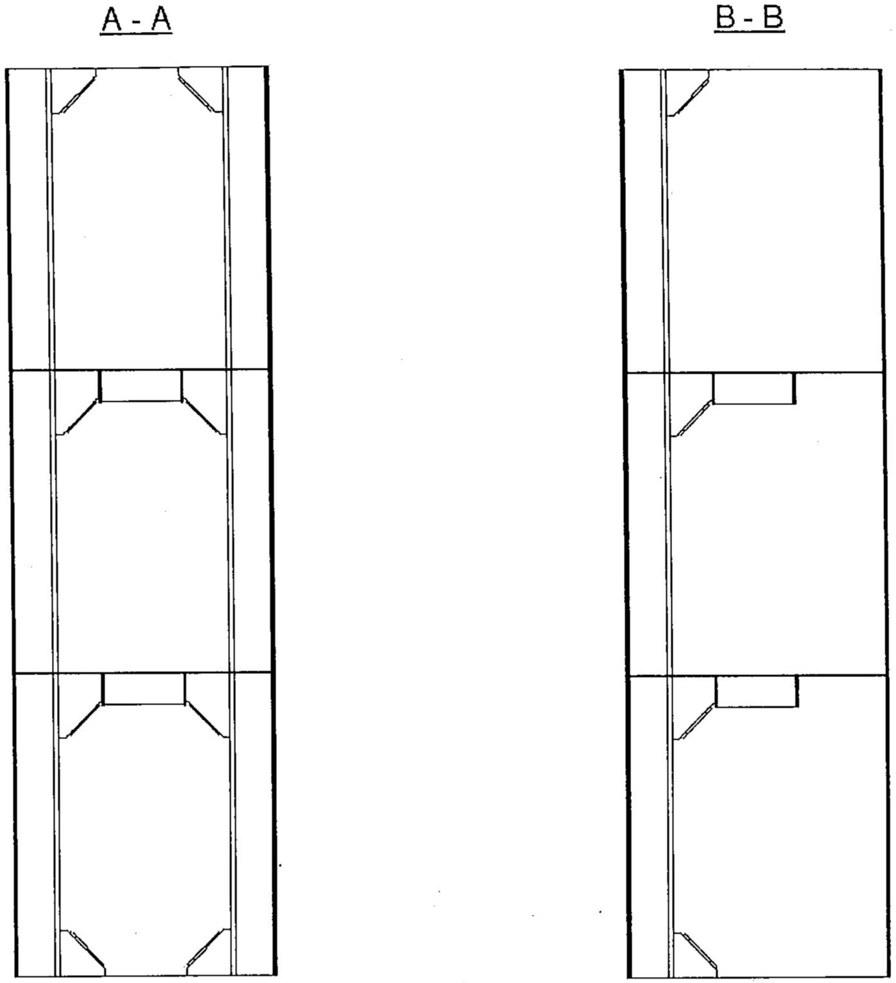

Fig.3.5 (Continuation). *<u>A-A</u>* *- section through the ordinary frame and stanchion of the longitudinal bulkhead;* *<u>B-B</u>* *- section through the intermediate frame*

3.3 Calculations

Calculations are made at several values of scantlings. Varied figures are indicated in tables 3.1-3.3.

Table 3.1

Calculated values of scantlings of the grillage with the uniform cross framing system

Version	1.1	1.2	1.3
Thickness of the shell plating, mm	12	15	18
Thickness of the frame web, mm	14	18	20
Cross section area of the frame free belt, cm^2	20	25	35

Table 3.2

Calculated values of scantlings of the grillage with the cross web framing system

Version	2.1	2.2	2.3
Thickness of the shell plating, mm	12	15	18
Web thickness for the ordinary frame, mm	14	18	20
Cross section area of the frame free belt, cm^2	20	25	35
Web thickness, mm	18	20	22
Cross section area of the frame free belt, cm^2	44	50	68

Table 3.3

Calculated values of scantlings of the double skin grillage

Version	3.1	3.2	3.3
Thickness of the shell plating, mm	12	15	18
Thickness of the longitudinal bulkhead plating, mm	12	12	12
Web thickness of the frame, mm	14	18	20
Cross section area of the frame free belt, cm^2	20	25	35
Thickness of the horizontal and vertical diaphragms, mm	15	15	15
Cross section area of the belt of cut-outs of the diaphragm, cm^2	15	15	15

Loading parameters are the following: ice pressure **p**, height of the contact area **b**, length of the contact area **l**, co-ordinates of the centre of the application of loading **x** and **y** in the grillage co-ordinate system. Ranges of the change of loading parameters are as follows:

p:	0,5 - 6,0 MPa
b:	0,3 - 1,0 m
l:	1,0 - 10,0 m
x:	0,1 - 0,5L (L - length of the grillage)
y:	0,1 - 0,5H (H - height of the grillage)

The wear is accounted for by the 20% reduction of thickness of the side shell plating, 30% reduction of thickness of the inner longitudinal bulkhead plating, 10% reduction of thicknesses of the framing members (webs and girders). The above reduction of the thickness of structural elements was actually observed on ice ships after their long operation (15 – 20 years). Plastic deformations were taken into account by the simulation of corrugation type damages over the whole area of the outer grillage with the permanent deflection of 1/20 of the frame spacing.

3.4. The results of 1997

The section contains the finite element models description for the grillages of two types and the results of test calculation in the elastic area.

Finite element models of the grillage of the cross uniform framing system (2420 finite elements) and of the grillage of the cross web framing system (2636 finite elements) were made up. Finite elements models are shown in figs.3.6, 3.7, 3.9. Results of the test calculation are shown in figs.3.8, 3.10 – 3.12.

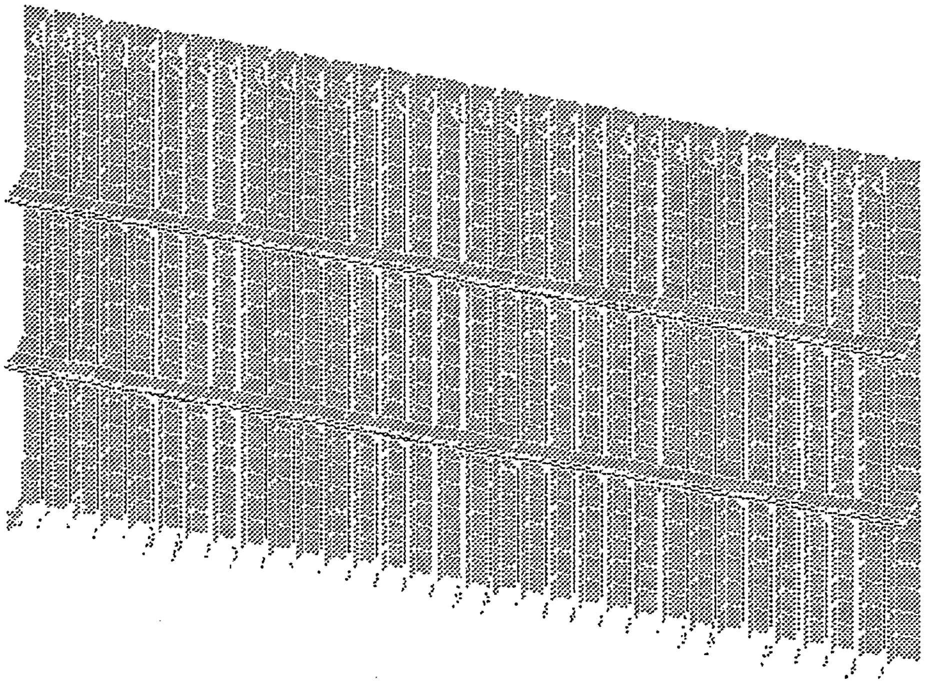

Fig.3.6. The finite elements model of the grillage with the uniform framing system

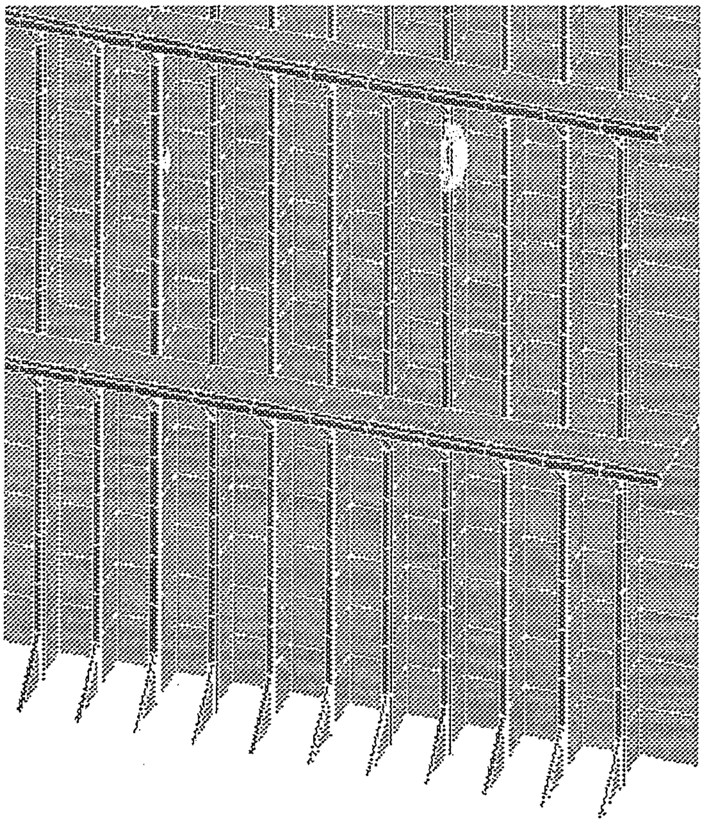

Fig.3.7. Details of the finite elements model of the cross uniform framing system

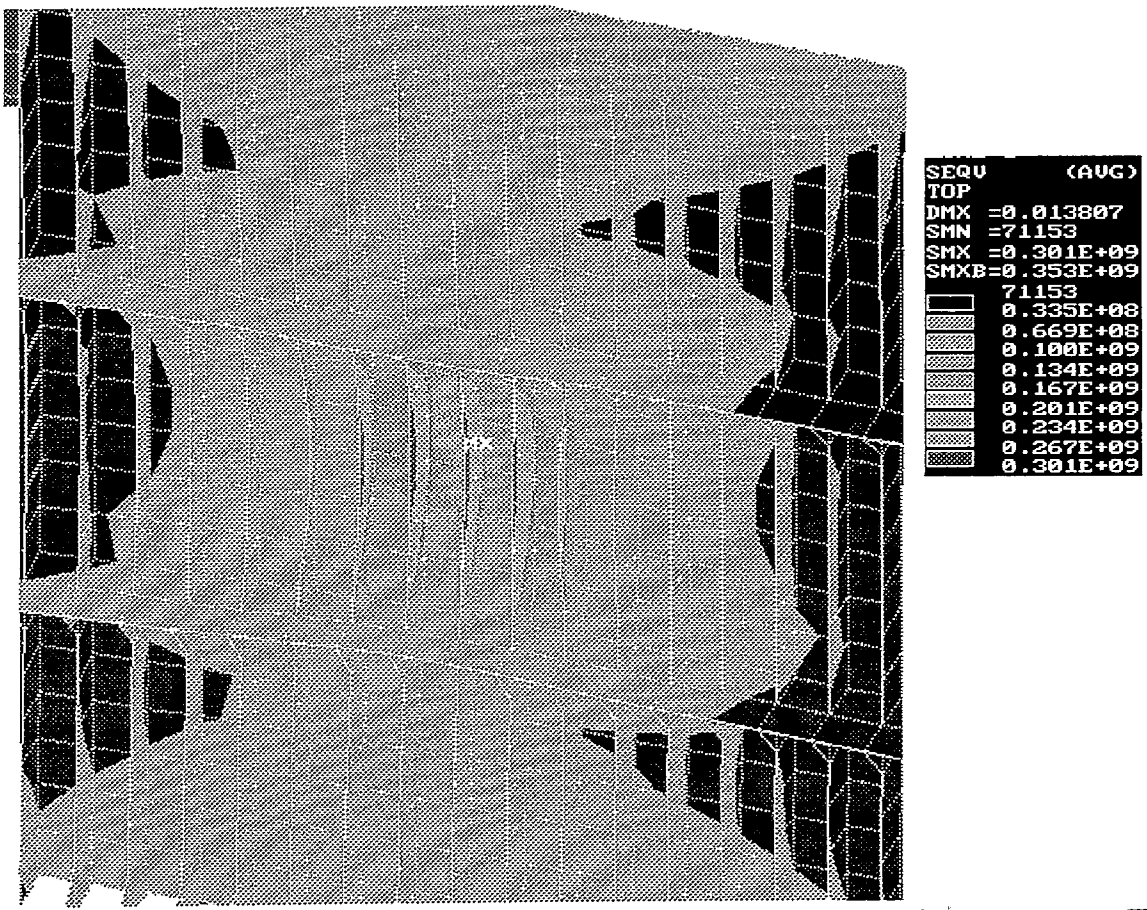

Fig.3.8. The elastic test calculation of the grillage by the uniform cross framing system. The diagram of equivalent stresses

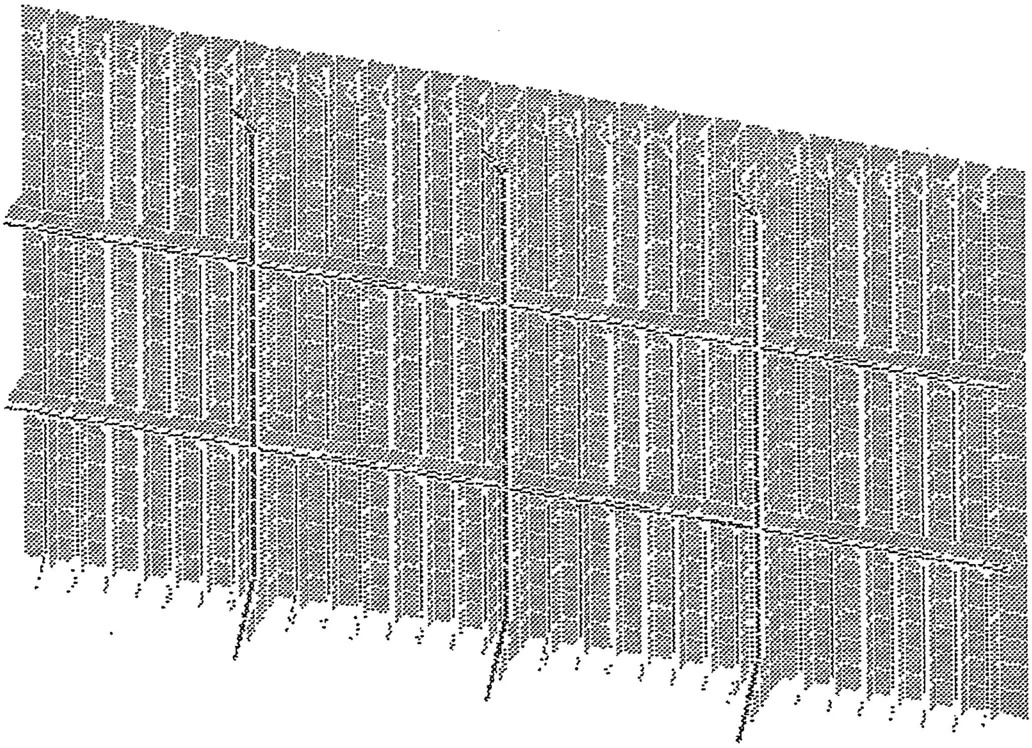

Fig.3.9. The finite elements model of the grillage with web frames

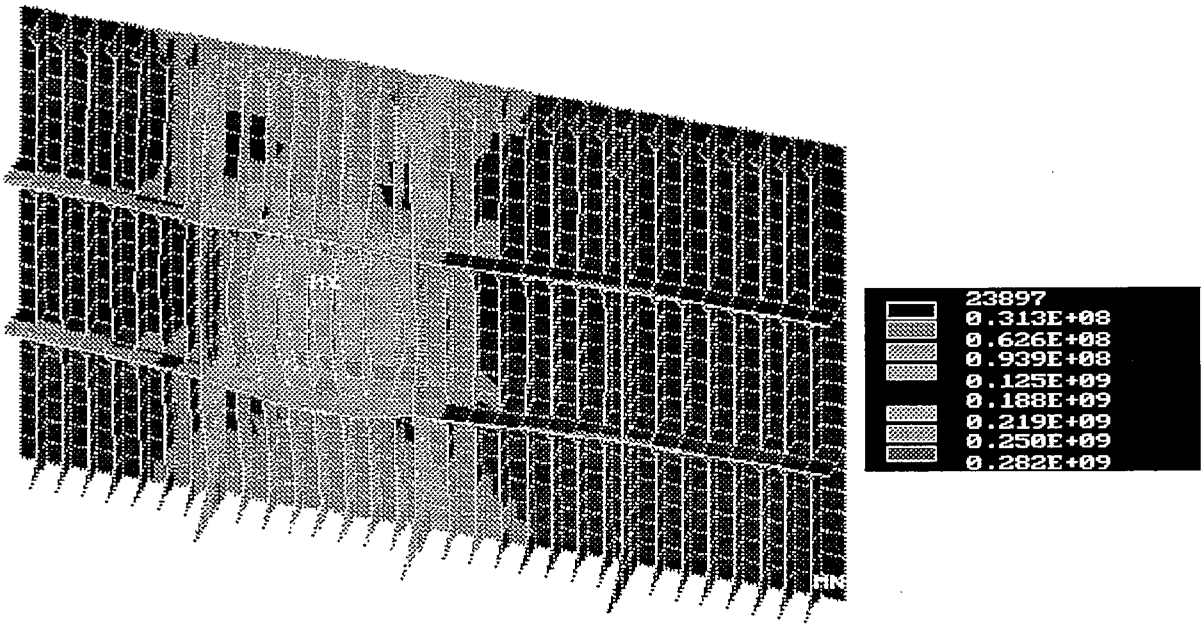

Fig.3.10. The results of the test calculation of the grillage with the cross web framing system. The diagram of equivalent stresses

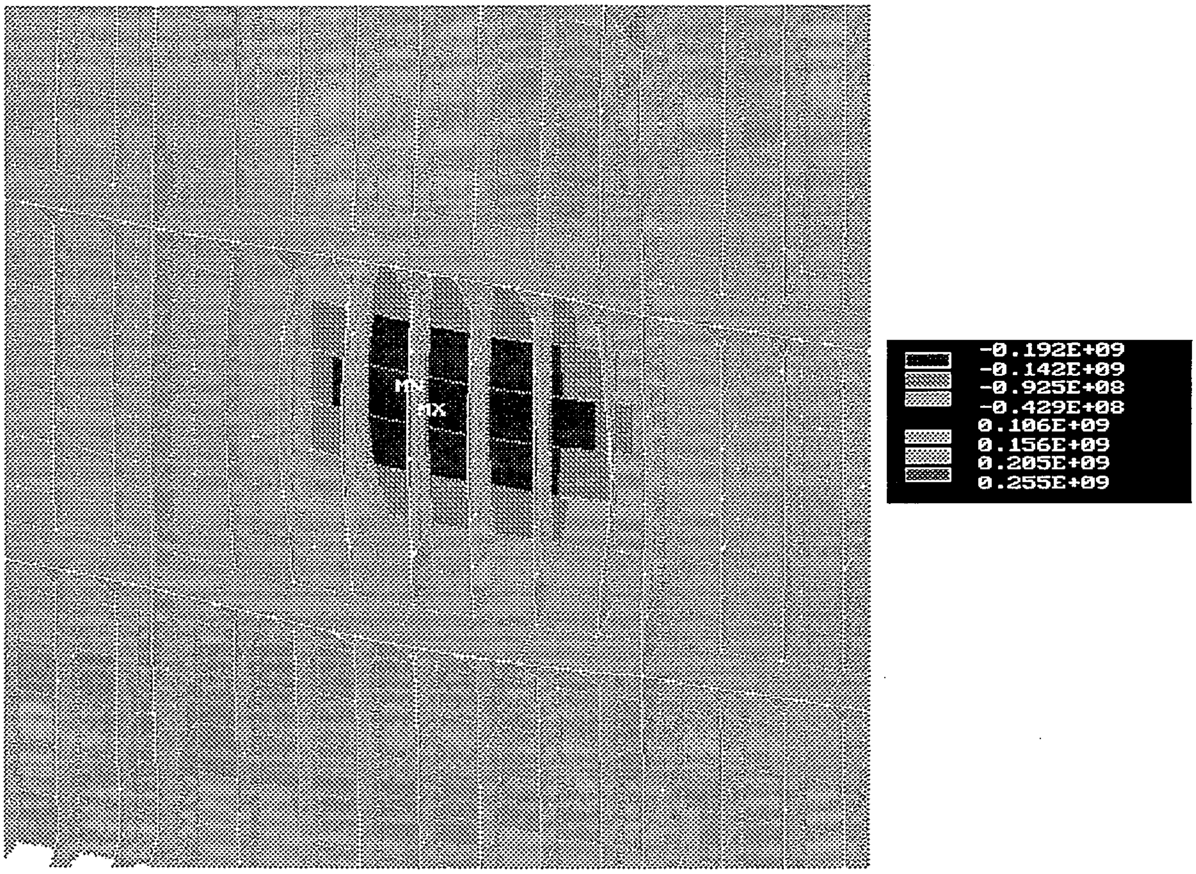

Fig.3.11. The results of the test calculation of the grillage with the cross web framing system. The diagram of the stresses σ_y

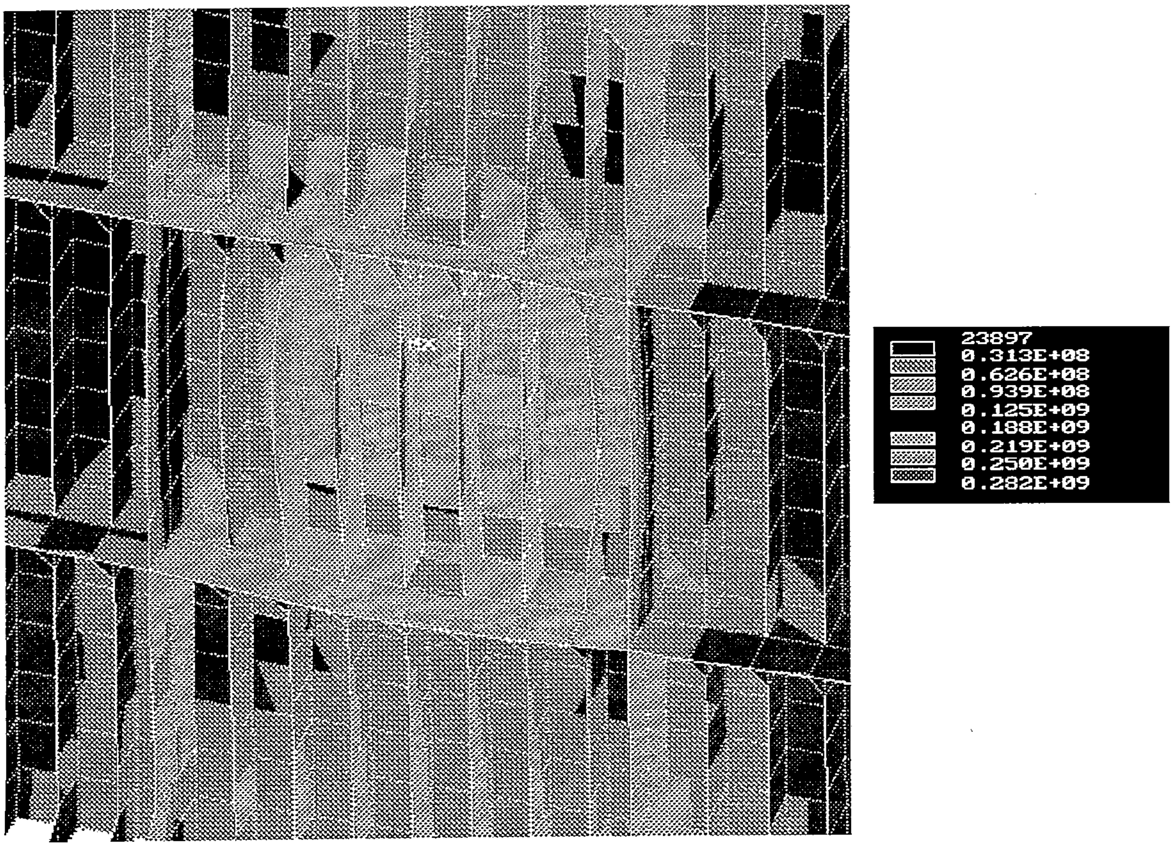

Fig.3.12. The results of the test calculation of the grillage with the web framing system. The diagram of the stresses intensity

3.5. Influence of the ice passport on the reduction of environmental pollution

The ice passport (IP) is a tool for navigator which allows to control the ship motion speed in ice to avoid heavy ice belt structure damages. Estimation of the efficiency to use the ice passport must be carried out by the comparison of the IP theoretical models with data on the actual damages.

Within the scope of works of 1997 the following steps in this direction were done.

1. The finite elements model of a part of the ice belt grillage of tanker of the "Samotlor" type (fig.3.13) was developed. The model had the following parameters: spacing - 400 mm; number of frames - 7; frame span - 4,0 m; thickness of the outside plating - 21,5 mm; frame profile HP280×11. The boundary of the grillage part are web frames and side stringers. The number of finite elements is 322.
2. Calculation of the ice loads was carried out under assumption of the localization of the plastic deformation in the contact area for the damage recorded by Dr. S.Karavanov on the tanker "Samotlor" in the lower part of the ice belt. The damage parameters are the

following: maximal value of the plastic deflection - 60 mm; vertical size of the damaged zone - 3,5 m; horizontal size of the damaged zone - 2,0 m. The recovery of the ice loads was carried out by the method of the stepwise loading of the structure at the following steel parameters: yield stress σ_y=300 MPa; tensile strength σ_u= 600 MPa with δ = 0,2. The results of calculation are shown in figs.3.14 – 3.17. The maximal plastic deflection as a function of the ice pressure is given in fig.3.18.

3. According to the results of calculation the ice pressure at which the mentioned damage is possible is 1,0 - 1,2 MPa taking into account the dispersion of steel properties. The zones of plastic deformation are shown in fig.3.19. The uniform distribution of pressure while analysing the mechanism of damages of tanker "Samotlor" is rightful due to small dimensions of the damaged area. The models of loading used today produce very large contact areas. Such damage could occur at the compression of ship in the second- or multi – year ice.
4. The above ice pressure range could be achieved under the reflected impact of ship against the ice edge with a speed of 6 - 7 knots. It proves the agreement between the theoretical models of IP and the real practice of getting damages.

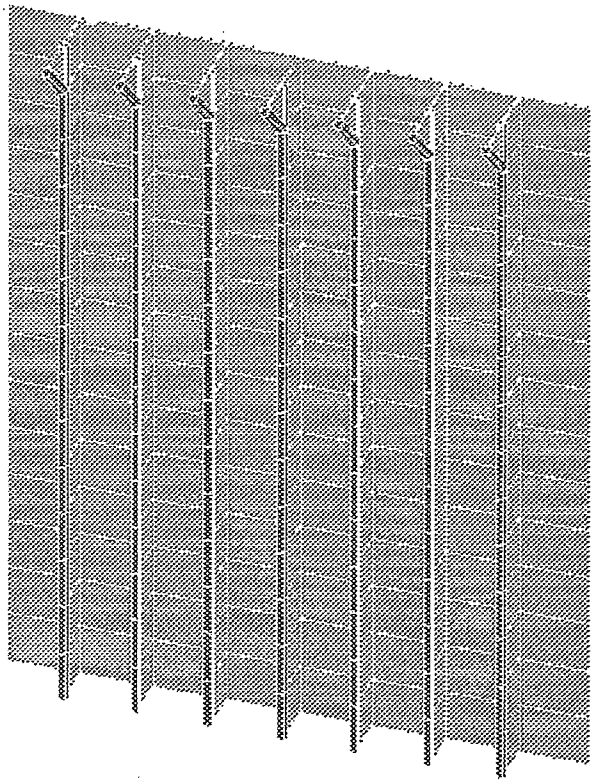

Fig.3.13. The finite elements model of the part of the side grillage amidship of the tanker "Samotlor"

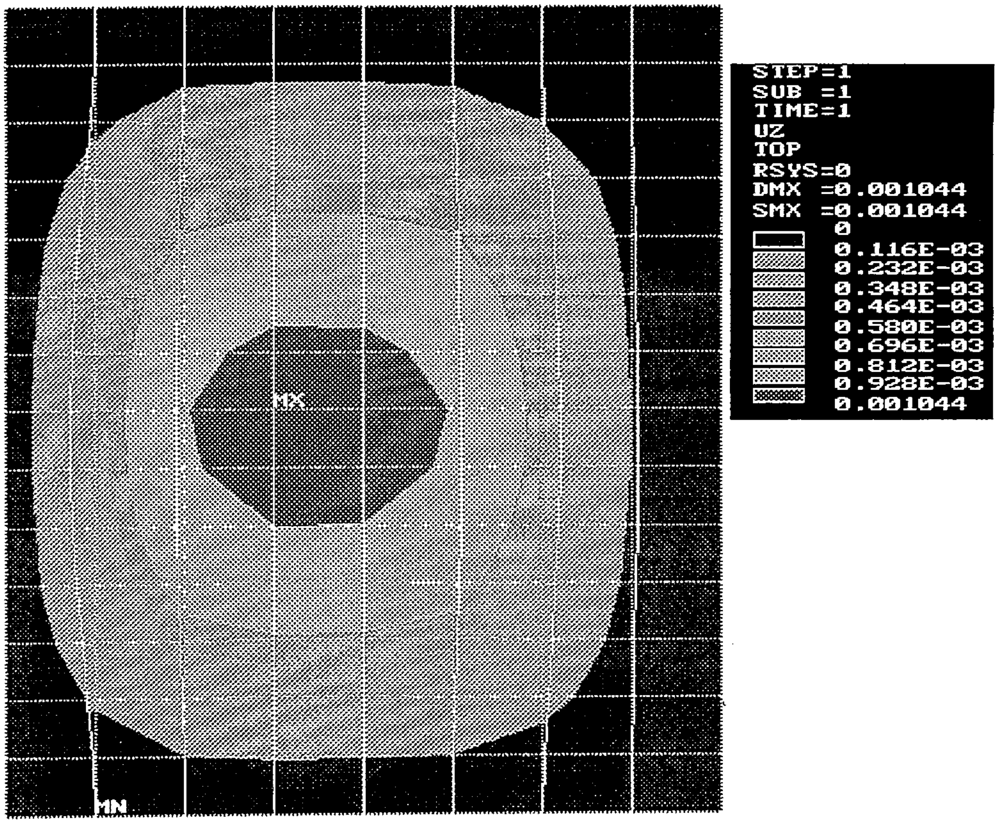

Fig.3.14. The diagram of deflection under ice pressure of 0,1 MPa

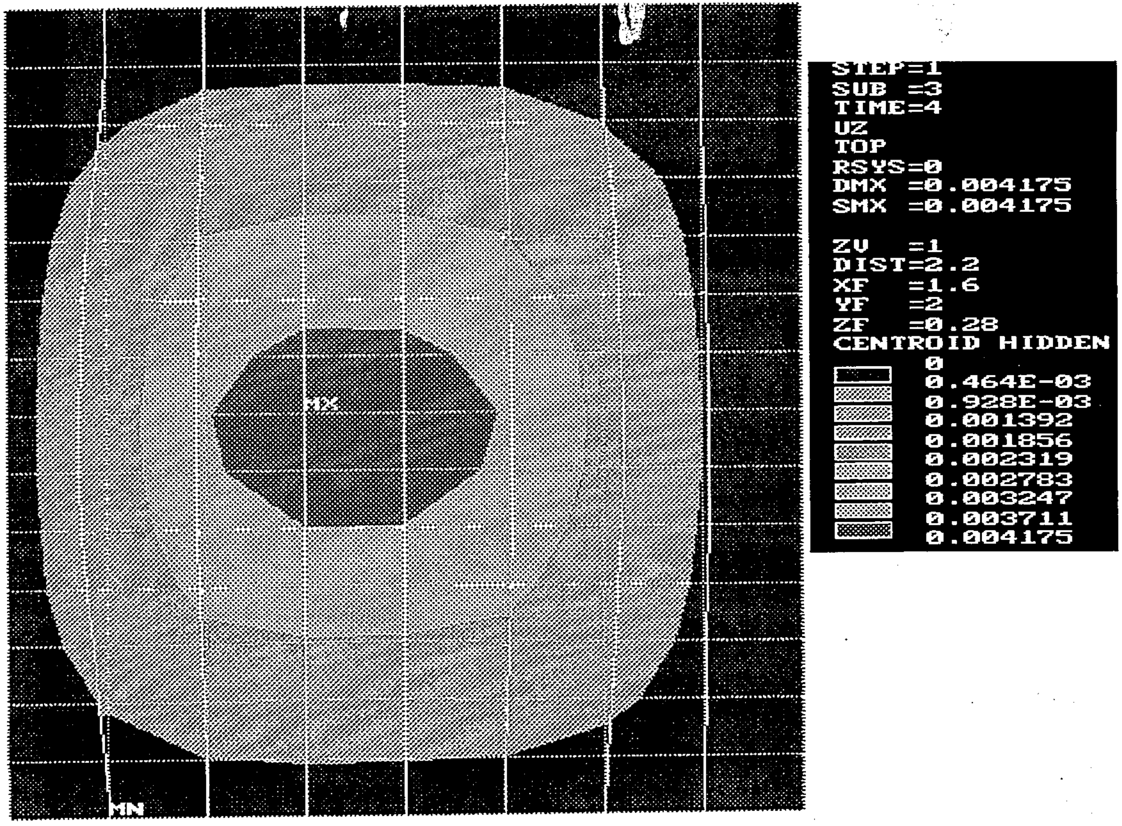

Fig.3.15. The diagram of deflection under ice pressure of 0,4 MPa

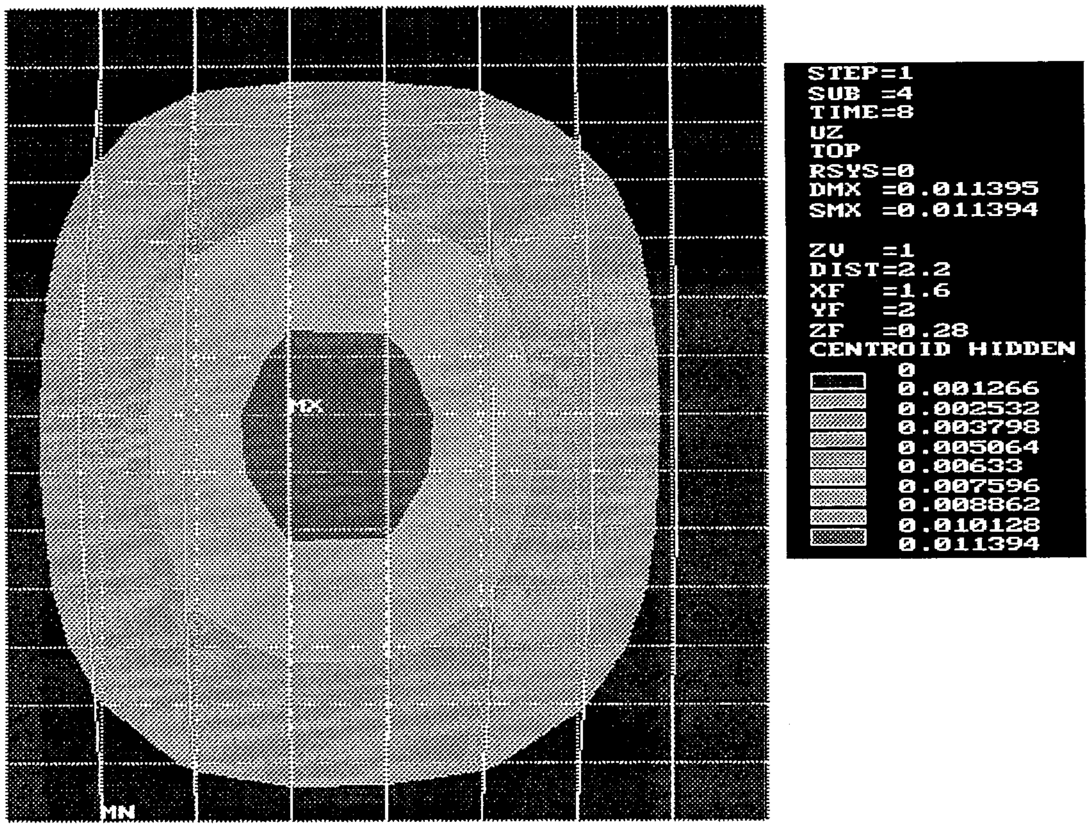

Fig.3.16. The diagram of deflection under ice pressure of 0,8 MPa

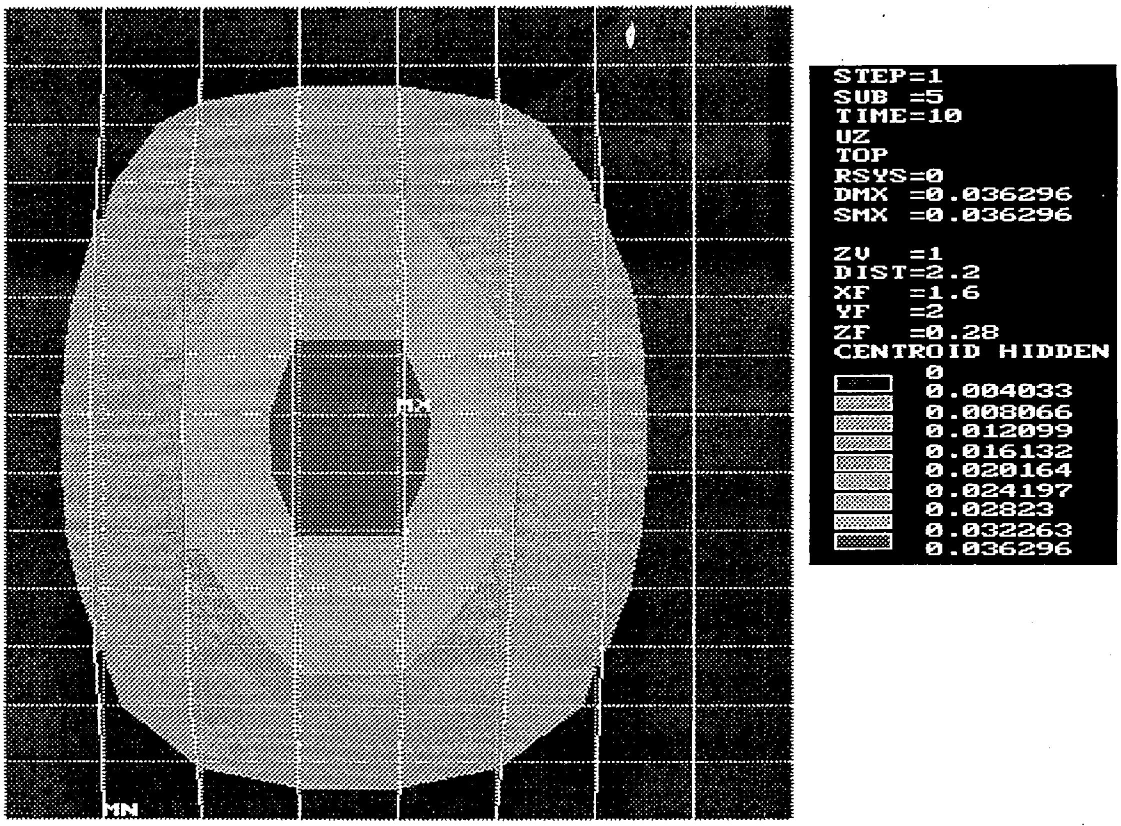

Fig.3.17. The diagram of deflection under ice pressure of 1,0 MPa

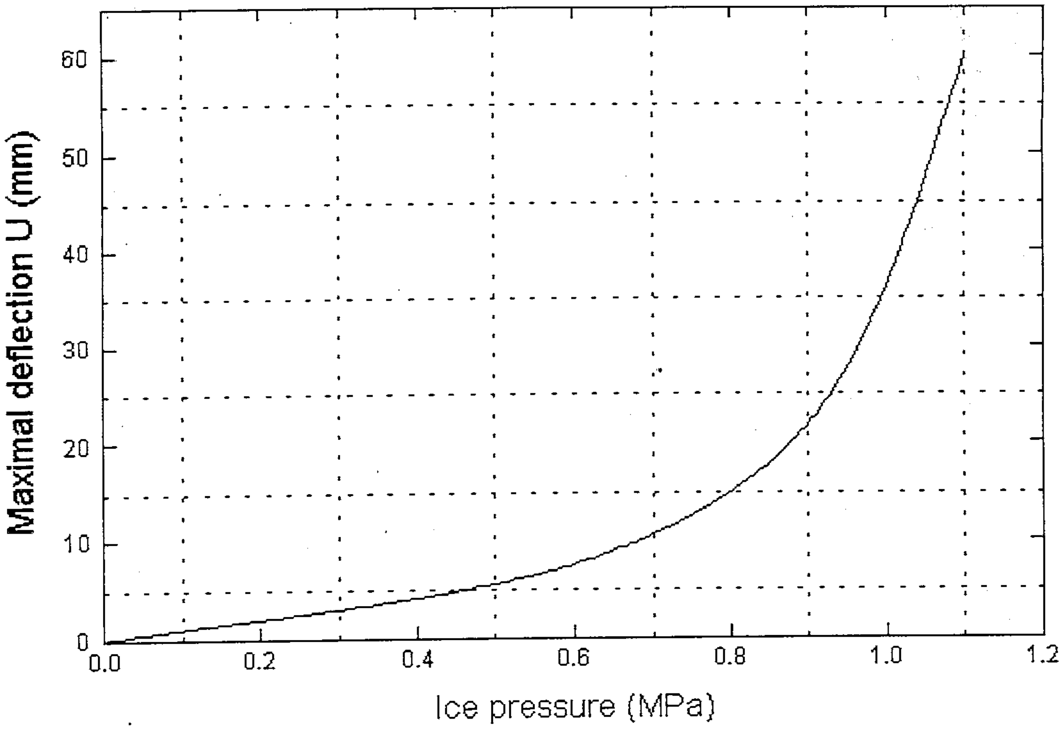

Fig.3.18. The maximal deflection versus ice pressure for the structure of fig.3.13

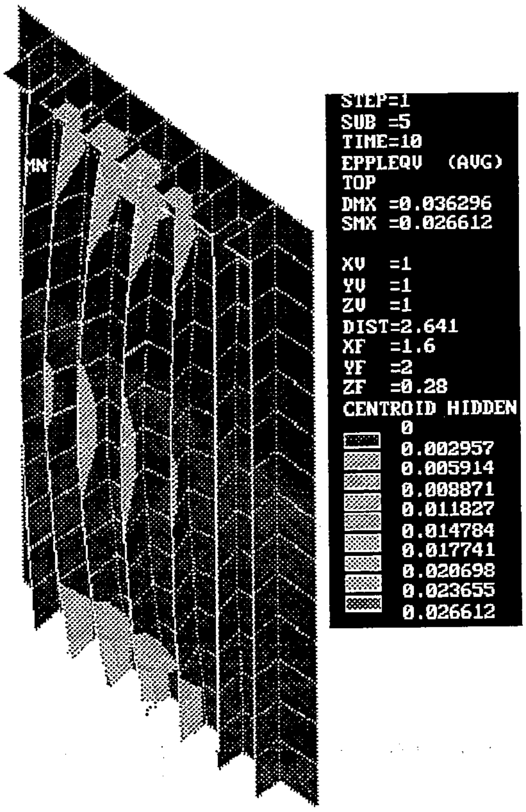

Fig.3.19. The diagram of the permanent plastic strains

The preparation part of the work was carried out during 1997. The parameters net for calculation was developed which is necessary for the construction of critical states structure surface by the chosen failure criteria. Given the distribution lows for ***p***, ***b***, ***l***, ***x*** and ***y*** it is necessary to calculate the structure reliability by yield and permanent plastic deformation criteria for grillages 3.3 - 3.5. The interpretation of design reliability as a function of scantlings allows to calculate such grillage 3.5 characteristics at which this grillage would be equally reliable as to 1 – 2 types grillages. The reviewer is absolutely right that it is necessary to take into account the number of impacts of ship against ice, that is the effect of the accumulation of the permanent plastic strain. Different approaches to the prediction of this phenomenon are developed by AARI at the first phase of INSROP and illustrated by separate structural elements. It was planned to use in the future the developed approaches of the analysis of the accumulation of plastic strain for actual grillages with different framing systems.

4. Recommendations on the selection of the ice class of tanker and on structural solutions.

Selection of an ice class

Operational experience of the domestic fleet on the NSR has shown that the reliable work in the Arctic may be provided only by the ULA class ships of the Marine Register of Shipping (MRS) and by those close as to the level of requirements of other classification societies (for instance, 1A of the Finnish-Swedish Rules). Ships of this class on the western sections of the NSR (that is long up to 125° E) for the major part of the year can independently navigate through ice of this area.

The design of ship for the UL class of the MRS would ensure its stable work under the icebreaker support in the western area of the NSR, but ice strengthenings of ships of this class may turn up to be insufficient for the operation in the East Siberian and Chuckchee Seas characterized by especially severe ice conditions due to the proximity to the route of large ice massifs and the penetration of pack ice. The heaviest conditions here are observed during the early period of navigation.

In the process of operation in the Arctic it became clear that the requirements imposed by the Marine Register Rules in force to the ice strengthenings of the L1 class ships are inadequate for the reliable operation in ice of the NSR because even at the beginning of the summer navigational period during the extended navigation the ships of this type suffered heavy damages and several ships of this class sank. It became also clear that for the stable work in ice of the NSR ships of higher classes should be used.

According to the "Requirements to constructions, equipment and supply of the ships proceeding along the Northern Sea Route" adopted by the Northern Sea Route Administration the ships with ice strengthenings of the L1 category of the Marine Register Rules may be admitted for navigation under the icebreaker assistance in the Western (up to 125° E) area of the NSR during the summer-autumn period of navigation and on separate sections of the Eastern area of the NSR during the summer period in favourable conditions of navigation and if the high-reliability forecast is available.

Structural recommendations

Along with the correct selection of the ice class of ship, for reasons of its environmental safety it is also essential while designing underwater hull structures to take into account gathered experience of the practical implementation of different solutions.

Analysis of the hull ice damages of domestic arctic ships has shown that in contrast to the damages caused by ships' collision the first ones are comparatively small in sizes in plan and low in penetration - on ships of the UL and L1 classes the maximum depth of dents does not exceed 300 and 400 mm, on the ULA class ships the same figure is 200 mm accordingly. Holes (cracks) in the shell plating have average extent up to 1.5 - 3 m and opening - within 10 - 50 mm. These sizes depend on the structural strength and on the force of impact.

Statistical processing of the data on the hull ice damages of ships sailing along the NSR has shown that probability of the destruction of the shell plating within the area of dents by the impact of ship against ice or as a result of compacting is rather high: at damages of the forebody half of ship the probability of the water leakage in the plating and holes-cracks with considerable (up to several centimeters) disclosure of edges is within 30-60 % of the total annual number of damages in dependence on the quality of ships participating in the arctic navigation and on the complexity of ice conditions.

Therefore for the reliable environmental protection of the water area of the NSR it is necessary to use double bottom and side structures on the tank ships carrying oil and hazardous cargo and to impose restrictions for all ships as to the use of double bottom compartments to store fuel there.

Total environmental protection might be provided in case of the installation of double sides combined with the double bottom within the cargo tanks area (as on tankers of the "Samotlor" type). Double bottom depth and distance from the shell plating of the inner side should comply with the "Requirements to the tanker hull structure aimed at the provision of the environmental safety" and be less than 2 m or B/15 (whichever is shorter) for the double bottom and 0.76 m for double sides.

Partial environmental protection (as applied to bilge damages at impacts against grounded hummocks or "tuckings") might be achieved either by extending double bottom up to the side or by the installation of double sides in such a way that they completely overlap the bilge as the most damageable hull area within cargo compartments.

As the analysis has shown, the frequency of the occurrence of ice damages in the after part of hull is considerably lower than in the forepeak or in the ship's midbody. Sizes of damages of the bilge strake and bottom in the afterbody are much smaller than in the forebody half of the hull. As a rule, these damages have no water leakage and are not dangerous for ship.

On the basis of the above stated, the following may be suggested as recommendations directed to the rational provision of safety:

1. Use of double bottom and side structures the double sides being installed in such a way to overlap the plating bilge area, better until the beginning of the flat bottom .
2. To preclude transportation of oil products in the double bottom and double side compartments if these compartments are located in the forebody half of ship*
3. With the aim of improving the environmental protection to strengthen additionally bottom structural members and the bilge strake (plating and framing) in the area of bottom fuel cisterns and cargo tanks on tankers.

---

* As dangerous bottom damages occur only in the forebody, fuel can be located in the after compartments.

REFERENCES

1. Н.В.Барабанов, В.А.Бабцев, Н.А.Иванов “Ледовые нагрузки на днищевые конструкции судов”, – Судостроение № 11, Л., 1982, с. 9 – 11.
2. В.Н.Бугаков “Некоторые вопросы развития судов активного ледового плавания”, – Судостроение № 11, Л., 1982, с. 11 – 14.
3. С.Б.Караванов Анализ повреждения корпусов транспортных судов арктического плавания в кн. “Перспективные типы судов, мореходные и ледовые качества”, –Л., 1985, с. 72 – 76.
4. Александров и др. “Технология изготовления судовых трубопроводов с использованием раструбных соединений и компенсирующих патрубков”, – Судостроение № 2, март – апрель, Л., 1997, с. 47 – 48.

ANNEX

Subject: INSROP report I.5.11
Date: Thu, 25 Jun 1998 10:30:47 GMT+1
From: "Claes Lykke Ragner" <Claes.Ragner@fni.no>
Organization: Fridtjof Nansen Institute
To: vdg@aari.nw.ru, cniimf@neva.spb.ru

Dear Dr. Likhomanov and Dr. Moreynis,

We have now received from Dr. Mark Fuglem the review of your INSROP report I.5.11: "Structural Safety of Ships Operating in Ice". Please find it attached as a Word for Windows 6.0 file.

Dr. Fuglem's review is mainly very positive, but in the last part of his review, he has some critical questions and suggestions for improvements. We kindly ask you to revise your report according to Dr. Fuglem's comments. In case you do not agree with some of Dr.Fuglum's comments and suggestions, please write a "Reply to the Reviewer", explaining why you do not agree. When the report is finally published, both Dr. Fuglum's review and such a "Reply to the Reviewer" will be printed at the end of the report.

We are very much looking forward to receiving your revised report!

Yours sincerely,
Claes Lykke Ragner

****
Claes Lykke Ragner
Deputy Head of INSROP Secretariat
The Fridtjof Nansen Institute
P.O.BOX 326 Lysaker, NORWAY
Tel: +47-67111915 (dir)   Fax: +47-67111910
E-mail: Claes.Ragner@fni.no
****

Review of INSROP report
SUB-PROGRAM 1. Natural Conditions and Ice Navigation.
1.5.11 Requirements to Environmental and Structural Safety of Ships

In the report, sections are presented dealing with the following topics:

1) Statistical analysis of observed ship hull damages during interaction with ice.
2) Work on improving the safety of ship pipelines for unloading.
3) Numerical simulations of response of ship structure to ice impacts.
4) Recommendations on the selection of ice class and on the construction of tankers.

In Section 1, a brief background on the use of L1, UL and ULA class ships is given and a statistical analysis of damages to these vessels is presented. In the analysis, it is shown how the relative number of incidents for each class of ship have changed over time. In addition, interesting observations have been presented regarding the locations of damages on vessels, the distributions of sizes of dents and cracks, and observations regarding the locations of cracks and the deformations at which cracks occur. Information regarding the relationship between ice conditions and the percentage of ships with damage that have water leakage is included. Additional information regarding the differences in damages and number of leakages for different classes of vessels in included. It is of particular note that 70 to 80% of damages occur when vessels are following icebreakers.

In Section 2, which deals with oil pollution, most of the discussion deals with offloading pipelines for oil for locations where there is no berth. It is stated that other sources of pollution have largely been dealt with through implementation of the MARPOL rule 13 F of the International Convention for the Prevention of Pollution from Ships. This rule was implemented in 1990 and through requirements for double bottoms and sides, segregation of ballast tanks, and (in case of arctic vessels) prohibition of discharge of dirty washing waters, is significantly reducing pollution events. The report identifies cargo handling as the most probable pollution source; especially in the case of unloading to unequipped shore through hoses and pipelines. The report discusses some of the improvements being made in offshore pipelines, and in particular the development of bellmouth pipeline joints at the Central Research Institute of Shipbuilding Technology. The report states that these joints require a simpler manufacturing process, are quicker to implement, and are more reliable than previous joints.

In Section 3, the development and application of numerical simulations of response of ship structure to ice impacts is presented. In particular, finite element analyses are being set up for the following three structures: cross uniform framing, cross web framing, and double skin grillage. It is planned that the analysis will allow optimization of the structure spacing and scantlings and comparison of the reliability of the different structures. In analysing the structures, the ice pressure is applied as a constant load over a rectangular patch. Different scantlings, ice pressures, and patch sizes are being considered. In addition, different amounts of wear and corrosion, modelled as a reduction in plate thickness, are being applied. Example analyses for the cross uniform framing and cross web framing are presented.

In addition to the above analysis, a finite element analysis of the structure on the ice belt for a Samotlor type tanker has been conducted as the initial part of an evaluation of the efficiency of the ice passport system (IP) in reducing environmental pollution. The basis for evaluating the ice passport system is the relationship between vessel velocity and the amount of damage. Finite element analysis is carried out to determine the amount of indentation as a function of impact velocity. The steel is described by the elastic modulus, yield strength, and tensile strength. Maximum deflection is given as a function of ice pressure. Damage is assumed to occur at an indentation of 60 mm. The model shows that this indentation occurs at an ice pressure of 1.1 MPa. A relationship is assumed between ice pressure and impact velocity; this relationship is not described. The ice pressure of 1.1 MPa is assumed to correspond to an impact velocity of 6-7 knots.

In Section 4, recommendations on the selection of the ice class of tanker and structural solutions is given. Comments are given regarding the use of ULA, UL, and L1 vessels in different regions and under different ice conditions. The relatively high rate of amount of damage events resulting in leakage is noted and the consequent need for double bottoms and sides reiterated. It is noted that restrictions regarding the storage of oil and hazardous cargo in double bottom compartments should be applied. It is also noted that damages of the bilge strake and bottom and the after body are small and as a rule do not result in water leakage.

The main recommendations are as follows:

1) the double bottoms and sides be extended to overlap the bilge plating,
2) to preclude storage of oil products in the double bottom and side in the forebody half of the ship
3) additionally strengthening should be applied in the bottom structural members and bilge strake in the areas of bottom fuel cisterns and cargo tanks.

The report overall is fairly well presented. The details on damage events are very informative and should be useful calibrating models and assessing the risk of leakage. It would be useful in future work to include additional details as follows:

1) the total ship kilometres travelled each year through ice and the total number of vessels,

2) the fraction of vessel incurring damage and leakage, and
3) the approximate damage rate by 1000 kilometres.

These figures would give a better indication of the overall improvement in ice strengthening and ice passport regulations over time than percentage breakdowns. In specifying damage events, it would be helpful to discuss the criteria for defining an event as this can affect the lower end of the distributions in Figures 1.5 and 1.6 as well as the estimated number of events. It appears that, given the number of damage incidents occurring during escorting and towing events, that conditions are much more severe at these times and, as noted in item 4 on page 16, that further consideration of tactics during icebreaker support is important.

The development of finite element analyses work in Section 3 looks very promising for comparing different structure. Is the reduction of side shell plating thickness of 20% versus the reduction of inner longitudinal plating of 30% based on observations? Further explanation is required regarding the effectiveness of the ice passport system and assessment of reliability. In particular, the choice of an ice patch of constant pressure and the relationship between ice pressure and vessel speed need justification. Should not consideration be given to the distribution of floes sizes impacted and the types of ice encountered (first year, multi-year, etc)? In addition, a significant amount of available research indicates that ice pressures have a random component. Further description of the rationale for the method and the distribution of ice types being considered would be helpful. Where impact loads are random, the number of impacts has a significant effect on maximum loads encountered.

The recommendations that the double bottoms and sides be extended to overlap the bilge plating and that additional strengthening be applied to bottom structural members and bilge strake in the areas of bottom fuel cisterns and cargo tanks appear sound. In not recommending explicitly that the storage of oil products in the double bottom and side only in the aft half of the ship, has consideration been given to damage due to grounding events and other regulations?

Response to the reviewer, Dr Fuglem

We have examined the review of Dr Fuglem on our work (I.5.11) and are very grateful for his detailed and highly professional consideration of this work.

Side by side with the general high appraisal the reviewer expressed some wishes to be taken into account in the future work, some comments however were taken into consideration in the final editing of the present report.

Main wishes of the author of the review involve the suggestion to include into future work the following information:

1. data on the length of ice stretches per navigation,
2. information about the ship's areas subject to ice damages (with leakage?),
3. number of damages per 1000 km of the route.

Generalization of the statistics characterizing the operation of ships in ice suggested in items 1 - 3 seems to us very useful. Therefore we agree to consider these problems as well as the advisability and tactics of the icebreaker support while continuing the work in the future.

Curves shown in figs. 1.5 and 1.6 represent probabilities of the excess by permanent framing deflections (depth of dents) of the depth of ice dents plotted on the abscissa. Under the ice damage (dent) we understand a permanent deflection of frame or of plate structure supporting the shell in the zone of the impact against ice. Fig. 1.5 shows probabilistic curves for a number of icebreakers and cargo ships. In fig. 1.6, generalized curves for ships of the UL and ULA classes being the major portion of the domestic arctic fleet are plotted.

As one can see from these graphs, the probability of the excess by permanent deflections of high values of the depth of dents ($f \geq 150 - 350$ mm) is very low and is 1-7% for different classes of ships. For domestic ships operating on the Northern Sea Route these probabilities are the following:

ULA $f \geq 150$ mm $\approx 5\%$
≥ 200 mm $\approx 1\%$

UL $f \geq 200$ mm $\approx 6\%$
≥ 250 mm $\approx 2\%$
≥ 300 mm $\approx 1\%$

L1 $f \geq 200$ mm $\approx 7\%$
≥ 250 mm $\approx 3\%$
≥ 300 mm $\approx 2\%$

Number of the analysed events of framing damages for ships of the UL and ULA classes was 200 and 250 accordingly, for the L1 class - 380.

The above reduction of the thickness of structural elements was actually observed on ice ships after their long operation (15 – 20 years). In the continuation of work it is necessary to draw up a more frequent net of wear of the probabilistic character being important for the risk analysis.

The uniform distribution of pressure while analysing the mechanism of damages of tanker "Samotlor" is rightful due to small dimensions of the damaged area. The models of loading used today produce very large contact areas. Such damage could occur at the compression of ship in the second- or multi – year ice.

The reviewer is absolutely right that it is necessary to take into account the number of impacts of ship against ice, that is the effect of the accumulation of the permanent plastic strain. Different approaches to the prediction of this phenomenon are developed by AARI at the first phase of INSROP and illustrated by separate structural elements. It was planned to use in the future the developed approaches of the analysis of the accumulation of plastic strain for actual grillages with different framing systems.

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.