

STYRELSEN FÖR
VINTERSJÖFARTSFORSKING

WINTER NAVIGATION RESEARCH BOARD

Research Report No 50

Pentti Kujala

DAMAGE STATISTICS OF ICE-STRENGTHENED SHIPS IN THE BALTIC SEA 1984 - 1987

Sjöfartsstyrelsen
Finland

Finnish Board of Navigation

Sjöfartsverket
Sverige

Swedish Administration
of Shipping and Navigation

PENTTI KUJALA

**DAMAGE STATISTICS OF ICE-STRENGTHENED SHIPS IN THE BALTIC SEA
1984-1987**

**HELSINKI UNIVERSITY OF TECHNOLOGY
Laboratory of Naval Architecture
and Marine Engineering**

Espoo, April 1991

FOREWORD

The Winter Navigation Research Board herewith presents its research report No.50. This report depicts the outcome of a study, over several years, of ice damages, including minor ones, sustained by ships moving regularly in the Northern Baltic in the winter. It gives valuable information about which parts of the hull are exposed and how the ice load works.

Together with the earlier report No.47, which presented results from long time ice load measurements on a ship in regular traffic in the Baltic, this report should provide some basis for the ice-strengthening of a Baltic merchant ship.

The Winter Navigation Research Board warmly thanks the author, Mr Kujala, as well as the owners and crew of the ships involved, for their assistance.

Helsinki and Norrköping

May 1991

Kyösti Vesterinen

Kaj Janérus

LIST OF CONTENTS

	page
ABSTRACT	1
1 INTRODUCTION	2
2 DESCRIPTION OF THE WINTERS 1984-1987	4
3 DESCRIPTION OF THE SHIPS INCLUDED IN THE STUDY	8
4 DESCRIPTION OF THE DATA GATHERING METHODS	
4.1 General	15
4.2 Visual observations	15
4.3 Application of stereo photography	16
5 DAMAGE STATISTICS OBTAINED	
5.1 Summary of the damages	19
5.2 Detail description of the damages found	21
6 ANALYSIS OF THE DAMAGES FOUND	
6.1 General	45
6.2 Characteristics of the damages	50
6.3 Evaluation of ice-induced loads causing damage	51
7 CONCLUSIONS	58
8 ACKNOWLEDGEMENTS	60
9 REFERENCES	61

APPENDICES

ABSTRACT

Ice damage to Finnish ships navigating in the Baltic during the winters 1984 to 1987 are described and analysed in this report. The main focus is on hull damages. The study includes 61 ships of which 31 have ice class 1A Super, 28 ice class 1A and 2 ice class 1C. All the longitudinally framed ships navigating in Bothnian Bay have sustained damages. For the transversely framed ships, 26 % of the 1AS class and 54 % of the 1A-class have experienced damages. Part of the damages are only on the plating so that 18 % of transversely framed 1AS-class ships and 23 % of 1A-class ships have damage to the frames. Most of these are occurred in the Bothnian Bay. The damages are typically local with minor denting of plating or frames. The most serious damages include one case with extensive yielding of the ice-strengthened shell structure of a bulk carrier and a couple of cases resulting in the buckling of webframes. No damages resulting in leakage were found. Most of the damages appear at midship and have occurred while the ships have been stuck in compressive ice. The maximum lineload in the midships area, calculated on the basis of damage, is exponentially decreasing as a function of the apparent load length. The maximum lineload has a value of 1600 kN/m with load length 0.4 m and a value of 400 kN/m with load length of 3 m.

1 INTRODUCTION

Gathering of damage statistics is an important aspect at the development of rules to strengthen ships navigating in ice conditions. Damage statistics enable definition of the proper level and extent for ice-strengthening. The last damage statistics from ships navigating in the Baltic Sea were gathered during the sixties. The 1971 ice rules were based on the statistics (Johansson 1967).

The basic level of ice-strengthening as defined in the 1971 rules have been considered satisfactory in general terms (Edelmann, 1984). The formulation of design ice loads were, however, renewed for the latest ice rules (1985). The ice-induced pressures and contact height were revised to correspond more closely with observed values during full-scale measurements (Varsta, 1985). Also, the scantling requirements were updated and generalised, based on elastic structural analysis. Due to the updated definition of the design load, the scantling requirements for longitudinally framed shell structure were increased.

When developing the latest ice rules (1985) it was considered important to gather damage statistics from ships built according to the 1971 rules, and the project reported here was initiated. The statistics were gathered during the years 1984 to 1987 and include most of the Finnish ships navigating in Baltic ice conditions. The statistics were gathered by surveying the ships during dry dockings. The damage location, extent and maximum permanent deflection were estimated. Based on this data, the ice-induced loads causing these damages can be calculated. Some assumptions are needed for the characteristics of the contact between ship and ice. Consequently the load values obtained are also related to the assumptions made of the contact shape and extent.

The report starts by describing the ships included in the study. Only Finnish ships are included in the study as they usually go to drydock in Finland, and are representative of ice-strengthened tonnage navigating in the Baltic Sea. The methods used to obtain the statistics are presented and results are given. The main focus is on the hull damages. Finally the characteristics of the damages are discussed and the ice-induced loads which caused the damages are outlined.

The main object of the report is to describe in as much detail as possible, the damages found. The reasons for these damages are discussed only briefly. The question of proper levels of ice-strengthening is considered to be out of the scope of the present report.

2 DESCRIPTION OF THE WINTERS 1984 TO 1987

The severity of a winter is usually determined on the basis of the maximum ice extent. In an average winter, the whole Bothnian Bay and Bothnian Sea are covered by ice so that the maximum ice extent is about 210 000 km² (Leppäranta & Seinä, 1985). Fig. 1 gives the maximum extent of ice during the winters 1900 to 1990. As can be seen, the winters 1985, 1986 and 1987 were considerably harder than average while 1984 was near average.

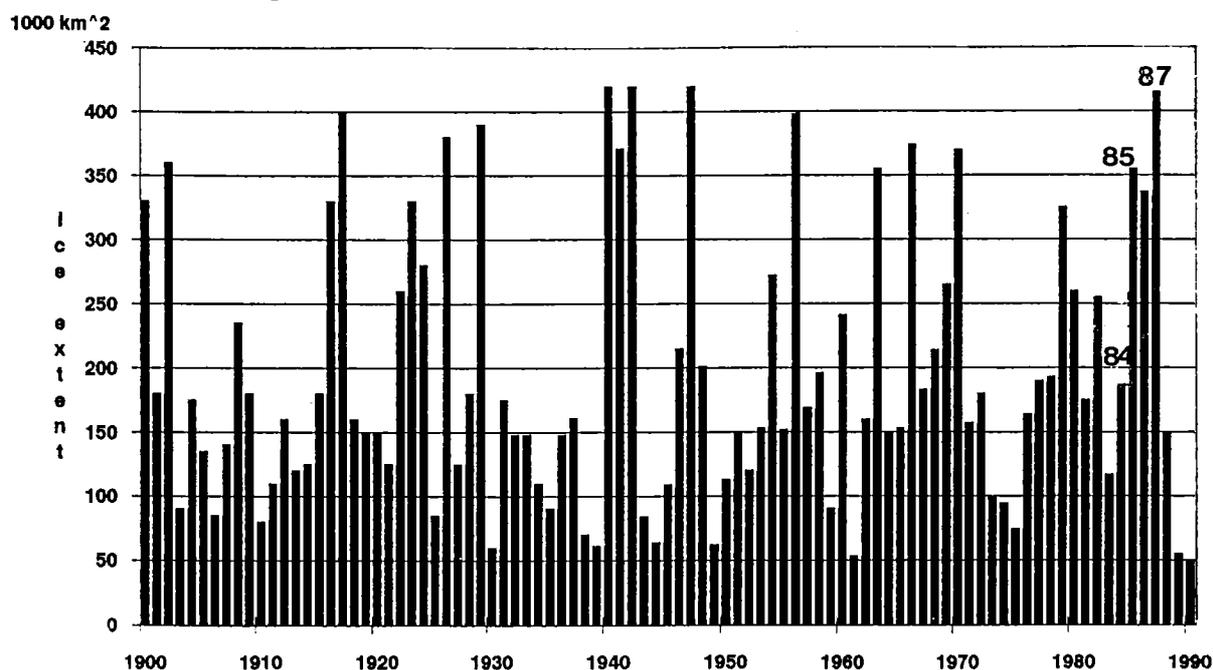


Fig. 1. The maximum extent of ice during the winters 1900 to 1990.

For the present study the Baltic Sea is divided into four sea areas as shown in Fig. 2 (Kujala 1989). The length of the winter season in these sea areas during a hard winter can be seen in Fig. 3 (Kujala 1990), where the time evolution of the maximum level ice thickness during the winter 1985 is given for each sea area. The length of the winter in the Bothnian Bay was about 5.5 months, in the Bothnian Sea and Gulf of Finland 4.5 months and in the Baltic proper about 3 months.

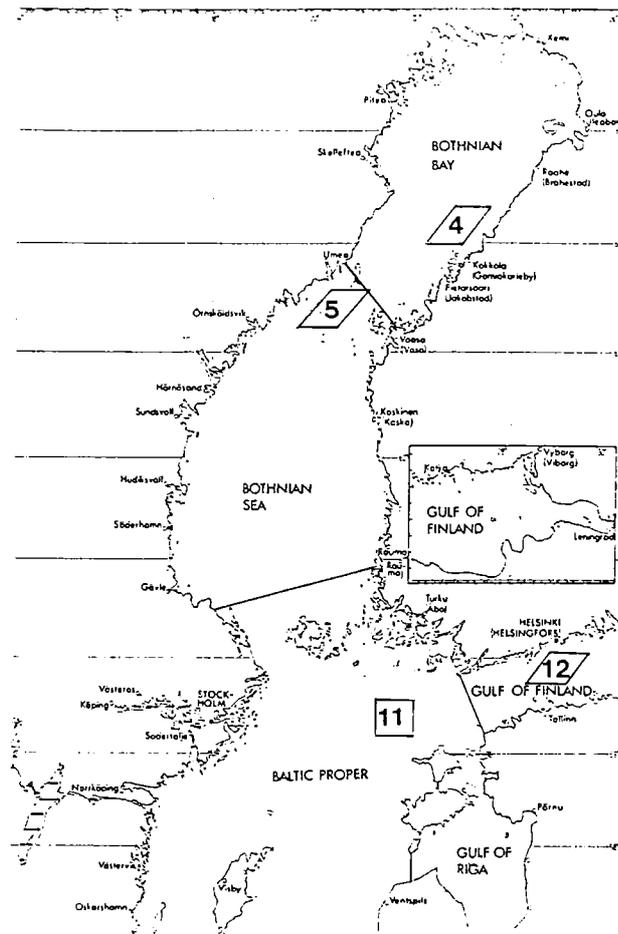


Fig. 2. The division of the Baltic Sea into various sea areas.

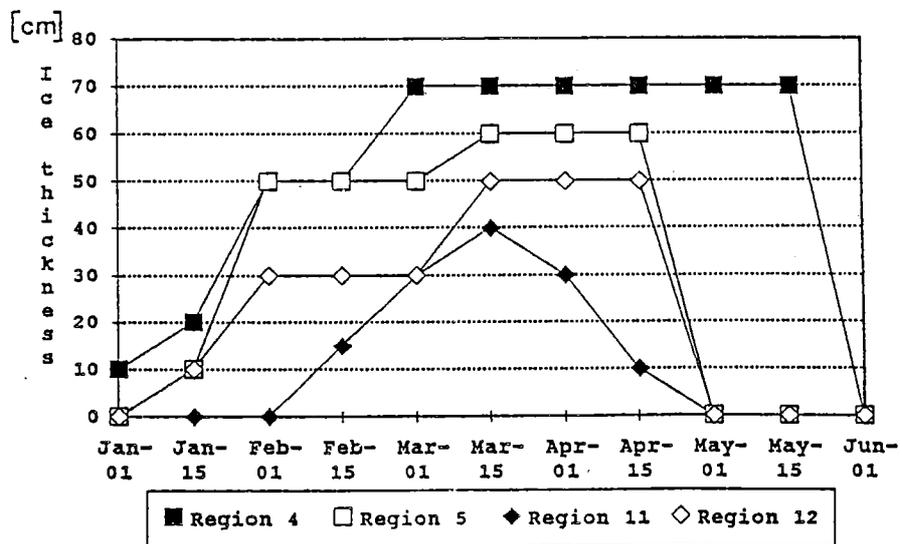


Fig. 3. Time evolution of the maximum level ice thickness in the four regions specified in Fig. 2 during the winter 1985.

Great variations take place in the length of the season and ice conditions from year to year. Table 1 summarises the maximum fast ice thicknesses, maximum sea ice thicknesses outside the fast ice region and duration of the ice cover during the winters 1984 to 1987. The maximum fast ice thickness outside Oulu represents the Bothnian Bay, outside Vaasa represents the Bothnian Sea, outside Turku represents the Baltic proper and outside Kotka represents the Gulf of Finland. Some general features of the development of ice conditions during the four winters are briefly summarised as follows.

The ice conditions during the winter 1984 were fairly easy for ships except in the Bothnian Bay. There the ice became ridged at the middle of January on the northern part of the sea area and remained ridged until the end of the winter. For other sea areas the ice was typically drifting ice without any considerable ridging.

Winter 1985 was severe, therefore the ice conditions were difficult for the winter navigation with ridged and rafted ice on all the sea areas. The severity had, however, some positive effects on winter navigation due to the heavy ice formation. The ice fields in the Bothnian Bay remained stationary from the beginning of february to the end of April.

Winter 1986 started about two weeks earlier than normal so that the Bothnian Bay was totally covered by ice by the end of December. In addition, ships encountered problems due to the westerly winds, which formed heavily ridged ice near the Finnish coast in the Bothnian Bay, Bothnian Sea and Gulf of Finland.

Winter 1987 was again severe due to the long extremely cold period in January. The conditions were, however, near normal in the Bothnian Bay. In the other sea areas the winter navigation was more difficult than usual due to the thicker ridged ice.

Table 1. Summary of ice conditions during the winters
1984 to 1987 in various sea areas.

	Sea area	Max sea ice thick. (cm)	Max fast ice thick. (cm)	Duration of ice cover (day)
1984	Baltic proper	20	60	30
	Gulf of Finland	50	50	97
	Bothnian Sea	40	55	102
	Bothnian Bay	70	80	150
1985	Baltic proper	40	50	107
	Gulf of Finland	50	90	136
	Bothnian Sea	60	75	136
	Bothnian Bay	70	110	143
1986	Baltic proper	30	50	70
	Gulf of Finland	40	60	121
	Bothnian Sea	60	55	130
	Bothnian Bay	60	70	145
1987	Baltic proper	40	70	100
	Gulf of Finland	50	70	127
	Bothnian Sea	60	90	140
	Bothnian Bay	70	100	145

3 DESCRIPTION OF THE SHIPS INCLUDED IN THE STUDY

The study includes most of the finnish merchant ships which navigate regularly in ice conditions and which were built using the 1971 ice rules. The list of the ships considered interest for this study was assembled in close co-operation with the main Finnish ship owners. The list includes ships navigating both to the southern and northern Finland. Table 2 summarises the data according to ship type, ice class, framing system and factor k. The factor k is defined in the ice rules as follows:

$$k = \frac{\sqrt{\Delta P}}{1000} \quad (1)$$

where Δ is the displacement [tonnes] of the ship at maximum ice class draught and P is the nominal engine output [kW]. This factor relates the ship's ability to move in various ice conditions and the design ice loads. The main particulars of all the ships included in the study are given in table 3.

Table 2. A summary of the ships included in the study

Ship type	Total No.	Ice class			Framing	
		1AS	1A	1C	Trans.	Long.
Cargo ferry	14	9	5		3	1
Dry cargo	14	10	4		4	
Tanker	14	6	8		10	4
Bulk carrier	10		8	2	6	4
Passeng. ferry	9	3	6		8	1
Total	61	28	31	2	51	10

Table 3. Main particulars of the ships included in the study

Ship n:o	Type	Year of construction	Ice class	Displacement [ton]	Dwt [ton]	Length [m]	Breadth [m]	Draught [m]	Machinery [kW]	k	Framing
1	Cargo ferry	1972	1A Super	11000	5454	132	24.6	6.1	10300	10.64	Transverse
2	Dry cargo	1972	1A	10500	7214	110	18	7.4	3678	6.21	Trans/Long
3	Dry cargo	1980	1A Super	20780	14906	154	21	9.1	7281	12.30	Transverse
4	Dry cargo	1978	1A Super	20780	14931	154	21	9.1	7281	12.30	Transverse
5	Dry cargo	1978	1A Super	20780	14931	154	21	9.1	7281	12.30	Transverse
6	Dry cargo	1972	1A	11700	8050	122	19.5	8	6105	8.45	Transverse
7	Dry cargo	1972	1A Super	10500	7214	110	18	7.4	3678	6.21	Trans/Long
8	Dry cargo	1977	1A Super	20780	14931	154	21	9.1	7281	12.30	Transverse
9	Dry cargo	1979	1A Super	20780	14883	154	21	9.1	7281	12.30	Transverse
10	Dry cargo	1979	1A Super	20780	14938	154	21	9.1	7281	12.30	Transverse
11	Cargo ferry	1973	1A Super	11000	4995	132	24.6	6.1	10300	10.64	Transverse
12	Cargo ferry	1982	1A Super	19700	13025	146	25.1	6.5	13200	16.13	Transverse
13	Tanker	1980	1A Super	10900	8145	107	17.5	8.2	4119	6.70	Trans/Long
14	Bulk carrier	1976	1A	14800	10935	139	18.6	7.5	4413	8.08	Transverse
15	Passenger ferry	1977	1A super	16000	2825	204	24.5	6.5	55200	29.72	Longitudinal
16	Dry cargo	1972	1A	8300	5919	101	17	7.1	3236	5.18	Transverse
17	Dry cargo	1971	1A	10500	7214	110	18	7.4	3095	5.70	Trans/Long
18	Dry cargo	1972	1A Super	10500	7214	110	18	7.4	3678	6.21	Trans/Long
19	Dry cargo	1978	1A Super	23900	17160	149	22.5	9.3	8826	14.52	Transverse
20	Dry cargo	1977	1A Super	23900	17160	149	22.5	9.3	8826	14.52	Transverse
21	Cargo ferry	1982	1A Super	19700	13090	146	25.1	8.5	13190	16.12	Transverse
22	Bulk carrier	1977	1A	24000	16560	161	22.9	8.7	6840	12.81	Longitudinal
23	Bulk carrier	1977	1A	24000	16560	161	22.9	8.7	6840	12.81	Longitudinal
24	Bulk carrier	1978	1A	24000	16560	161	22.9	8.7	6840	12.81	Longitudinal
25	Bulk carrier	1978	1A	24000	16560	161	22.9	8.7	6840	12.81	Longitudinal
26	Passenger ferry	1981	1A Super	17600	3998	159	28.5	6.7	20944	19.20	Transverse
27	Passenger ferry	1975	1A	10200	1800	138	22	5.8	17652	13.42	Transverse
28	Passenger ferry	1981	1A Super	17600	3998	159	28.5	6.7	20944	19.20	Transverse
29	Cargo ferry	1978	1A	18400	12200	159	25.5		15592	16.94	Transverse
30	Cargo ferry	1978	1A	18400	12200	159	25.5		15592	16.94	Transverse
31	Cargo ferry	1984	1A Super	19700	12870	148	25		12940	15.97	Transverse
32	Tanker	1980	1A	15800	11474	136	21	7.3	5560	9.37	Transverse
33	Tanker	1974	1A	9200	6060	104	17.6	6.6	3678	5.82	Transverse
34	Cargo ferry	1984	1A	11500	7600	118	21		5520	7.97	Transverse
35	Bulk carrier	1985	1A	7000	4693	91	16	6	2600	4.27	Transverse
36	Tanker	1981	1A	5500	3512	84	14	6.2	2427	3.65	Transverse
37	Bulk carrier	1980	1A	43000	31850	178	25.7	11	9450	20.16	Transverse
38	Bulk carrier	1973	1C	11500	8001	112	17.6	7.7	3972	6.76	Transverse
39	Bulk carrier	1977	1A	11300	7885	110	19	6.8	3972	6.70	Trans/Long
40	Bulk carrier	1983	1C	64100	47442	175	32.2		9267	24.37	Transverse
41	Passenger ferry	1980	1A	11300	2874	139	25.5	5.5	19124	14.70	Transverse
42	Passenger ferry	1980	1A	11300	3345	144	24.2	5.6	17600	14.10	Transverse
43	Passenger ferry	1980	1A	9570	2300	127	24.2	5.4	17652	13.00	Transverse
44	Passenger ferry	1979	1A	9570	2300	127	24.2	5.4	17652	13.00	Transverse
45	Cargo ferry	1982	1A Super	12070	7000	131	20.6	6.9	5737	8.32	Longitudinal
46	Cargo ferry	1972	1A	6900	4100	107	16	5.9	6620	6.76	Transverse
47	Tanker	1976	1A Super	22100	15954	151	22	9.5	11474	15.92	Longitudinal
48	Tanker	1976	1A Super	22100	15954	151	22	9.5	11474	15.92	Longitudinal
49	Tanker	1977	1A Super	22100	15954	151	22	9.5	11474	15.92	Longitudinal
50	Tanker	1977	1A Super	22100	15954	151	22	9.5	11474	15.92	Longitudinal
51	Tanker	1974	1A Super	9600	6863	124	17.6	6.3	3678	5.94	Transverse
52	Tanker	1982	1A	16600	11538	134	21.2	7.3	6000	9.98	Transverse
53	Tanker	1982	1A	16600	11538	134	21.2	7.3	6000	9.98	Transverse
54	Tanker	1984	1A	27700	20000	150	23.1	10	7290	14.21	Transverse
55	Tanker	1984	1A	27700	20000	150	23.1	10	7290	14.21	Transverse
56	Cargo ferry	1980	1A Super	16000	8000	136	23	7.6	8826	11.88	Transverse
57	Cargo ferry	1980	1A Super	16000	8000	136	23	7.6	8826	11.88	Transverse
58	Cargo ferry	1977	1A	10600	6100	124	19.2	6.4	5884	7.90	Transverse
59	Cargo ferry	1977	1A Super	13300	7200	141	19.3	7	4414	7.66	Transverse
60	Tanker	1981	1A	9800	6954	101	17.5	7.3	3692	6.02	Transverse
61	Passenger ferry	1972	1A	4800	1118	102	17.2	4.6	5884	5.31	Transverse

* some of the displacements estimated based on the main dimensions and deadweight

As shown in Table 2 a total of 61 ships are included in the study, of which 31 have ice class 1A Super, 28 ice class 1A and 2 ice class 1C. About 84 % of the ships have transverse framing and 16 % longitudinal. Six of the ships have both transverse and longitudinal framing in the ice-strengthened region. These ships are all in the category of transverse framing in table 2. Later in this report these areas are considered separately so that the type of damages in various parts of the shell structure can be distinguished.

The navigation sea areas of the ships were studied. Ship owners were asked to give ship positions during the winter 1985. Based on this data the number of visits to the ports in various sea areas during that winter could be established. The frequency of the visits to the ports in the various sea areas are given in table 4 for the ships studied. Fig. 4 gives the data in graphic form with ship type and ice class as a parameter. Table 5 tabulates the number of ships navigating to the various sea areas with only the most northern sea area taken into account for each ship.

The ships with regular time schedules, like passenger and cargo ferries are the most frequent visitors during winter to the Finnish ports. As well oil tankers navigating on the Finnish coast and some bulk carriers can have 20-40 visits to Finnish ports during one winter. For other ships, like dry cargo ships, the number of visits is typically 5 or less. There seems to be no clear relationship between the ice class and number of voyages in various sea areas.

Table 4. Number of voyages of the studied ships in various sea areas during the winter 1985

Ship n:o	Type	Number of voyages in various sea areas, winter 1985			
		Baltic proper	Gulf of Finland	Bothnian Sea	Bothnian Bay
1	Cargo ferry		24		
2	Dry cargo		4		1
3	Dry cargo		1		1
4	Dry cargo		1	1	1
5	Dry cargo		2		1
6	Dry cargo				1
7	Dry cargo				6
8	Dry cargo	2	1		1
9	Dry cargo		2	1	
10	Dry cargo				2
11	Cargo ferry		24		
12	Cargo ferry		12		
13	Tanker	1			12
14	Bulk carrier	3			16
15	Pas. ferry		32		
16	Dry cargo			1	
17	Dry cargo		4		1
18	Dry cargo				7
19	Dry cargo		1		2
20	Dry cargo		3		
21	Cargo ferry		12		
22	Bulk carrier		2		
23	Bulk carrier		2		
24	Bulk carrier		1		2
25	Bulk carrier		2		
26	Pas. ferry		60		
27	Pas. ferry	85			
28	Pas. ferry		60		
29	Cargo ferry		12		
30	Cargo ferry		2	2	
31	Cargo ferry		12		
32	Tanker		10	5	2
33	Tanker		8	1	2
34	Cargo ferry		1	7	1
35	Bulk carrier				6
36	Tanker		5	3	2
37	Bulk carrier	1	5	1	3
38	Bulk carrier	7	3	2	
39	Bulk carrier	2			15
40	Bulk carrier		4		
41	Pas. ferry		60		
42	Pas. ferry	85			
43	Pas. ferry	85			
44	Pas. ferry	85			
45	Cargo ferry				12
46	Cargo ferry				
47	Tanker	1	17		2
48	Tanker	3	21	7	10
49	Tanker		9		5
50	Tanker	1	5		6
51	Tanker	6	17	8	3
52	Tanker	2	16	2	3
53	Tanker	2	11		1
54	Tanker	1	9	1	1
55	Tanker	1	8		
56	Cargo ferry				
57	Cargo ferry				
58	Cargo ferry				
59	Cargo ferry				
60	Tanker	7	16	7	
61	Pas. ferry			30	

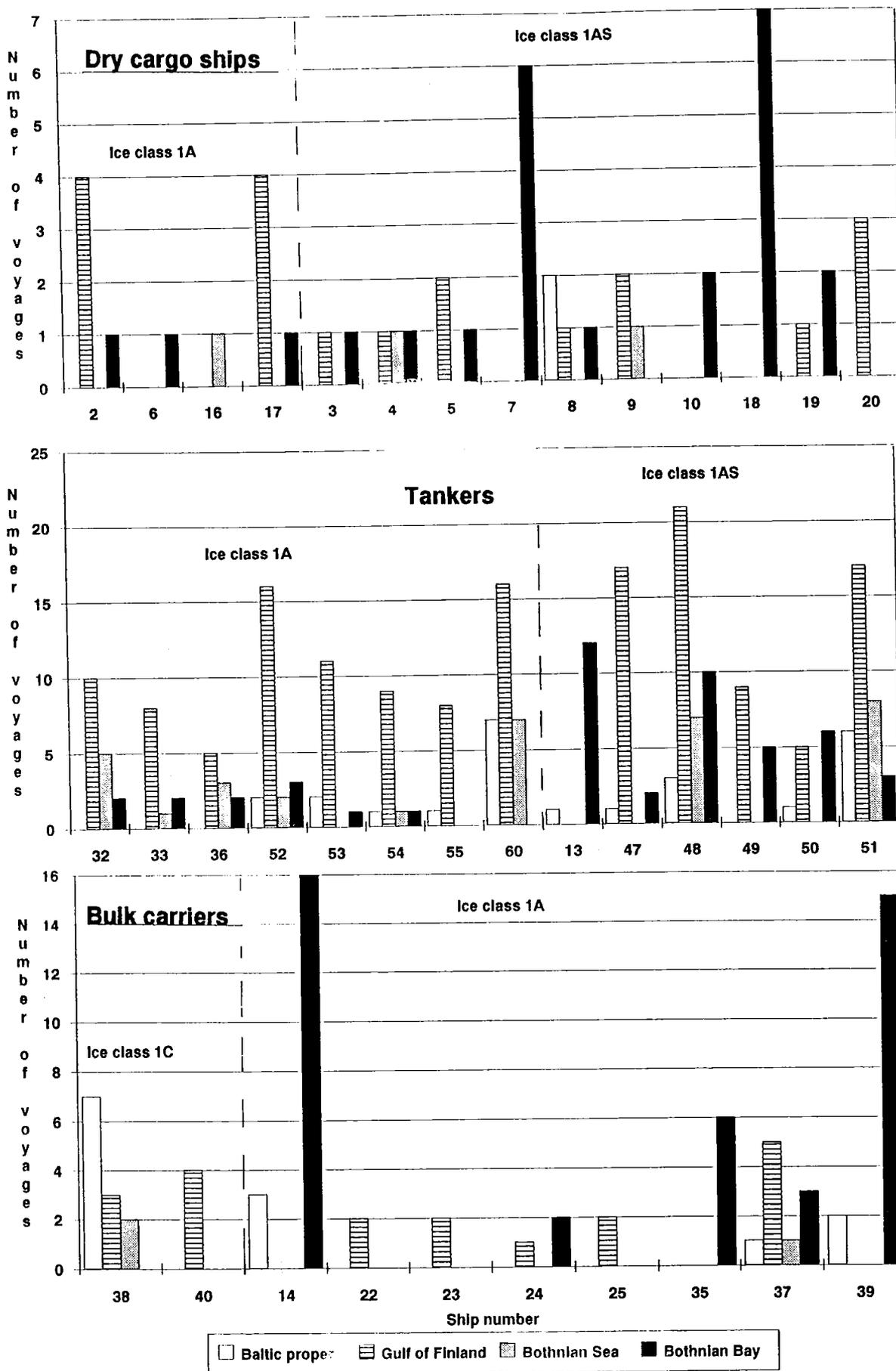


Fig. 4a. Number of voyages of the dry cargo ships, tankers and bulk carriers in the various sea areas during the winter 1985. Ship number given in x-axis is defined in Table 3.

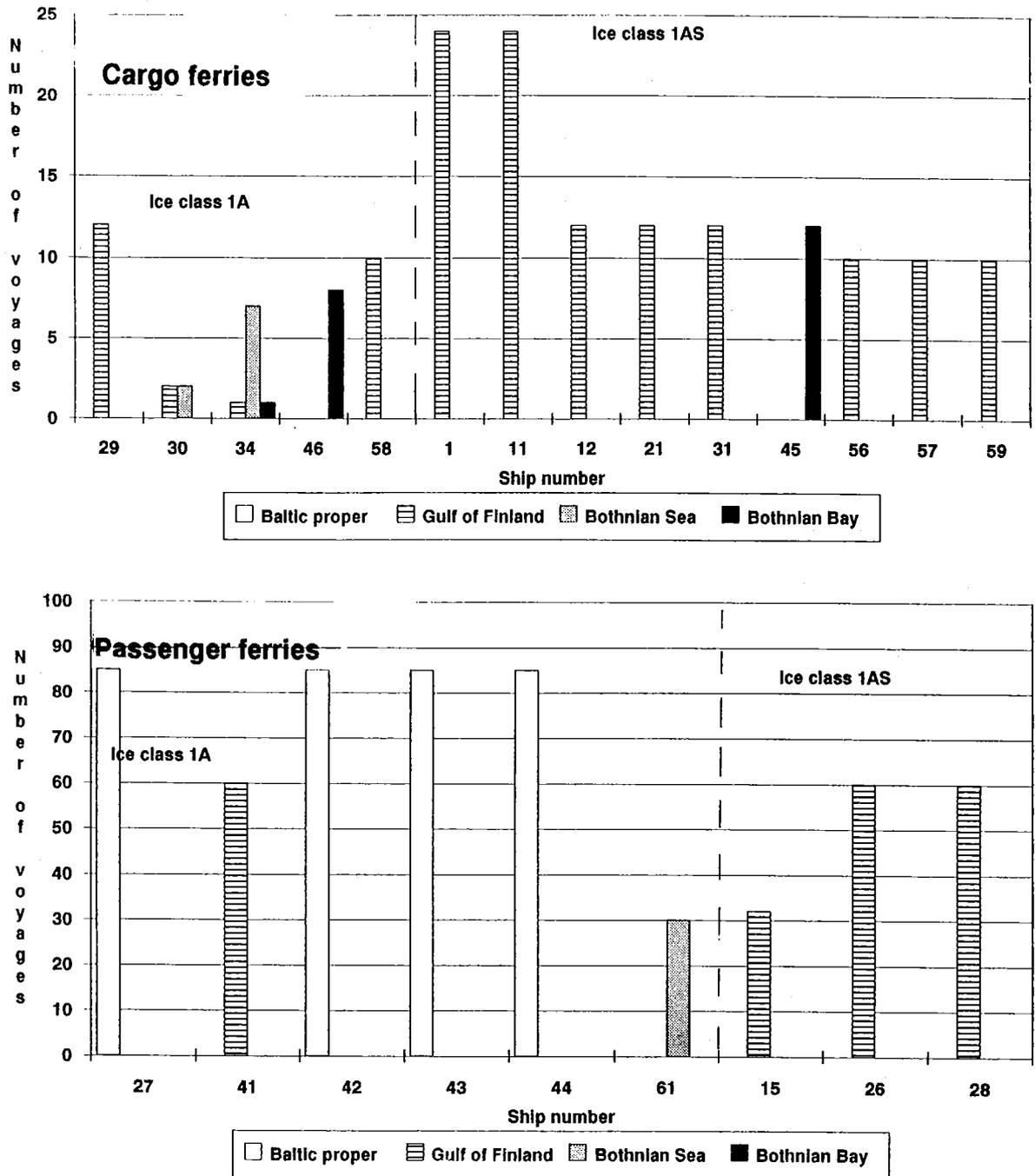


Fig. 4b. Number of voyages of the cargo and passenger ferries in the various sea areas during the winter 1985. Ship number given in x-axis is defined in Table 3.

Table 5. The number of ships in various categories classified according to the most northern navigation sea area and ice class during the winter 1985.

Ship type	Total No.	Baltic proper		Gulf of Finland		Bothnian Sea		Bothnian Bay	
		Ice class		Ice class		Ice class		Ice class	
		1A	1AS	1A	1AS	1A	1AS	1A	1AS
Cargo ferry	14			3	8			2	1
Dry cargo	14				1	1	1	3	8
Tanker	14			1		1		6	6
Bulk carrier	10			3				5	
Passeng. ferry	9	4		1	3	1			
Total	61	4		8	12	3	1	16	15

The navigation schedule of the ships was obtained only for the winter 1985. This schedule is used to specify the typical winter navigation characteristics for the ships studied. No remarkable changes occur in the navigation profile of the merchant ship from year to year. Winter 1985 was also the severest of the winters during which the damage statistics were gathered, as is discussed in chapter 2.

4 DESCRIPTION OF THE DATA GATHERING METHODS

4.1 General

Gathering the damage statistics started during the winter 1984 and continued until the winter 1987. After each winter the ship owners delivered the timetable for the dry docking of the ships included in the study. Thereafter the ships were visually surveyed while in drydock. Sometimes it was not possible to send a representative to the docking. Then the condition of the ship was reported by the surveyor of the shipowner after the docking.

After the survey, ship's personel was interviewed to find out the amount of ice navigation and the position and date for the possible ice damages observed. The term "ice damage" is used in this report for all the observed, permanent deflections on the hull, which according to the location and shape of the deflections could be classified as caused by ice. The damage can be a permanent deflection of the shell plating between frames or it can consist of deformation of large areas with collapse of frames and webframes. These are, however, put into different categories as discussed later in this report.

Normally only a visual survey was conducted. In the case of damages on large areas stereo photography was applied to obtain the shape of the damage. These approaches are discussed in the following chapters.

4.2 Visual observations

During the visual survey, shell plating was first inspected. Possible ice damages were noted by visually estimating the extent and depth of the maximum permanent deflections. The accuracy of these kinds of observations can be estimated to be about ± 10 mm. When it was possible, the deflection were also measured with measuring tapes. After this survey the internal structures, such as frames and web frames, were surveyed, if damages were

observed on the shell structures. The survey of the internal structures enabled more accurate definition of the damage and description of the behaviour of the various structural elements during the development of the damage under consideration. All the damages found were photographed.

4.3 Application of stereo photography

Some of the larger damages observed were studied using stereo photography. In this method the area of interest is first marked with signal platens on the ship hull. For one area, at least three of these platens are needed. They define the level relative to which the permanent deflection of the shell structure is measured. The accurate positioning of these signal platens is important for the accuracy of the measurements. Therefore these positions are usually obtained with theodolites, see Fig. 5.

Thereafter the area under interest is photographed using stereo camera. The stereo camera consists of two cameras about one meter apart taking pictures simultaneously. Fig. 6 illustrates the system used.

The signal platens have to be included in the stereophotos as they are used to calibrate the pictures when they are analysed. The analysis is done on a special stereographic machine where the image from the two pictures is seen in three dimensional form. The shape of the damage is digitized and plotted. The digitization is done manually, but thereafter the picture can be handled in digital form. The accuracy of the stereo pictures is about ± 5 mm.



Fig. 5. The measurement of the position of the signal platens with theodolites.

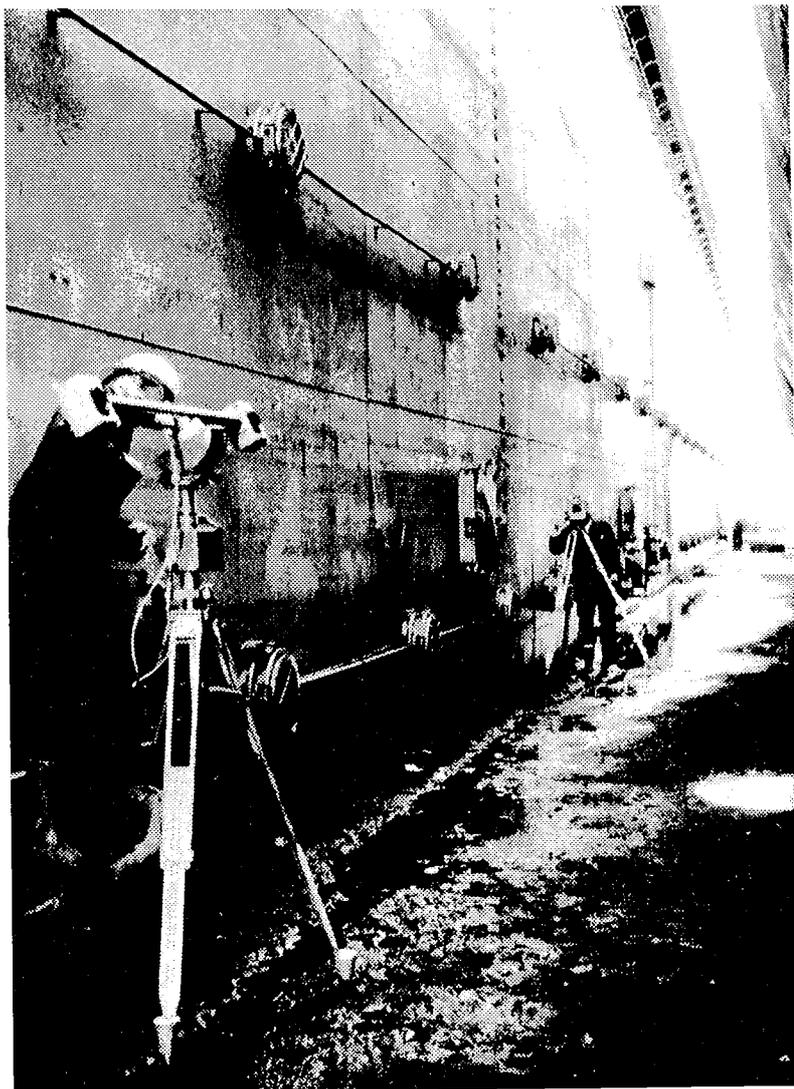


Fig. 6. The stereo camera used.

5 THE DAMAGE STATISTICS OBTAINED

5.1 Summary of the damages

The damages are classified in groups according to the location of the damage and structural element in which the damage was found. The structural elements are plating, frames and web frames. The locations are bow, midship and after ship. These are again divided into three regions: ice-strengthened region, above ice-strengthened region and below ice-strengthened region.

Table 6 summarises the results obtained by defining the following factors: the year of survey given by the ship owner or the author, the year of occurrence for the damage observed in various structural elements. As can be seen from table 6 the years 1984 to 1986 include the most active surveys of ships, whereas during the year 1987 only the ships known to be damaged were surveyed.

The year of the occurrence of the damages is known for all ships except the longitudinally framed ships nos. 22-25 and the transversely framed ships nos. 7 and 46. Probably most of the damages for the ships no. 22-25 have occurred before the period included in this study, since the ships saw almost no ice navigation during the years 1984-1986 (see also chapter 5.2.7 for further detail). According to the ship owners the damages onboard ships no. 7 and 46 have mainly occurred before the study period (see also chapter 5.2.2). The damages are described more detail on a ship by ship basis, in the following pages.

Table 6. A summary of the damage statistics obtained. Table gives the location and year of occurrence for the damages found on various ships (<84 means that the damages found have developed before the winter 1984).

Ship n:o	Docking Years	Damage summary										Remarks		
		On the ice-strengthened region						Outside ice-strengthened region					Propeller	
		Plating		Framing		Web frames		Plating above		Plating below				Rudder
bow	mid	aft	bow	mid	aft	bow	mid	aft	bow	mid	aft			
1	84.86													
2	86													
3	84.85													
4	84.86		85			85								see Fig. 7
5	85													
6	84													
7	84.86		<84	<84		<84					<84			see Figs 8-9
8	84.85													
9	84.86													
10	84.86											87		
11	84.85													
12	84.86													
13	84.87		85	85		85		85	85			87		see Figs 10-11
14	84-86		84/86			84/86	84	84			85			see Figs 12-13
15	84.86													
16	84.86		86			86		86						see Figs 14-15
17	85.86													
18	85.86										85			
19	85													
20	84.85			85		85								
21	86													
22	84		<84			<84		<84				86		see Fig. 16
23	84.86		<84			<84		<84						
24	85		<84			<84		<84						see Figs 17-19
25	85		<84			<84		<84						
26	84.86													
27	85								85					see Fig. 20
28	84													
29	84.86													
30	84.86													
31	85													
32	84.86											85		
33	84.86											87		
34	86												87	
35	86.87		86/87			86/87		86			86	86		see Figs 21-23
36	84-86								86				84	see Figs 24-25
37	84.86				86									
38	84-86													
39	84-87		85/87	85		85/87	85	85/87			86			see Figs 26-28
40	84-86													
41	84-86								85		85		87	
42	84-87								87		87			
43	84-87								85-87		85-87		87	see Fig. 29
44	84-87								85-87		85-87 86/87 86/87		85	see Fig. 29
45	84-86		85			85								see Figs 30-33
46	84.86		<84			<84								
47	84.86												86	
48	84-86		84						84				85/87	see ch. 5.2.14
49	85.86		85						85					see ch. 5.2.14
50	84-86										85			
51	84-86		85	85					85					see ch.5.2.15
52	84.86													
53	84-86													
54	85													
55	85													
56	87													
57	84.87													
58	85.87													
59	85.87													
60	85													
61	85.86											85		

5.2 Detail description of the damages found

5.2.1 Ship no. 4. (14931 DWT dry cargo ship)

Only one small damage was observed onboard ship no. 4, Fig. 7 illustrates the damage together with the scantlings of the ship. The maximum deflection of the frame was about 10 mm and plating 20 mm. The exact date and position during the winter 1985 when the damage occurred is not known.

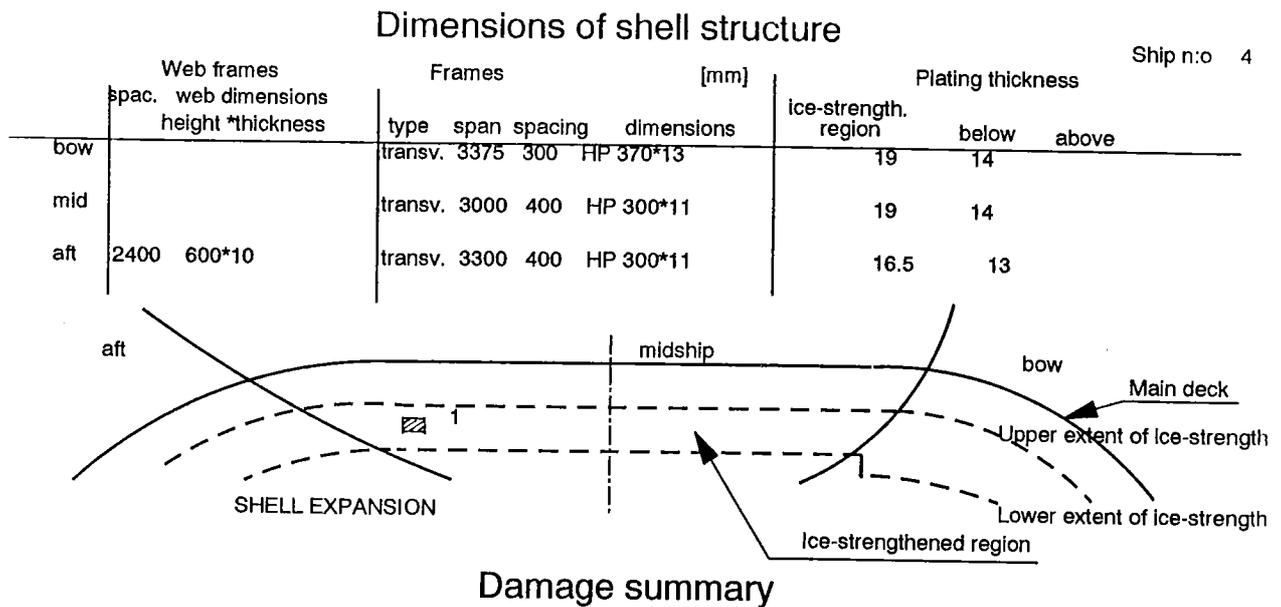


Fig. 7. The dimensions of the shell structure and location of the damage found from ship no. 4.

5.2.2 Ship no. 7 (7214 DWT dry cargo ship)

This ship had a number of small damages on the plating and two permanent deflections of transverse frames as is shown in Figs 8-9. The ship has both transverse and longitudinal framing system on the ice-strengthened region so that the longitudinal framing forms the upper part extending up to the level of the main deck. The permanent deflections of the plating are both on the transversely and

longitudinally framed area. The damages have developed during the long ice navigation history of the ship, which started during the year 1972. The bigger damages have most probably occurred on the 2nd of April 1982, when the ship was under heavy compression of ice about 12 miles southwest from the Kemi lighthouse. The draught of the ship was then 4.5 m at the bow and 5.95 m aft. Wind speed was about 15 m/s from the SW. Appendix 1/1 contains further details of the ice conditions.

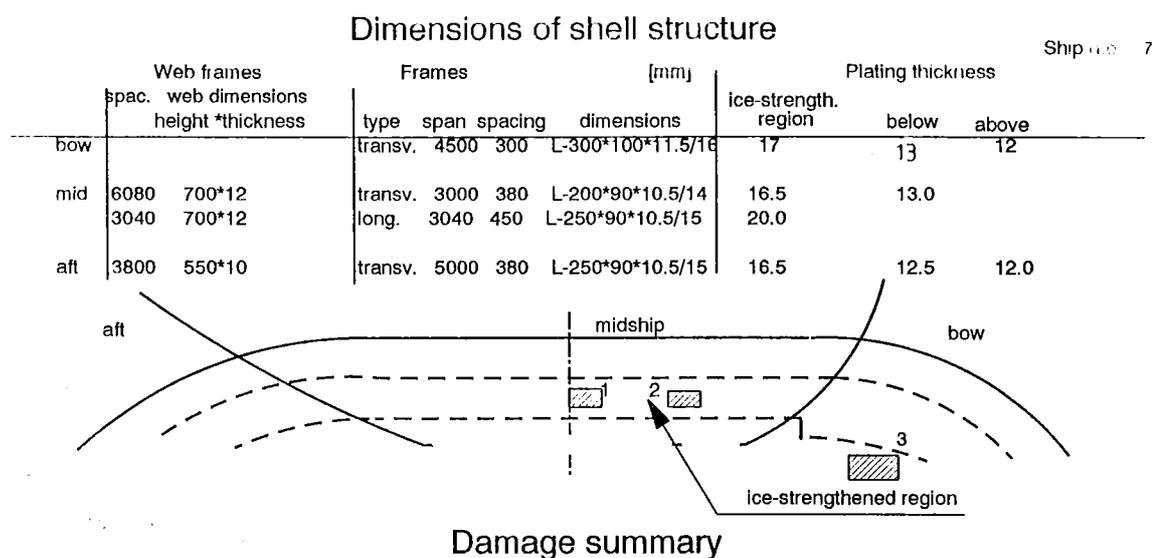


Fig. 8. Scantlings of ship n:o 7 and ice damages found on the shell structures.



Fig. 9. Ice damage on the area 2 (fr. 90) of ship no. 7.

5.2.3 Ship no. 13 (8145 DWT chemical tanker)

Ship no. 13 has also both transverse and longitudinal frames on the ice-strengthened region as shown in Fig. 10, along with the damages. Two of the longer damages are due to the buckling of the web of the webframe in the longitudinally framed area, see Fig. 11 and one is due to shear yielding at the lower end of a transverse frame. The damages on the webframes occurred on the 27th of March 1985, when the ship was in compressive ice about 40 miles south of the Nordvalen lighthouse with a draught of 8.1 m

at bow and 8.5 m at aft. Wind speed was 7 m/s from the south. See Appendix 1/2 for further details of the ice conditions. The shear damage at midship took place on the 1st of May 1985, near Kokkola lighthouse. Again, the ship were in compressive ice, with a draught of 7.3 m at bow and 7.9 m at aft. Wind speed was about 7 m/s from the northeast. See Appendix 1/3 for further details of the ice conditions.

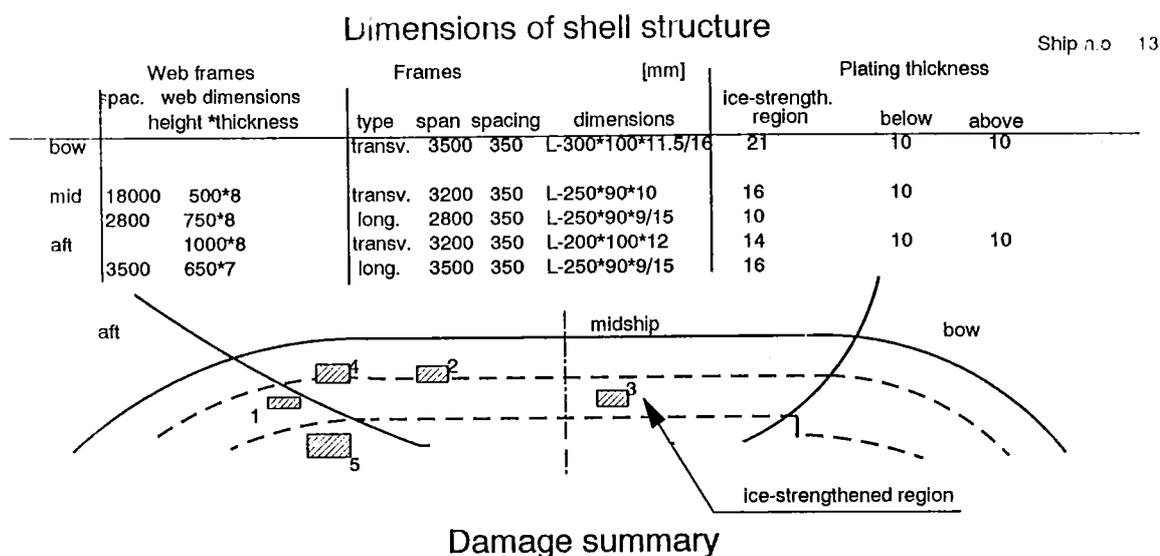


Fig. 10. Dimensions of the shell structure and summary of ice damages on the ship no. 13.

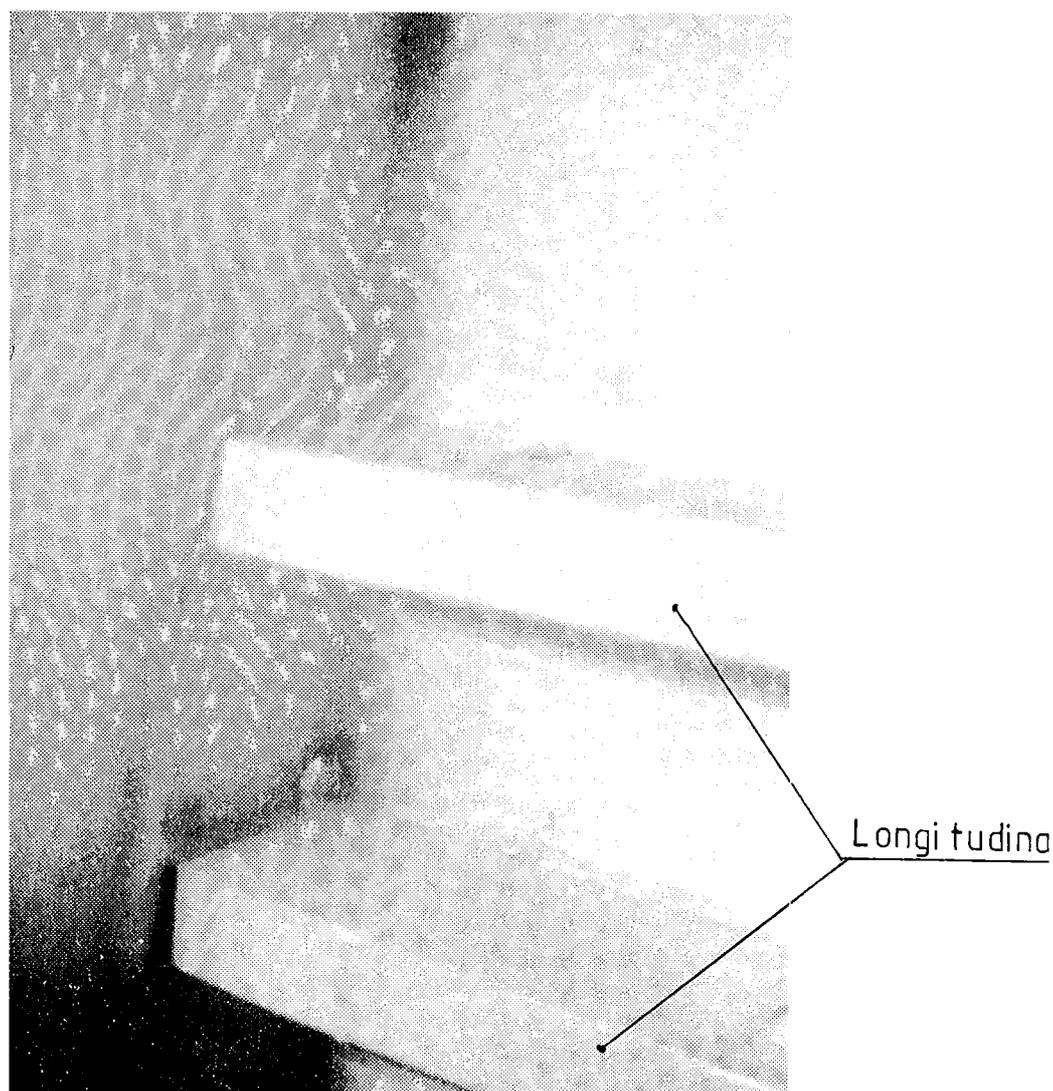


Fig. 11. The damage on the webframe at the area 2 (fr. 60) of the ship no. 13.

5.2.4 Ship no. 14 (10935 DWT bulk carrier)

Ship no. 14 was frequently in Bothnian Bay. Damages on the hull have been observed during dockings in the years 1984, 1985 and 1986. The damages found are summarised in Figs 12-13. Exact date for the damages are not known, but the midship damages have occurred during the winter 1984 and 1986, while the ship had been in compressive ice in the northern part of Bothnian Bay. The bow damage took place during the winter 1985, when the ship was navigating independently between Luleå and Raahé.

Dimensions of shell structure

Ship n:o 14

	Web frames		Frames			Plating thickness			
	spac.	web dimensions height * thickness	type	span	spacing	dimensions	ice-strength. region	below	above
bow			transv.	1375	350	HP 280*11	19.5	16	19.5
mid	1400	550*10	transv.	2375	350	HP 220*10	14	13	
aft	2100	450*10	transv.	2925	350	HP 200*10	13	13	

Damage summary

Area n:o	Damage type	length [m]	height [m]	max deflection [mm]
1	Yielding of frames Buckling of web frames end of ice frames unattached	10	1.5	100
2	Yielding of plating - ice-strengthened reg. (s=350) - below ice-strength. reg. (s=700)		1.5 1.5	15 25
3	Yielding of frames Buckling of web frames	7	3	100
4	Yielding of plating			70

Fig. 12. Dimensions of the shell structure and summary of damages onboard ship no. 14.

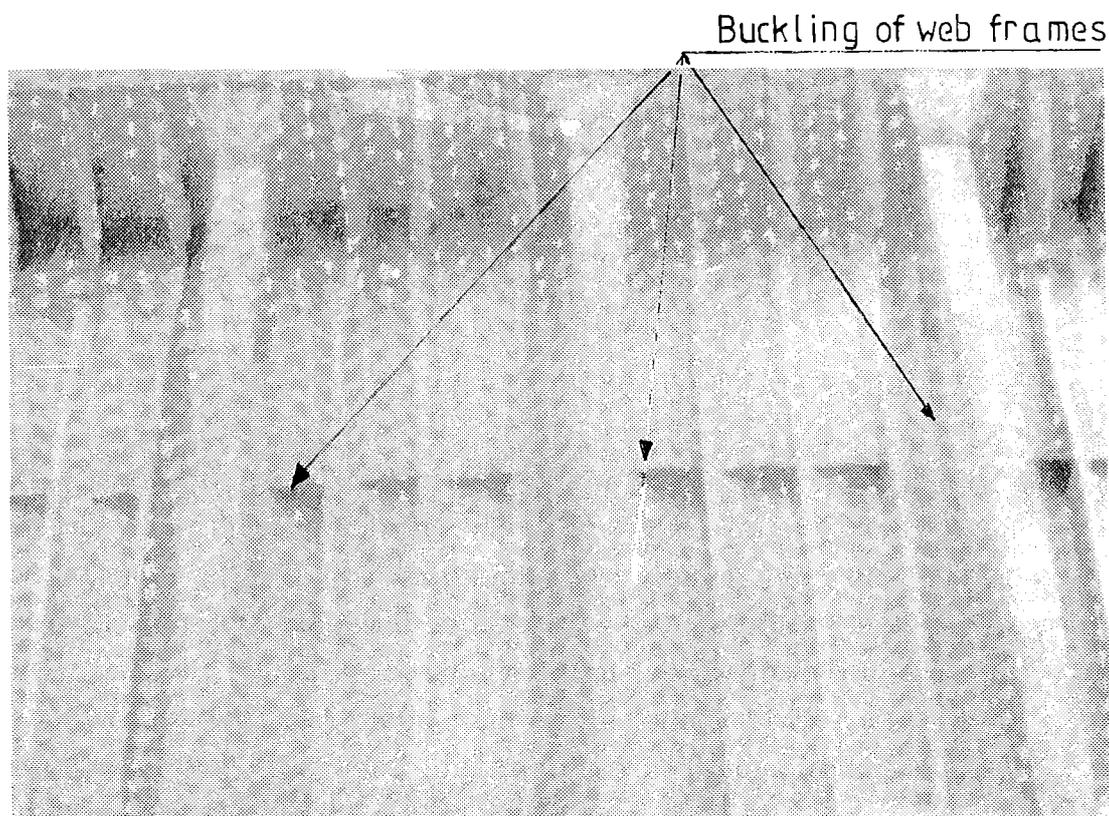


Fig. 13a. The damage on the area 3 of ship n:o 14.



Fig. 13b. The damage at the area 1 of ship n:o 14.

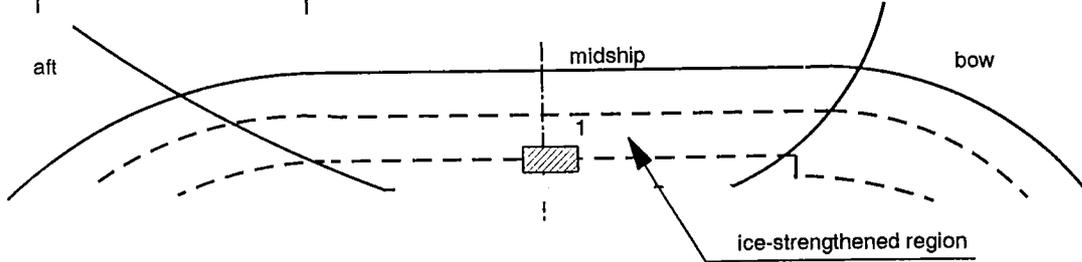
The damages at the lower end of the ice-strengthened region and below it are due to the fact that the ballast capacity of the ship n:o 14 is too small during winter time, when the wing tanks cannot be used. The ballast draught is then only 4.2 m, leaving unstrengthened structure exposed to ice loads.

5.2.5 Ship no. 16 (5919 DWT dry cargo ship)

One damage at midship was found on ship no. 16, see Figs 14-15. The damage includes permanent deflection of the plating, frames and webframes. The deflections of the plating and frames are due to exceeding the yield stress in bending. The damage on the webframes is due to the buckling of the web plating. The ship made only one voyage during the winter 1986 and the damage most probably occurred in the beginning of March outside Rauma.

Dimensions of shell structure

	Web frames		Frames			Plating thickness			
	spac.	web dimensions height * thickness	type	span	spacing	dimensions	ice-strength. region	below	above
bow		500*8	transv.	2750	350	T-260*100*10/20	17	10.5	10
mid	1050	430*8	transv.	3500	350	T-230*100*10	13.5	10	
aft	1050	950*8	transv.	4000	350	T-250*100*10	12	10	10



Damage summary

Area n:o	Damage type	length [m]	height [m]	max deflection [mm]
1	Buckling of web frames	4.2	1.9	50
	Yielding of frames			70
	Yielding of plating			25
	- below ice-strength. reg (s=350)			

Fig. 14 The dimensions of the shell structure and description of the damage on ship no. 16.

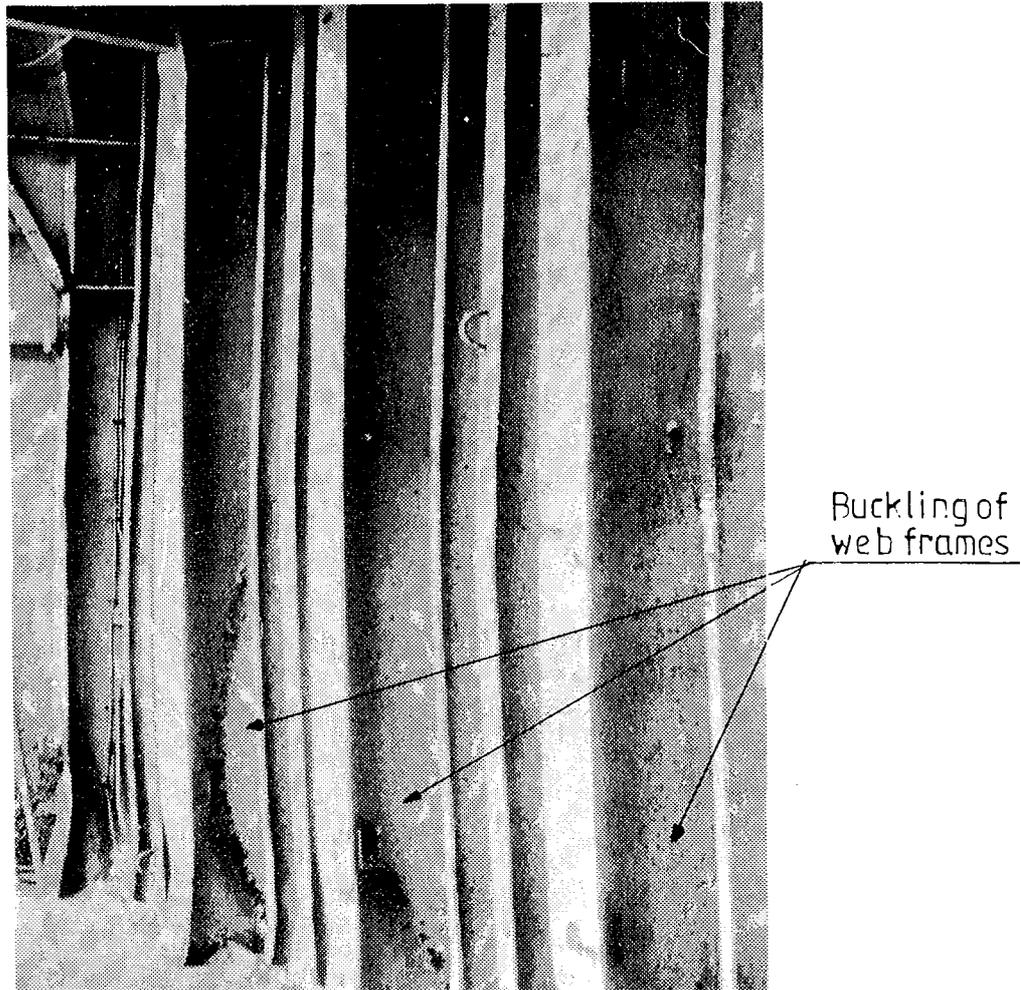


Fig. 15. The damage at midship of ship no. 16.

5.2.6 Ship no. 21 (13090 DWT cargo ferry)

Ship no. 21 has some minor damages on the shell plating below the ice-strengthened region at midships as shown in Fig. 16. The damages were observed during the docking in summer 1986.

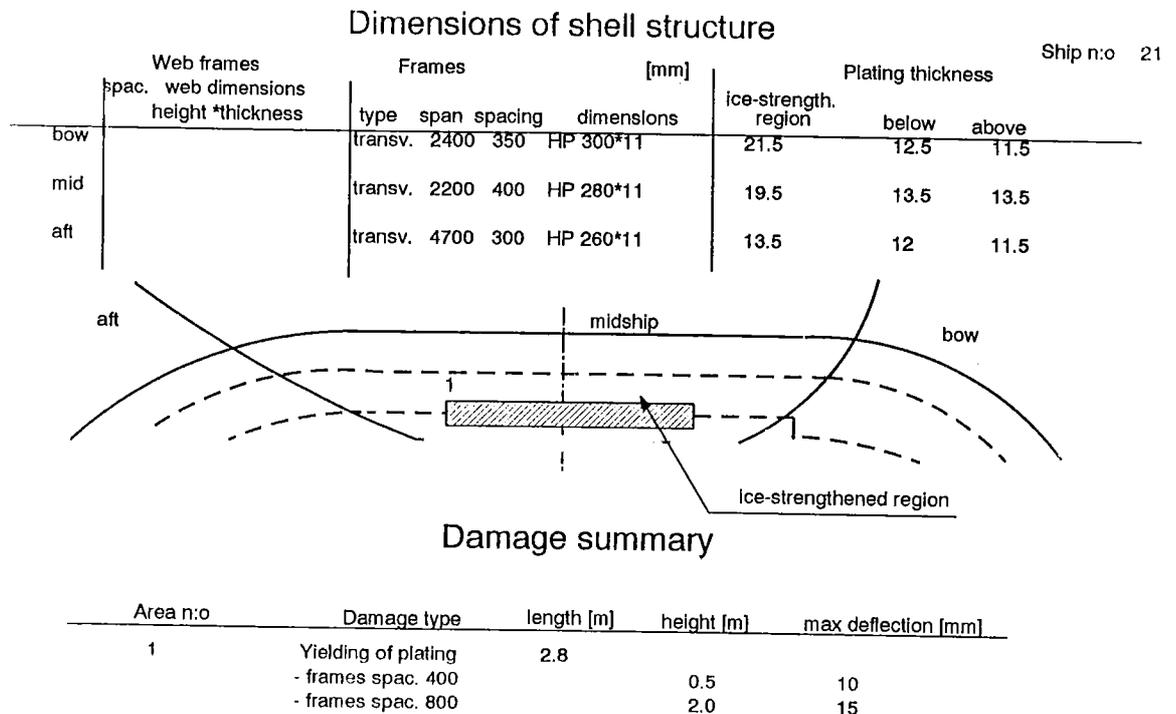
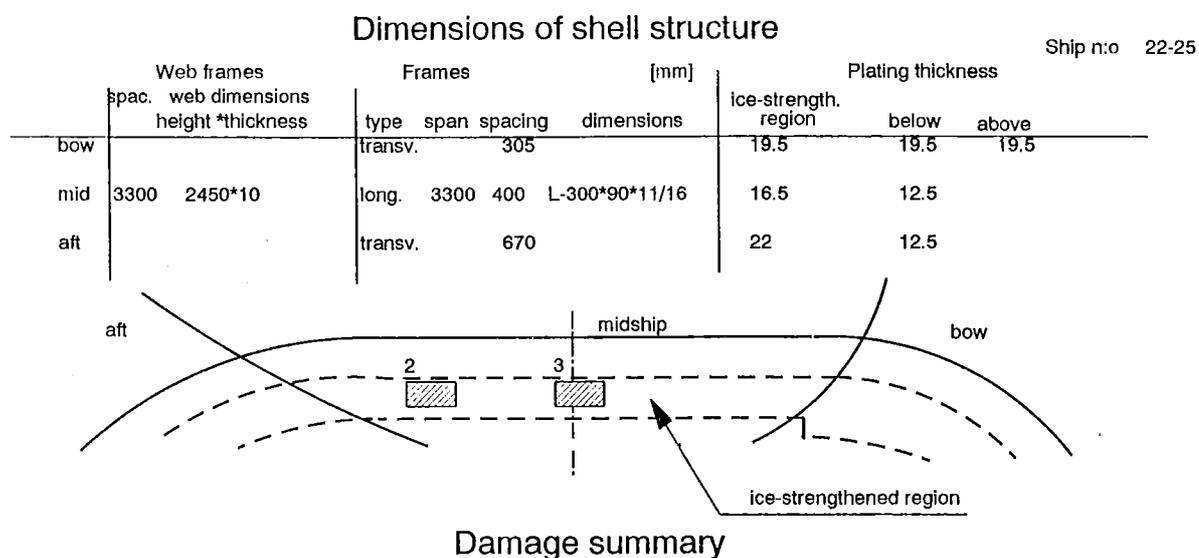


Fig. 16. Dimensions of the shell structure and permanent deflections on the shell plating of ship no. 21.

5.2.7. Ships no. 22-25. (16560 DWT bulk carrier)

These ships are sister ships and have longitudinal framing on the ice-strengthened region at midships. A number of damages were observed on the ships. Most of the damages have occurred before the studied period, when all the ships were frequently navigating to Bothnian Bay. During the studied period only one of the ships (ship no. 24) made two trips to the Bothnian Bay. According to the ship's owner the damages have increased gradually during the ten year navigation history of the ships. Fig. 17 illustrates the scantlings of the ships and damages observed in general. In addition Fig. 18 illustrates the permanent

deflections on the longitudinally framed plating and Fig. 19 describes in more detail the damages of area 2 observed on board ship no. 23 during summer 1986.



Area n:o	Damage type	length [m]	height [m]	max deflection [mm]
Longitudinally framed midship	Yielding of plating			30
2	Buckling of web frames Yielding of long. frames	7.5	2.8	50
3	..	6.7	2.0	30

Fig. 17. Dimensions of shell structure and summary of damages onboard ships no. 22-25.

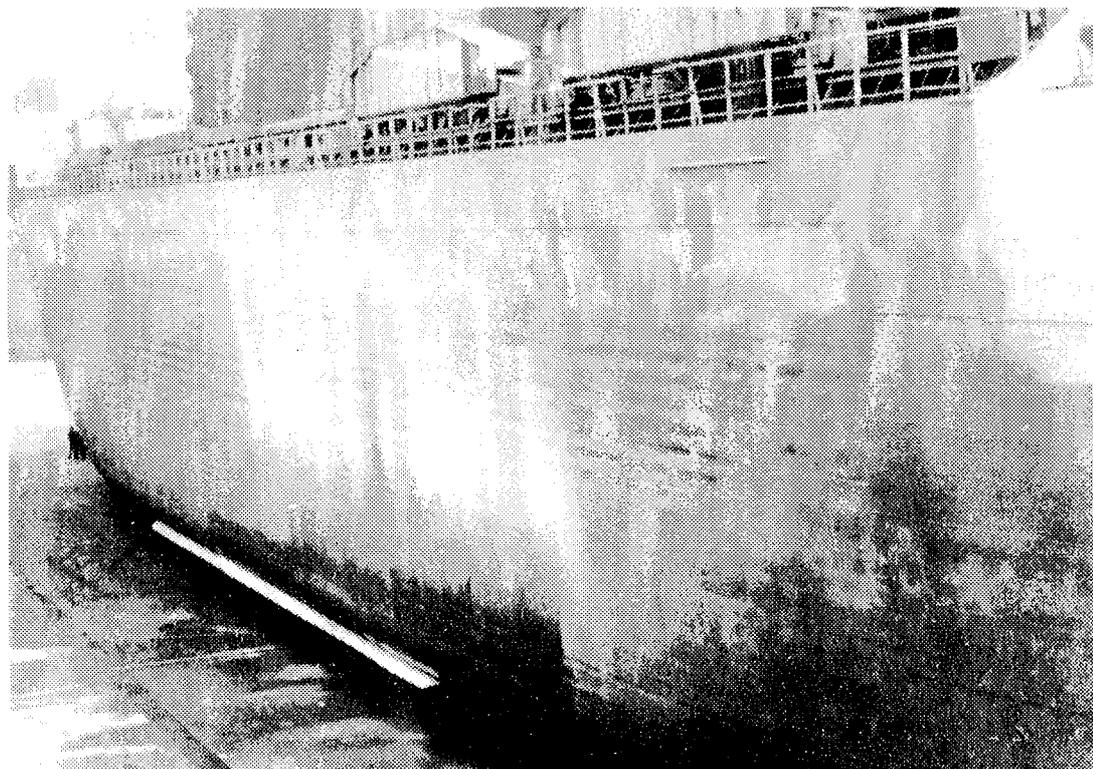


Fig. 18. General view of damages on board ship no. 24.



Fig. 19a. General view of the damage on area 2 onboard ship no. 23.

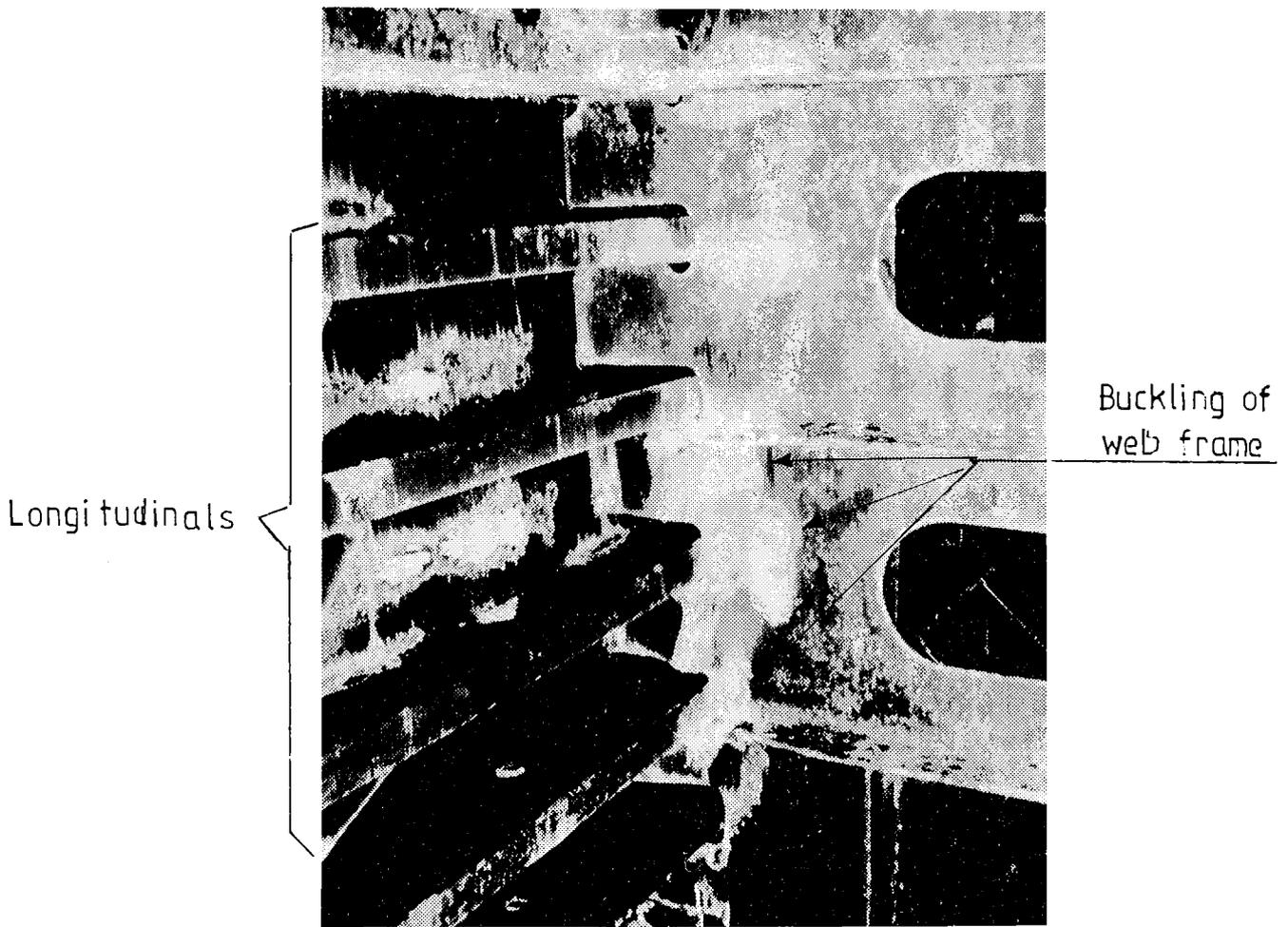


Fig. 19b. Inside view of the web frame buckling on area 2 of ship n:o 23.

5.2.8 Ship no. 27 (12343 BRT passanger ferry)

The damages on this ship are minor, consisting only of permanent deflections of the bow plating above the ice-strengthened region as shown in Fig. 20. According to the master of the ship these permanent deflections are caused by navigation with high speed in ice channels, when the bow wave increases the extension of ice-induced loads.

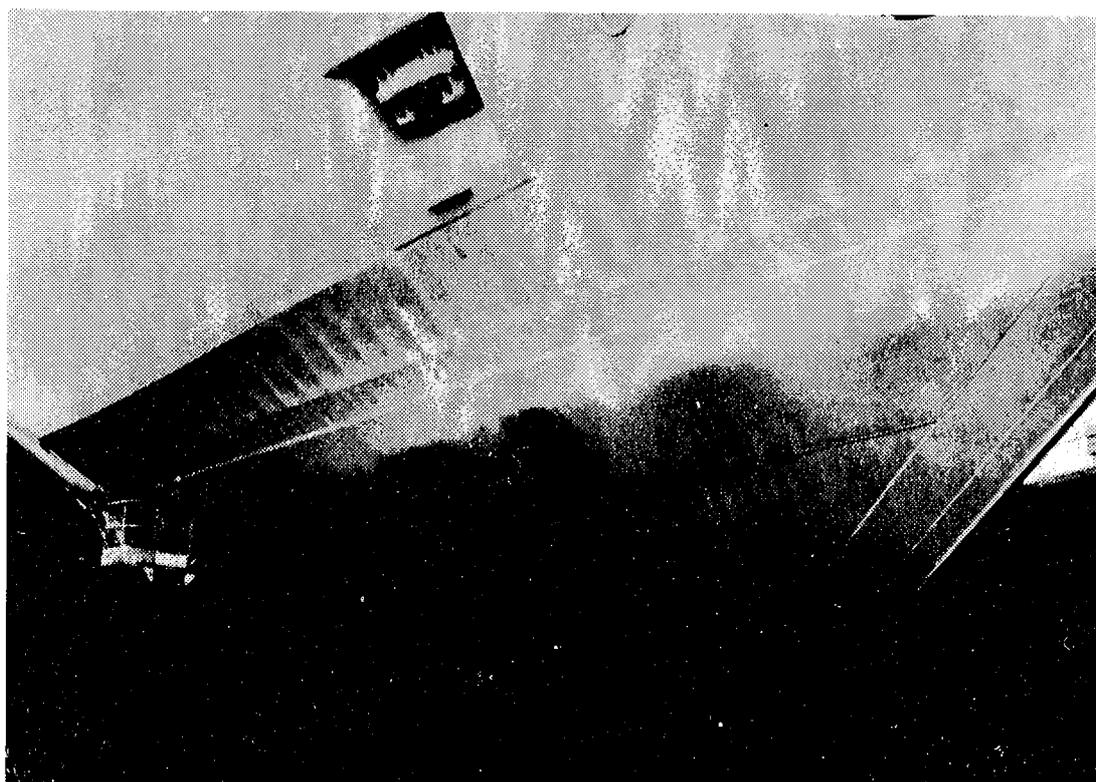


Fig. 20. The permanent deflections above the ice-strengthened region on ship no. 27.

5.2.9 Ship no. 35 (4693 DWT bulk carrier)

This ship has a number of minor damages on the shell plating and two larger damages, see Fig. 21. One of these larger damages took place during the winter 1986 (area 1) and the other during the winter 1987 (area 2). The exact date for the winter 1986 damage is not known, but the winter 1987 damage took place on the 16th of March in the Bothnian Sea near the Swedish coast (lat 62 30.6, lon 18 41.3). The ship experinedced heavy ice compression, when it was the seventh ship of an icebreaker convoy. The draft of

the ship was 5.7 m at the bow and 6.2 m aft. Wind was from the south at 3 m/s. See Appendix 1/4 for further details of the ice conditions.

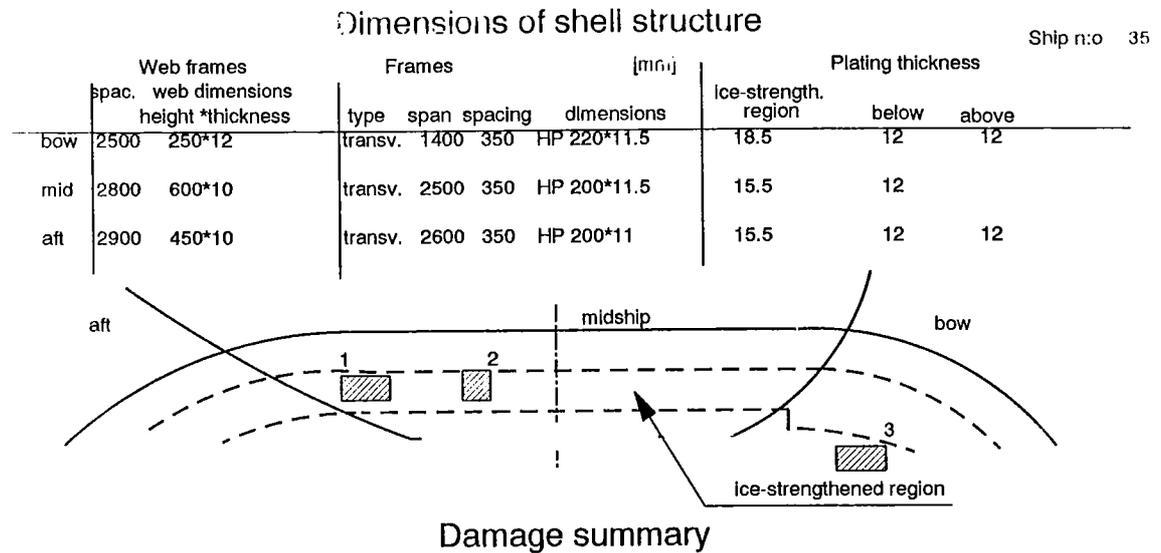


Fig. 21. Dimensions of shell structure and summary of damages onboard ship no. 35.

The stereographic photos were taken from the winter 1986 damage. The shape of the damage as determined from these photos is given in Figs 22-23. As can be seen the maximum permanent deflection of the shell structure is 55 mm. The deflection is largest at the after end of the damaged area with highest curvature near the web frame. This indicates that the ship was moving forward while the damage developed.



see
Fig. 23

Fig. 22. The damage occurred during the winter 1986 on area 1 of ship n:o 35.

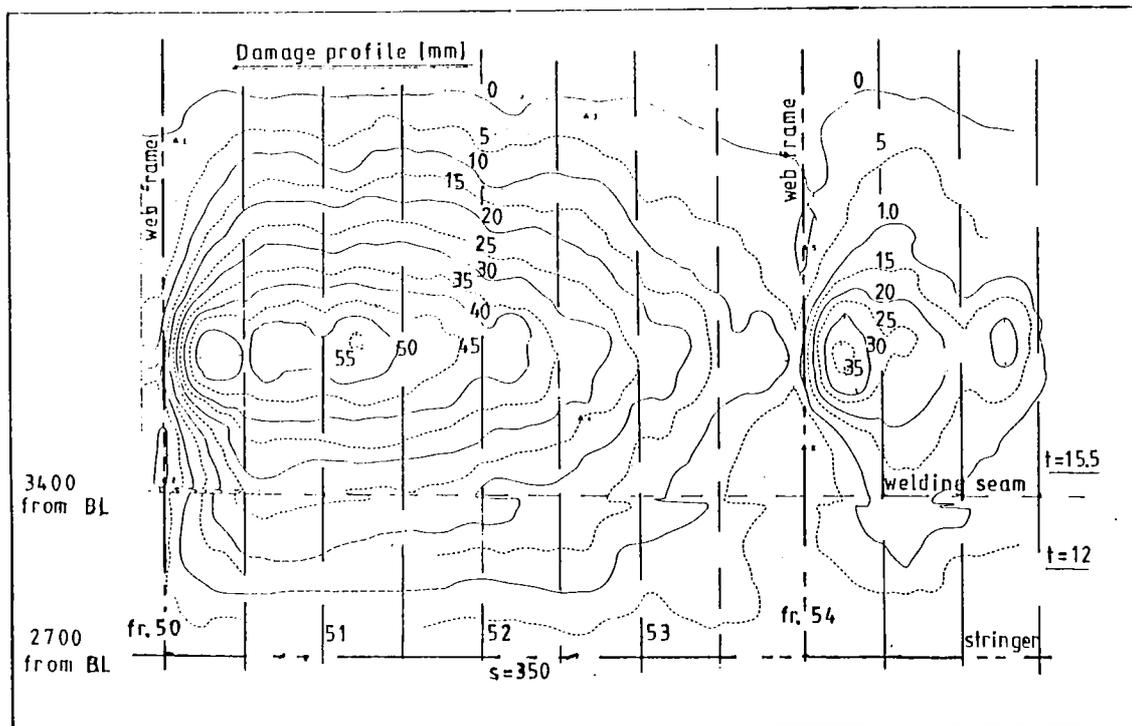


Fig. 23. The shape of the damage on area 1 of ship n:o 35.

5.2.10 Ship no. 37 (31850 DWT bulk carrier)

This ship has experienced one damage to the transverse frames on the bow ship. The damage took place in May 1986, when the ship hit some thick ice floes with fairly high speed. As a result about 5 frames collapsed and one also cracked due to shear at the upper end of the frame. The location of the damage is given in Fig. 24. Fig. 25 gives some photoes of the damage. The main reason for this damage is that the frame is attached at an angle of 45° to the shell plating, which decreases the plastic section modulus about 30 %.

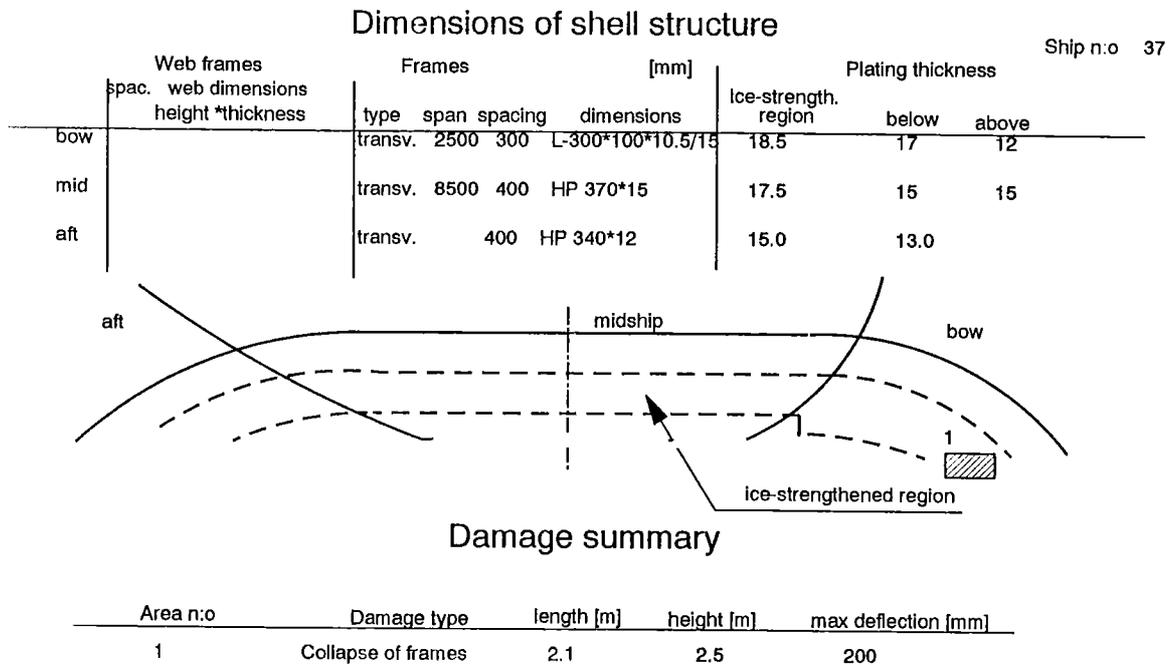


Fig. 24. Dimensions of shell structure and location of the damage on the ship no. 37.

Transverse frames



Fig. 25a. Inside view of the damage on the ship no. 37.

Transverse frames

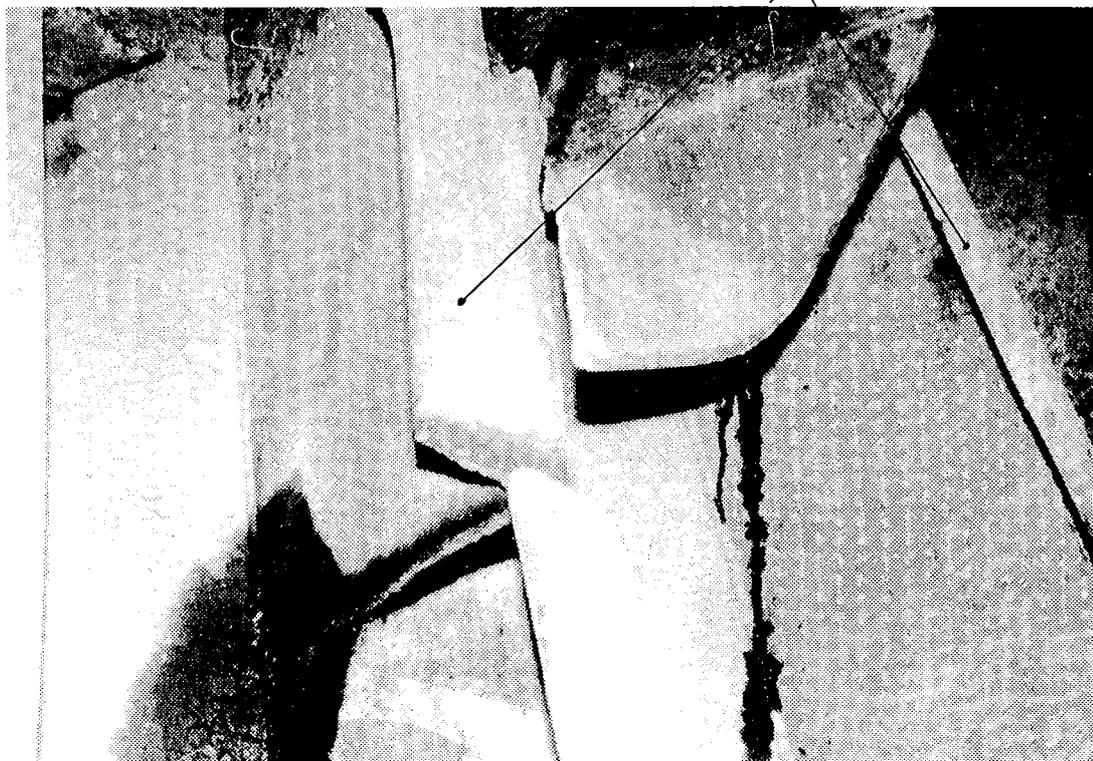


Fig. 25b. Inside view of the damage on the ship no.37.

5.2.11 Ship no. 39 (7885 DWT bulk carrier)

The largest damage during the survey was found on this ship. The damage took place on the 18th of April 1985 outside Luleå, when the ship got stuck in compressing ice. Fig. 26 illustrates the situation. The draught of the ship was then 6.90 m. Wind speed was 7 m/s from the southwest. See Appendix 1/5 for further detail of the ice conditions.



Fig. 26. Ship no. 39 stuck in compressive ice.

As a result of the compression four areas were damaged on the SB-side and one area on the PB-side as shown in Fig. 27. The maximum permanent deflection occurred at the level of the upper wing tank, where the shell structure is longitudinally framed, see Fig. 28. In addition to the shell damage the deck plating buckled between frames 35-42.

This ship was also damaged during the winter 1987 (area 4). The exact date for the incident is not known. The damage on the PB-side between frames 48-53.3 from the level of about 2 meters above the double bottom to about 0.5 m above the bottom of the upper wing tank. The maximum deflection of the damage was 80 mm.

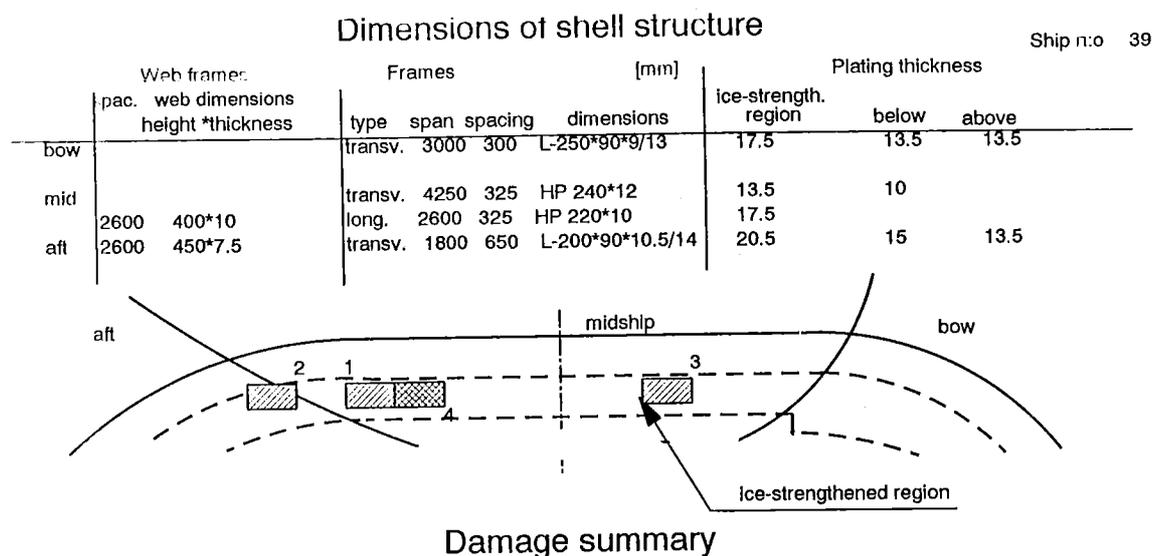


Fig. 27. Dimensions of the shell structure and summary of damages onboard ship no. 39.

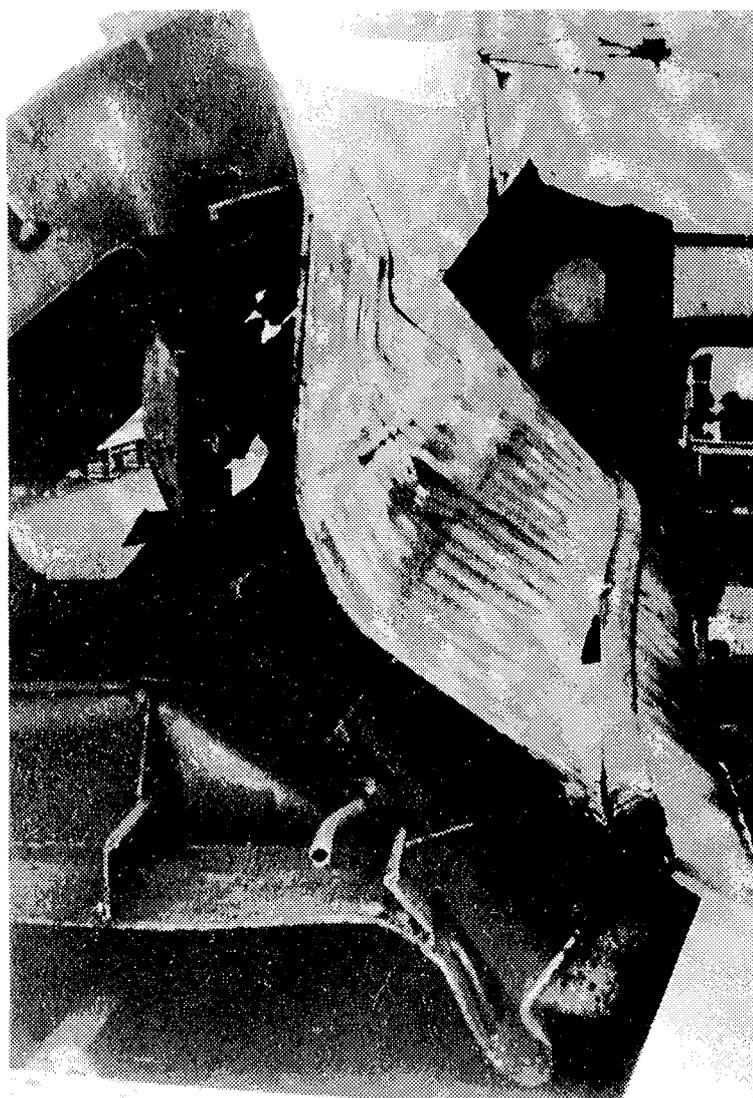
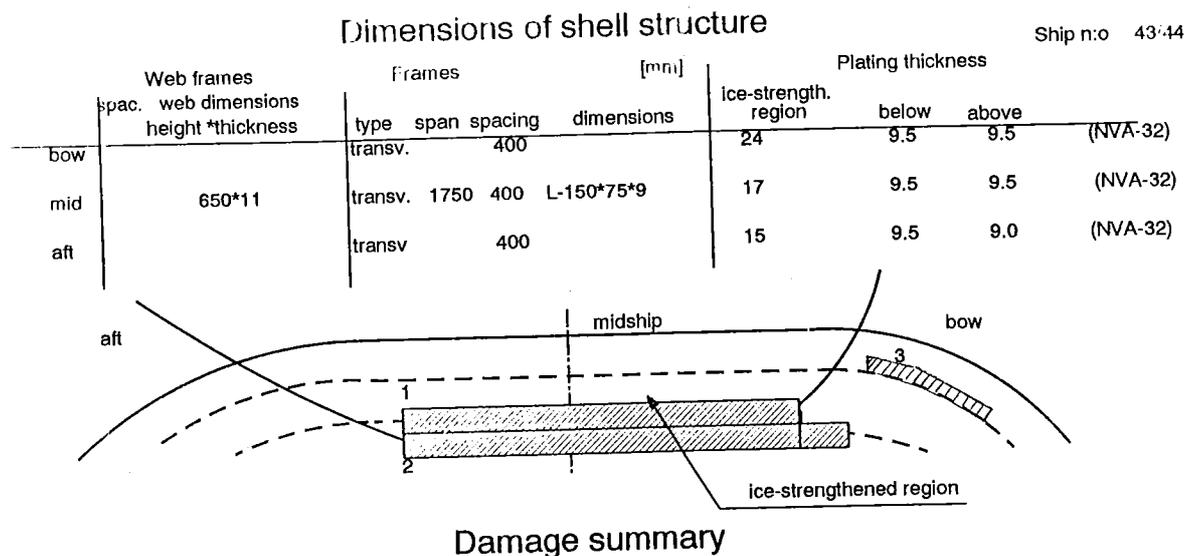


Fig. 28. The shape of the damage at the upper wing tank between frames 45-60 (area 1) of ship n:o 39.

5.2.12 Ships no. 43 and 44 (10604 BRT passenger ferries)

These ships are sister ships with the same navigation routine. Therefore the damages are also similar. The damage consists of denting of shell plating between frames, located either above or below the ice-strengthened region, see Fig. 29. The reason for the damage outside the ice-strengthening is obvious as the thickness of the plating changes from 24 mm to 9.5 mm when the ice-strengthening ends.



Area n:o	Damage type	length [m]	height [m]	max deflection [mm]
1	Yielding of plating (spac. = 400)		0.5	25
2	Yielding of plating (spac.=800)		1.0	30
3	Yielding of plating (spac.=400)		1.0	10

Fig. 29. Dimensions of shell structure and summary of damages onboard ship no. 43/44.

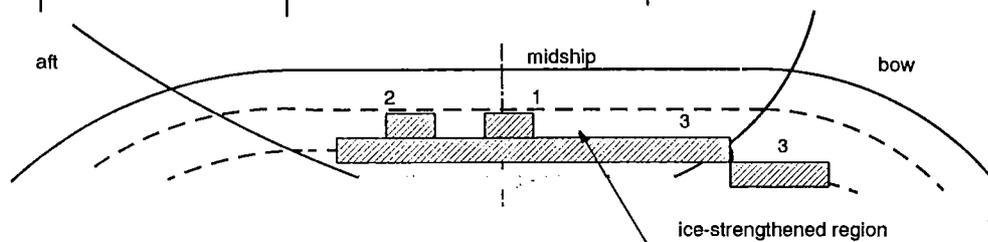
5.2.13 Ship no. 45 (7000 DWT cargo ferry)

This ship is longitudinally framed has two types of damage. One type consists of denting of plating at the ice-strengthened region and below it. The other type consists of two bigger dents at midships on SB and PB-sides, see Fig. 30. The damage of area 1 was also studied with stereo photography. Fig. 31 gives the shape obtained for the damage between frames 86-90 on SB-side. This damage had most probably occurred in march 1985 outside Rauma, when the ship was under compressive ice with the draught of 4.30 m at the bow and 4.80 m at the after end. A survey of the damage inside the tank was not possible. In addition Fig. 32 illustrates the permanent deflection of plating in area 3 under the ice-strengthened region.

Dimensions of shell structure

Ship n:o 45

	Web frames		Frames			Plating thickness			
	spac.	web dimensions height * thickness	type	span	spacing	dimensions	ice-strength. region	below	above
bow	2800	900*10	transv.	2600	300	HP 280*11	18.5		15
			long.	2800	300	HP 300*12	20	11	15
mid	2800	900*10	long.	2800	300	HP 260*10	14.5	10.5	10.5
aft	2800	600*10	transv.	2400	350	HP 260*11	13.5	13	10.5



Damage summary

Area n:o	Damage type	length [m]	height [m]	max deflection [mm]
1 (SB)	Yielding of long. frames	2.8	0.9	55
2 (BB)	Buckling of web frame	5.6	0.9	65
	Yielding of long. frames			
3	Yielding of plating (long. framed)		0.9 (3 fr.spac.)	24
Ice-strength. midship area	Yielding of plating			30

Fig. 30. Dimensions of shell structure and summary of damages onboard ship no. 45.

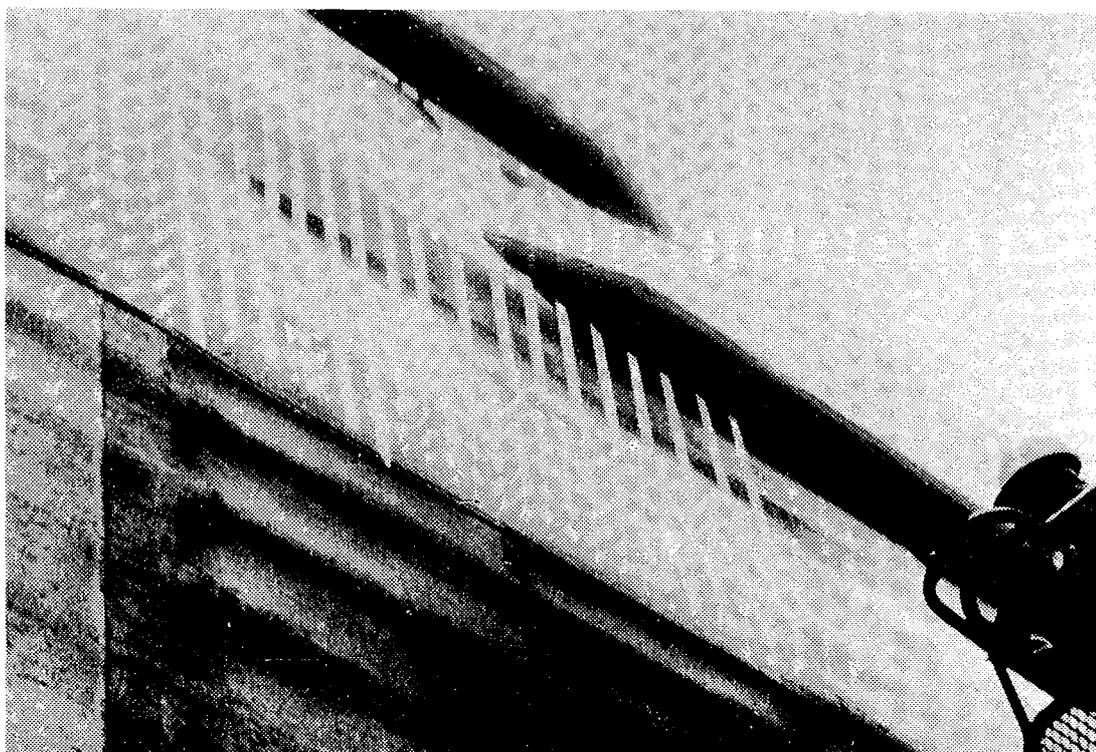


Fig. 31a. The shape of the damage at SB-side of ship no. 45 between frames 86-90 (area 1).

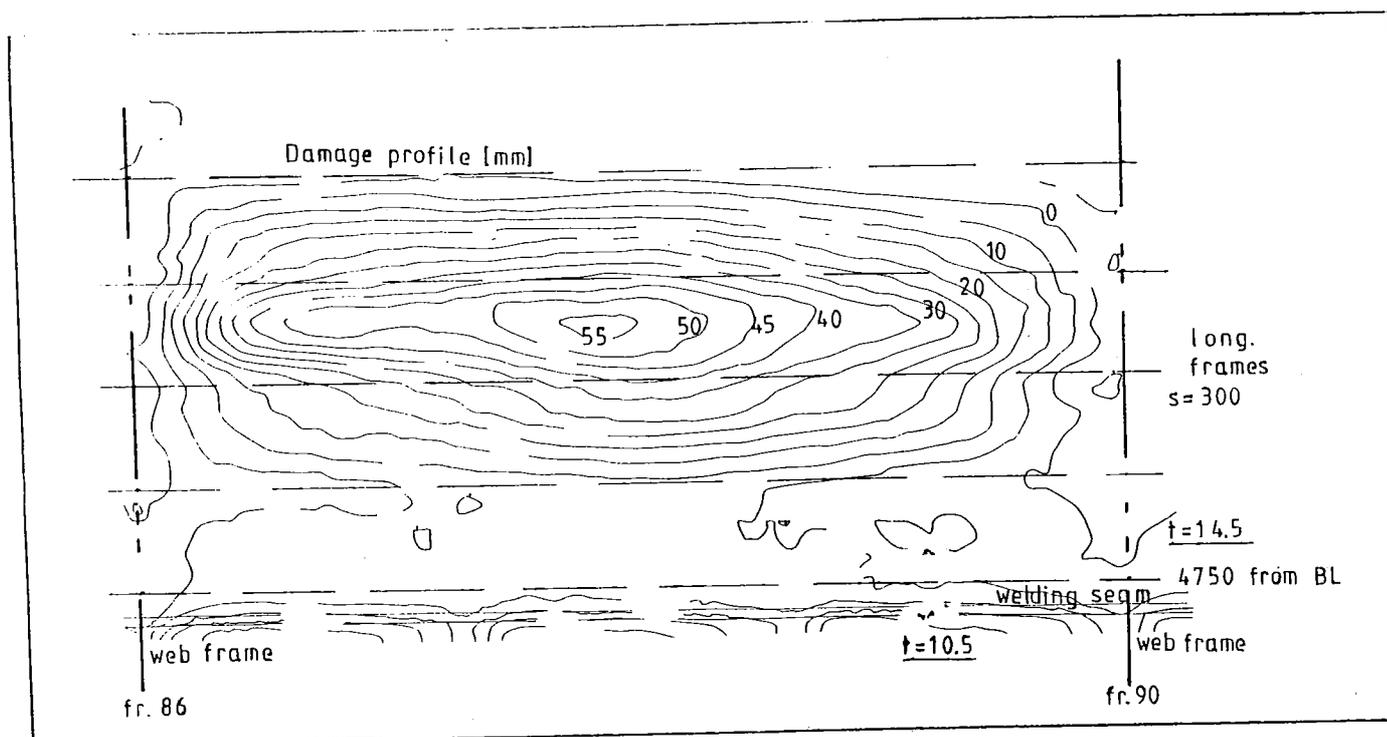


Fig. 31b. The shape of the damage at SB-side of ship no. 45 between frames 86-90 (area 1).



Fig. 32. The permanent deflection on the plating of area 3 on ship n:o 45.

5.2.14 Ships no. 48-50 (15954 DWT tankers)

These ships are sister ships with similar damages. They have transverse framing at the bow and longitudinal framing at midships. The damages consist of denting of plating, which at the bow has occurred above the ice-strengthened region and at midships at the longitudinally framed ice-strengthened region, see Fig. 33. Ship n:o 47 is also a sistership to these ships and she has similar damages, which have, however, occurred while navigating to the Canadian Arctic. Therefore these damages are excluded from this report.

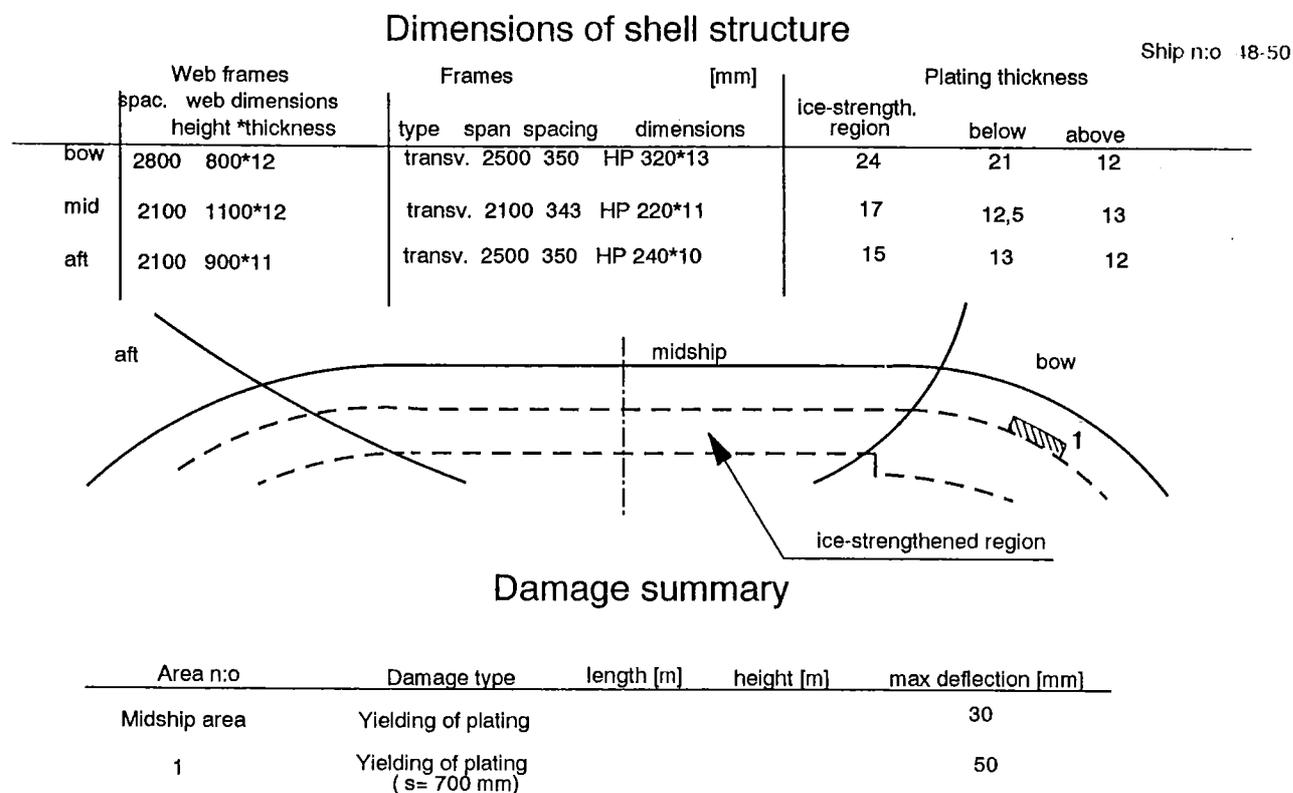


Fig. 33. Dimensions of shell structure and summary of damages onboard ship no. 48-50.

5.2.15 Ship no. 51 (6863 DWT tanker)

Similarly to the ships no 48-49, this ship also has damages on the plating above the ice-strengthened region at the bow and at the ice-strengthened region at the after end of the midship region, see Fig. 34. The ship is transversely framed.

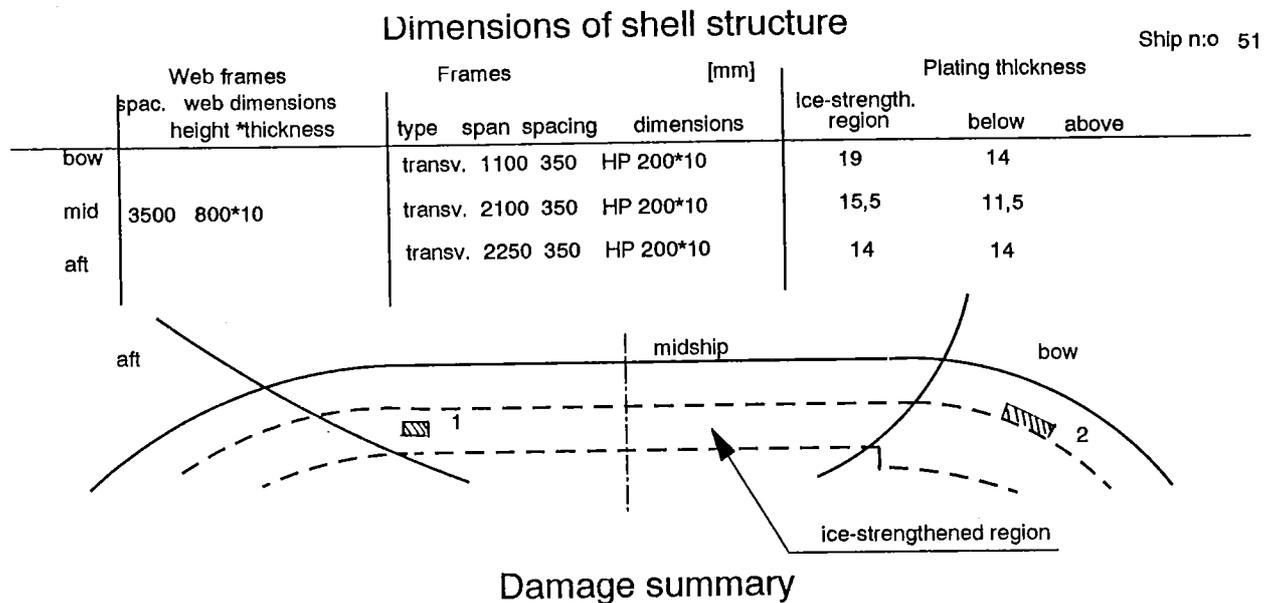


Fig. 34. Dimensions of shell structure and summary of damages onboard ship no. 51.

6 ANALYSIS OF THE DAMAGES FOUND

6.1 General

The discussion of the damages is in three parts. First some general trends are given, then the characteristics of the damages are considered and finally ice-induced loads causing the damages are estimated.

6.1.1 Longitudinally framed ships

The statistics include 10 longitudinally framed ships of which 9 have been navigating to the Bothnian Bay. All these 9 ships have damage on the plating at midships in the ice-strengthened region. In addition 4 ships have a number of damages on the web plating of the web frames. The reason for these damages is that the 1971 ice rules assumed a load height of 800mm, whereas the load height used in the 1985 ice rules varies from 220mm to 350 mm and the latest research results indicate even lower load heights (Riska et al. 1990). Therefore although the design load values are the same, the ice-induced pressures on the longitudinal frames are considerably higher than that given in the 1971 rules.

6.1.2 Transversely framed ships

Fig. 35 summarises the damages of transversely framed ships with ice classes 1AS and 1A, in various sea areas. The study includes 23 1AS class ships of which 6 (26 %) were damaged. Most damages have occurred on the ships navigating to the Bothnian Bay. Two of the ships have damage only on plating. From the 26 1A-class ships 14 (54 %) have damages. Of these, 8 ships (31 %) have damages only on plating outside ice-strengthened region and 6 ships (23 %) have damages also on ice-strengthened frames. The plating damages have mostly occurred on passenger ferries navigating in the Baltic proper and Gulf of Finland and they are above and below the ice-strengthened region. This is due to the fact that with high speed in a

fast ice channel the ice-induced loads extend to a greater area than specified in 1971 rules for the ice-strengthened region.

The damages on frames have occurred mainly on ships navigating to the Bothnian Bay. These are also summarised in Fig. 36 using ship type as a parameter. From the 1AS class, dry cargo ships have most of the damages and from the 1A class, bulk carriers have most of the damages. Most of the damages are located at midships.

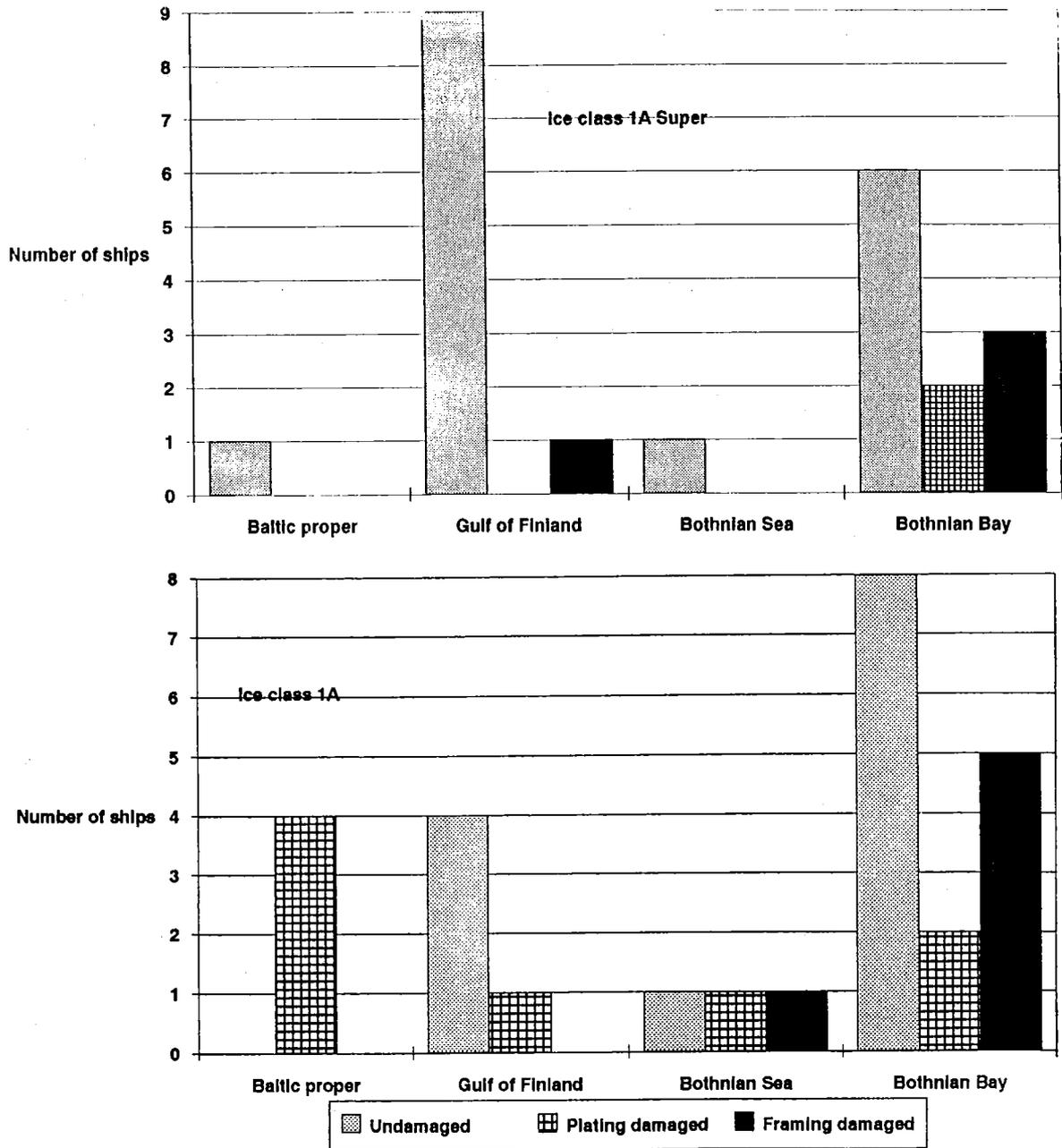


Fig. 35. Number of transversely framed ships damaged in the two ice classes in various sea areas.

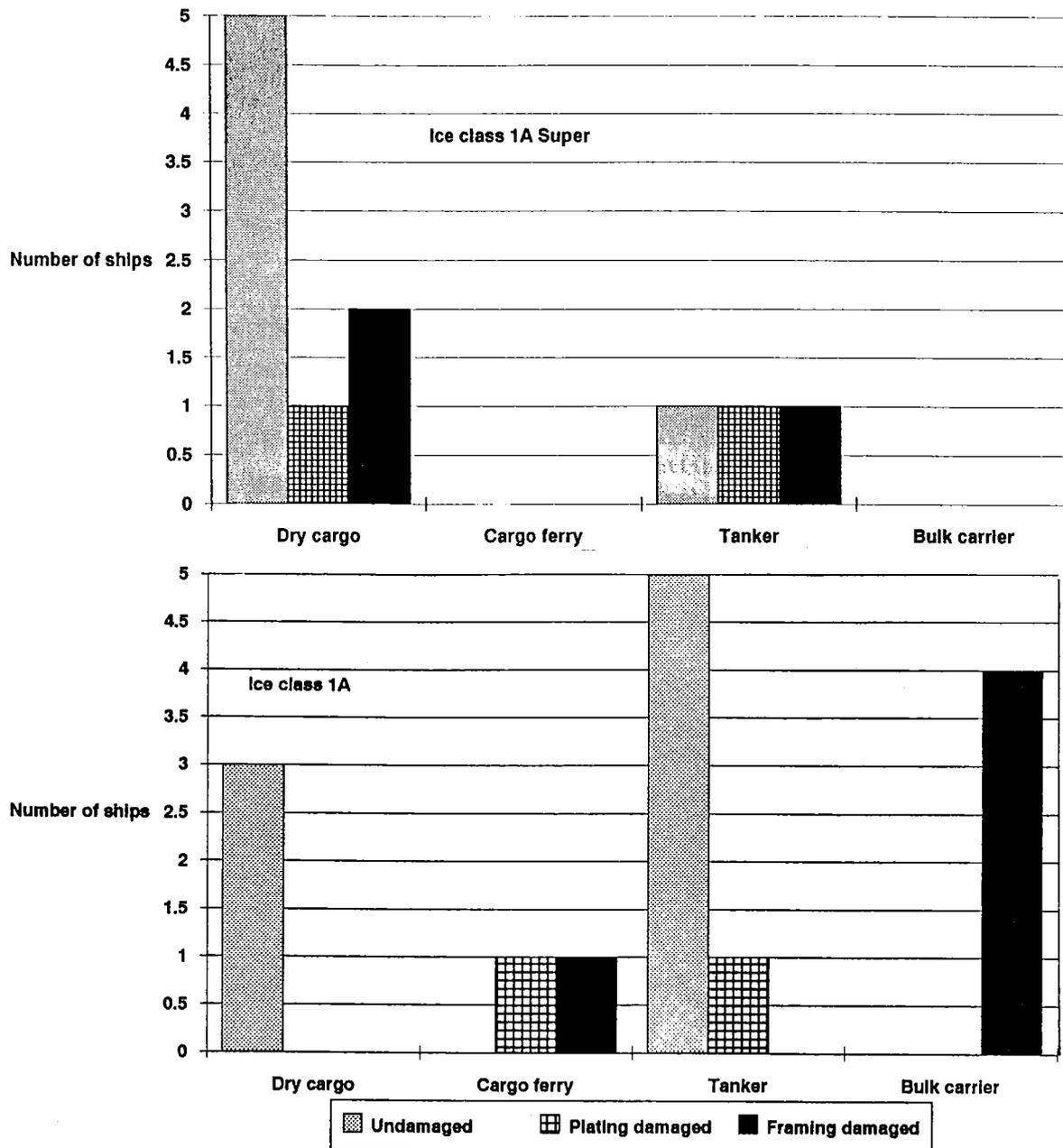


Fig. 36. Number of transversely framed ships damaged in the two ice classes when navigating to the Bothnian Bay.

Fig. 37 summarises the number of damages found annually on transverse frames. This figure includes only the damages on ice-strengthened frames, as typically the plating damages occur gradually over several winters. The highest number of damages occurred during the winter 1985. All the damages on the ice-strengthened region of 1AS-class ships with transverse framing have occurred during the winter 1985. The damage frequency of the winter 1986 is also high. Winter 1987 was also hard, but the damage

frequency is lower probably due to the nonsystematic gathering of statistics during that winter and due to the decrease of the Finnish ice-strengthened tonnage during the year 1986. Only one damage is observed during the average winter of 1984.

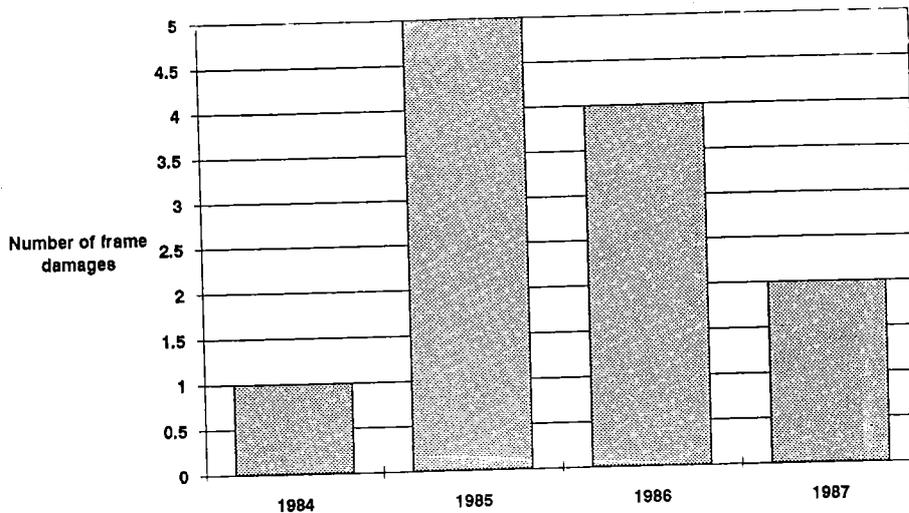


Fig. 37. Number of ships with damaged transverse frames found during various winters.

Some studies were also conducted to find the most important parameters affecting the probability of frame damages. The navigation frequency of ships to the Bothnian Bay is one of the key parameters as illustrated in Fig. 38. As can be seen from Fig. 38 all the 1A-class ships with navigation frequency higher than 3 voyages/winter have experienced frame damages. This can be understood as most damages have occurred in compressive ice, which occurs occasionally depending on movement of ice due to the wind. Therefore the probability of experiencing compressive ice increases with increasing navigation frequency.

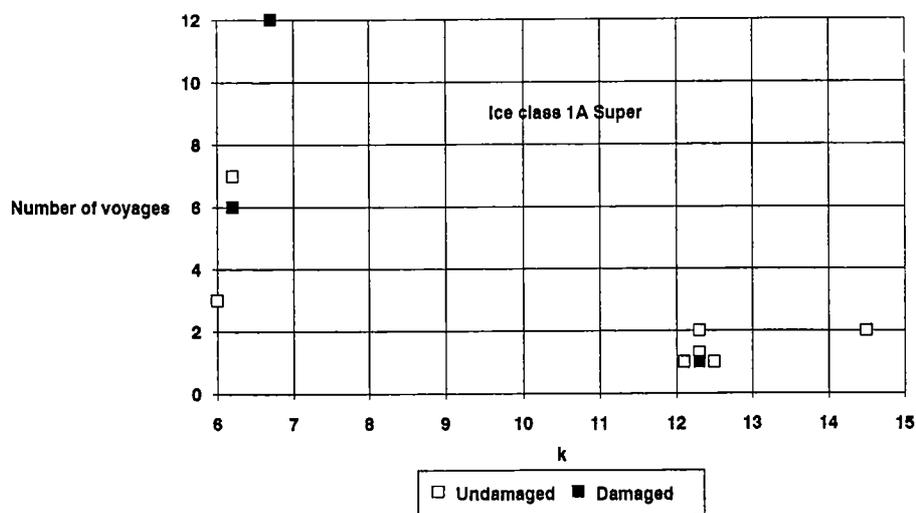
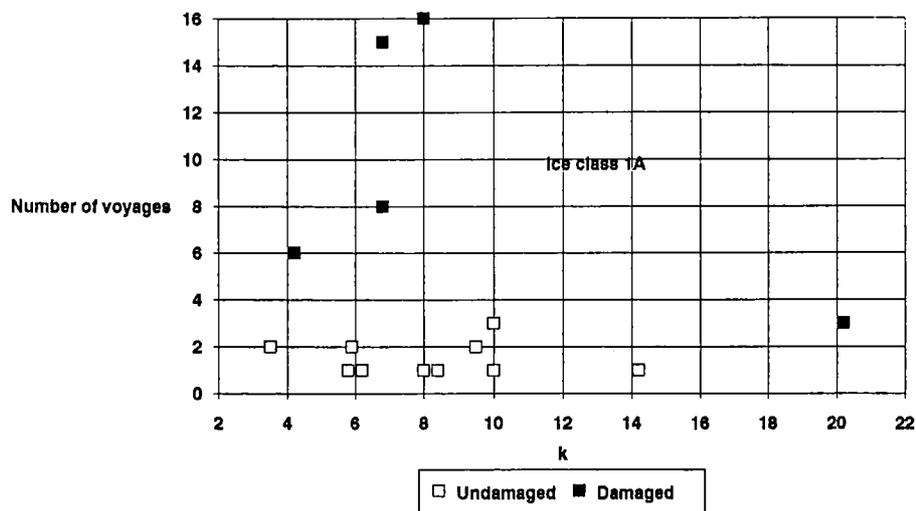


Fig. 38. Number of voyages to the Bothnian Bay during winter 1985 for the two ice class damaged or undamaged ships as a function of the factor k (see eq. 1). The figure includes only ships with damages on ice-strengthened transverse frames.

6.2 Characteristics of the damages

6.2.1 Plating damages

Typically the plating damages consist of permanent deflection of plating between frames in the order of 10-30 mm i.e. 1-2 two times the plate thickness. At the bow the damages locate above and below ice-strengthened region. At midships the damages are located in the ice-strengthened region or below it. The damages below the ice-strengthened region are usually due to the fact that the thickness of plating changes from ice-strengthened scantlings to open water scantlings in one step, whereas the ice loading only gradually diminishes downwards. The damages at the bow above the ice-strengthened region are due to the extension of loaded area caused by the bow wave with higher speed.

6.2.2 Frame damages

Typical damages on frames extend about 5 to 20 frame spacings with maximum deflections of about 50 mm. The height of the damages vary from 0.5 to 3 m as shown in Fig. 39.

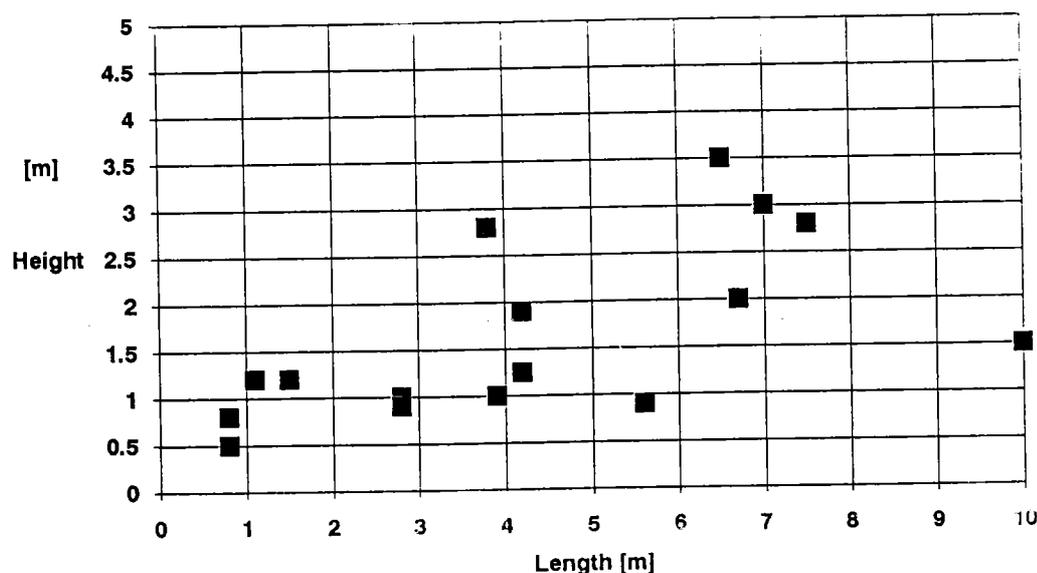


Fig. 39. The length versus height of the observed damages.

Fig. 40 summarises the location of framing damages. Most damages are located at midships on the ice-strengthened region, especially at the aft end of the midship region. Only one damage was observed on the bow area and two on the after ship area.

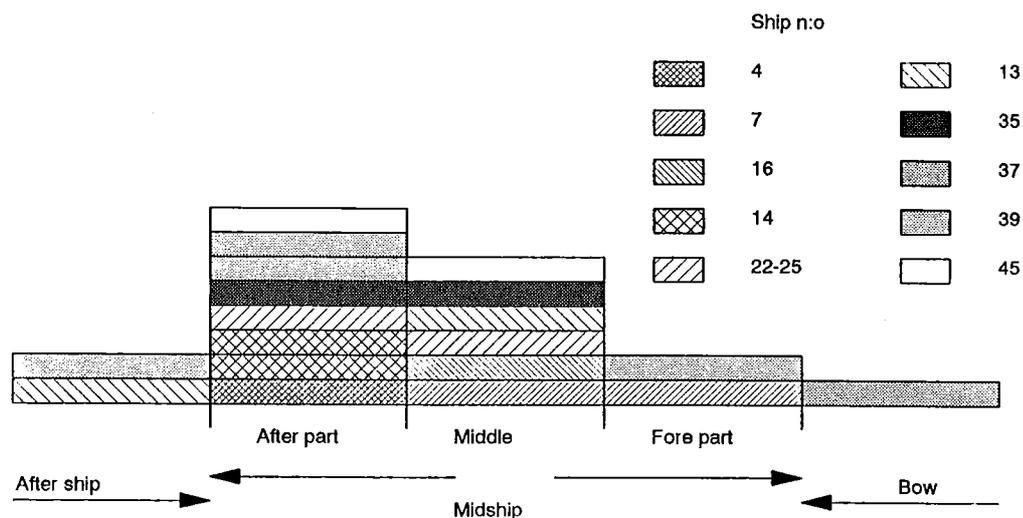


Fig. 40. The location of frame damages on various ships.

6.3 Evaluation of the ice-induced loads causing damage

6.3.1 Description of the methods used

The main problem in estimation of the loads to cause the damages is the unknown contact height and length. Some assumptions have to be made for these. The latest research results (Riska et al., 1990) indicate that the contact between ship and ice is linelike. The appearance of the contact can have, however, a number of varying forms with e.g. a fluctuating number of simultaneous contacts. The nature of these fluctuations are not properly known at present.

The problem of the unknown contact phenomenon is usually circumvented in design work by defining the mean design pressure as a function of the apparent contact area. The apparent contact area is again related to the task of the structural element in the load carrying hierarchy of the shell structure. This approach is used also in the following analysis, where the ice-induced load is taken as a line load. The load length varies for various structural elements so that for transversely framed structures the frame spacing is taken as the load length and for longitudinally framed structures the spacing of web frames is used as the load length. This is the usual assumption, when the design pressure and load area are adjusted for ice-strengthened structures (Ice rules, 1985).

The load to cause the permanent deflections on the transversely or longitudinally framed plating are evaluated with the following equations (Ranki, 1986):

$$\frac{w_0}{t} > 1.0 \quad ; F_p = \frac{8\sigma_y t^2}{l_p} (c+l_p) \frac{w_0}{t} \quad (2)$$

$$\frac{w_0}{t} \leq 1.0 \quad ; F_p = \frac{2\sigma_y t^2}{l_p} [(3c+2l_p) \frac{w_0}{t} + 2l_p + c] \quad (3)$$

where F_p is the the total load on the plating, w_0 is the permanent deflection, t is the plate thickness, σ_y is the yield strength, l_p is the load length and c is the load height. These equations assume that the plating is fully clamped and include the effect of membrane forces due to the large displacements of the plating. The load values given by equations (2)&(3) are also compared with a detailed non-linear finite element analysis for a typical, transversely framed shell structure (Katajamäki, 1988). The results indicate that the load values obtained with eq. (2)&(3) can underestimate the load values by about 10 %, but this difference is in the same range of accuracy

as specified for the observed permanent deflections (see chapter 4).

For estimation of the ultimate strength of the frame under bending, the plastic limit load approach is used. The frame can carry load as far as a plastic hinge mechanism is developed on the frame. When a typical ice frame is loaded at midspan, three plastic hinges are required to reach the ultimate strength: one in the middle and two at the ends of the frame. The load to reach the hinge mechanism can be obtained from the formulae (Johansson, 1967):

$$F_f = \frac{16\sigma_y W_p}{2l_f - c_f} \quad (4)$$

where F_f is the total load on a frame, W_p is plastic section modulus of the frame, l_f is the span of the frame and c_f is the load height on the frame. The load height c_f for transverse frames is equal to the load height c and for longitudinal frames is equal to the load length l . The plastic section modulus is equal to the first moment of area of the cross section about plastic neutral axis.

The use of formula (4) requires that no buckling or tripping of the cross section takes place before plastification. The possible buckling and tripping of the frames were checked using the approach given in reference (Varsta et al., 1978).

The observed collapse mode for the web frames was local buckling of the web plating. The total load on the webframe F_w to cause the buckling can be approximated with the formula (Roberts, 1983 p. 93):

$$F_w = 0.5 t_w^2 [E\sigma_y \frac{t}{t_w}]^{0.5} [1 + \frac{3C}{h_w} (\frac{t_w}{t})^{1.5}] \quad (5)$$

where E is elastic modulus, t_w is the thickness of web plating, h_w is the height of web plating and t is the thickness of shell plating. Fig. 41 summarises the load configurations used in the analysis.

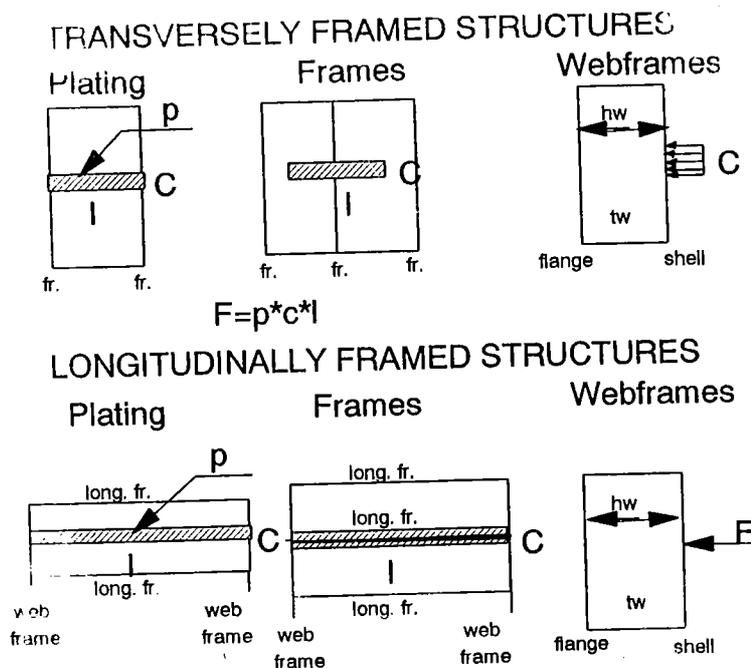


Fig. 41. The load configurations used in the analysis.

6.3.2 The damage load values obtained

Table 7 gives the load values calculated to cause the damages specified in chapter 5.2. The table gives the total load on various structural elements according to the formulae given in chapter 6.3.1, except the value for the shear yielding of the midship frame on ship n:o 13 (532 kN), which is based on the analysis given in (Kujala, 1989). A load height of $c=10$ mm is used in the analysis. Most of the ships included in the study are built using normal strength steel. The mean actual yield strength for this material is $\sigma_y=290$ MPa (Kujala, 1989), which is used in the analysis.

The collapse analysis of the frames indicated no possible buckling or tripping of the frames, which is also supported by the visual observations during the survey. The main reason for this is that most frames are supported with tripping brackets (about 1 m apart) preventing that type of collapse.

Table 7. Damage load on various structural elements [kN].

Ship n:o	Area	Ice-strengthened region			Outside ice streng. reg. Plating
		Plating	Frame	Webfr.	
4	Mid	653	738		
7	Mid/tra. Mid/lon. Bow	519 698	364		700
13	Aft Mid/tra. Mid/lon.	495 465	532	290 284	353
14	Mid	501	410	472	765
16	Mid		330	331	597
21	Mid				377 476
22-25	Mid	1151	1288	499	
35	Mid Bow	564	346	494	310
37	Bow		536		
39	Mid/lon.		770	528	
43/44	Mid Bow				681 808 272
45	Mid	1012	1062	474	587
48-50	Mid	1189			1411
51	Mid	564			759

The failure of frames and web frames specify only the lower limit for the load, as the behaviour of these structural elements after the initial collapse is not included in this study. The permanent deflection of plating specify the actual load required to cause the deflection. Therefore the load values based on these permanent deflections give a more realistic level for the maximum ice-induced loads.

The load values for the midship area are also given graphically in Fig. 42, where the load is divided by the apparent load length to obtain the mean intensity of the line load. A exponential curve is fitted to the maximum load intensity values and the following curve is found to fit the data:

$$q = 814 l^{-0.71} \quad (6)$$

where the unit of q is [kN/m] and of l is [m]. This curve gives the maximum load intensity calculated from the damages on the midship area, where most of the damages are located. Formula (6) enables the estimation of the local ice-induced pressures if the load height is known. As stated earlier the nature of contact is not properly known at the present stage, but contact heights of only a couple of centimeters have been observed. Assuming $c = 10\text{mm}$ the ice-induced pressure with an apparent contact length $l = 1\text{m}$ is 81,4 MPa and assuming $c = 30\text{ mm}$ the pressure with $l = 1\text{m}$ is 27.2 MPa.

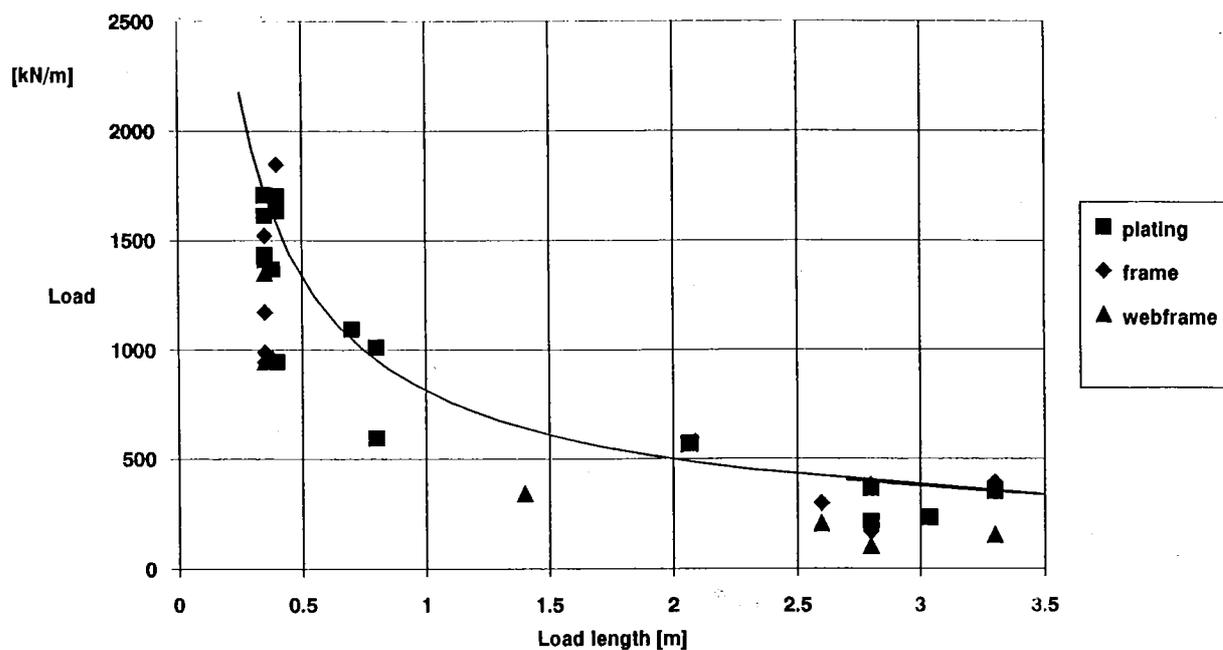


Fig. 42. The lineload intensity as a function of the load length for midship area based on the analysis of damages on various structural elements.

The results given above are based on straightforward analysis of the individual structural elements. The interaction between various elements during the damage process is not touched upon. The interaction has certainly an important role on the development of the bigger damages, like those described in Fig. 23, Fig. 28 and Fig. 31.

7 CONCLUSIONS

In total, 61 ships are included in the study, of which 31 have ice class 1A Super, 28 ice class 1A and 2 ice class 1C. About 84 % of the ships have transverse framing and 16 % longitudinal. The study includes winters 1984-1987, of which 1985, 1986 and 1987 were very hard winters and winter 1984 was an average winter.

Typical damages found during the study have a local character with total lengths varying from 1 to 7 m and heights from 0.5 to 3.5 m. Typically plating between frames have permanent deflections of 10-30 mm and frames have deflections of the order of 50 mm. No damage resulting in leakage was found during the study.

All the longitudinally framed ships navigating to the Bothnian Bay have damages on the plating at midships on the ice-strengthened region. In addition 4 ships have damages on the web plating of the web frames due to the buckling of the web. The reason for these damages is that the 1971 ice rules assumed a load height of 800 mm, whereas the load height used in the 1985 ice rules varies from 220 mm to 350 mm and the latest research results indicates even lower values. Therefore the ice-induced pressures on the longitudinally framed plating and longitudinal frames are considerably higher than given in the 1971 rules. The requirements for the minimum thickness of web plating of webframes requires modification due to this fact.

The study includes 23 1AS-class ships with transverse framing of which 6 (26 %) has sustained damages. Two of these have damage only to plating. Most damages have occurred on ships navigating to the Bothnian Bay. The extent of these damages is minor. From the 26 transversely framed 1A-class ships 14 (54 %) have damages. From these, 8 ships (31%) have damage only on plating outside the ice-strengthened region. Most of these damages are on passenger ferries navigating in the Baltic proper and Gulf

of Finland. They have experienced damages on the plating at the bow above and below the ice-strengthened region. The damages above the ice-strengthened region were caused by high speed in a fast ice channel, when the ice-induced loads extended beyond the specifications in the rules due to the bow wave. The damages below the ice-strengthened region at bow and midship are usually caused by the rapid change of ice-strengthened scantling to the open water scantling, whereas the ice loading decreases only gradually towards the bottom.

From the 6 frame damaged 1A-class ships with transverse framing, one had damage at the bow and five had damage at midships. All except one of the damage occurred in the Bothnian Bay. The navigation frequency of the ships to the Bothnian Bay is found to be an important parameter, as all the 1A-class ships with more than 3 voyages to the Bothnian Bay during the winter 1985 experienced damages. The effect of ship's size on the damage probability could not be studied in any considerable detail, as the statistics include no large ships with frequent visits to the ports in the Bothnian Bay. The highest number of frame damages (5) occurred during the hard winter of 1985, whereas during the average winter of 1984 only one damage occurred.

The brief analysis of the lineload required to cause the damages indicates an exponential decrease of the lineload intensity as a function of load length. The maximum lineload intensity at midship was found to be about 1600 kN/m with a load length 0.4 m and about 400 kN/m with load length 3 m.

Compressive ice has caused most of the damages found in the midship area. Studies related to the methods to calculate the ice-induced loads in this situation are rare. Therefore this is an important topic in which additional theoretical work is needed. Once a more thorough understanding of ship-ice interaction in this situation is gained, the analysis of the larger damages

described in this report including the process of damage development should be continued.

8 ACKNOWLEDGEMENTS

The damage statistics were gathered during the years 1984 to 1987, while the author was working at VTT/Ship laboratory. The financial support from the Winter Navigation Research Board has made this study possible, which is here gratefully acknowledged. The author is also indebted for the close and fruitful co-operation with a number of representatives of Finnish ship owners, surveyors and ship's personnel, who gave valuable help and information in the course of this work.

9 REFERENCES

Edelmann, G. 1984. Updating of the Finnish-Swedish ice class rules. VTT symposium 52, Ship Strength and Winter navigation, Espoo, January 10-11, 1984. Technical Research Centre of Finland, Espoo. Pp 231-245.

Finnish-Swedish ice class rules 1971. Board of Navigation, Helsinki. 43p.

Finnish-Swedish ice class rules 1985. Board of Navigation, Helsinki. 43p.

Johansson, B. 1967. On the ice-strengthening of ship hulls. International Shipbuilding Process, vol. 14, pp. 231-245.

Katajamäki, K. 1988. Analysis of permanent deflection on ship shell plating. VTT Symposium 92, The 5th Marine Technology Symposium, Espoo, January 11-12, 1988. Technical Research Center of Finland, Espoo. Pp 43-71.

Kujala, P. 1989. Probability based safety of ice-strengthened ship hull in the Baltic Sea. Licenciate thesis. Espoo. Helsinki University of Technology. 109 p. + app 13 p.

Kujala, P. 1990. Safety of ice-strengthened ships in the Baltic Sea. London. Royal Institution of Naval Architects. Spring Meeting. April 21-23. 1990.

Ranki, E. 1986. Determination of ice loads from the permanent deflections of shell structures of a ship. (In Finnish). Licenciate's thesis, Espoo. Helsinki University of technology. 98 p.

Riska, K. et al. 1990. Full scale observations of ship-ice contact. Espoo. Helsinki University of Technology, Laboratory of Naval Architecture and Marine Engineering, Reprt M-97. 54 p. + app.

Roberts, T.M. 1983. Patch loading on plate girders. In: Narayanan, R. (ed.). Plated Structures. Applied Science Publishers. p. 77-102.

Varsta, P. et al. 1978. On plastic design of ice-strengthened frame. Helsinki. Winter Navigation Research Board, Report no. 27. 54 p.

Varsta, P. 1985. Itämerellä liikennöivän aluksen jäävahvistuksesta (On the ice-strengthening of a ship navigating in the Baltic Sea). Navigator, No. 10, pp. 18-22. (in Finnish).

ICE CONDITIONS ON 2ND OF APRIL 1982 WHEN SHIP N:O 7 WAS DAMAGED

Wind 15 m/s from SW

MERENTUTKIMUSLAITOS
HAVSFORSKNINGSINSTITUTET
INSTITUTE OF MARINE RESEARCH

Yhteiskäytynyt, yhteiskäytynyt tai hyvin tiheä ajojää
Consolidated, compact or very close ice (9 - 10/10)
Sammanhängande kompakt eller mycket tät drivis

Ahtautunut tai ryykköitynyt jää (1=ahautuma/moai)
Ridged or hummocked ice (1=number of ridges/moai)
Vallar och upptornad is (1=vallar/sjömoai)

Päälettään ahtautunut jää
Rifted ice (C = concentration)
Hopskjuten is

Tiheä ajojää
Close ice (7 - 8/10)
Tät drivis

Harva ajojää
Open ice (4 - 5/10)
Spridd drivis

Hyvin harva ajojää
Very open ice (1 - 3/10)
Mycket spridd drivis

Jään reunat tai jään rajat
Ice edge or ice boundary
Istant eller isgräns

Arvioitu jään reunat tai jään rajat
Estimated ice edge or ice boundary
Uppskattad iskant eller isgräns

Veden lämpötilan tasa-ankkuri, °C
Water temperature isotherm, °C
Vattentemperatur isotherm, °C

Mittaus jään paksuus, cm
Thickness measured in cm
Uppmätt isjocklek i cm

Avovesi
Open water <1/10
Öppet vatten

Uusi jää
New ice
Nyis

Tasainen jää
Level ice
Jäms is

Kiinteää
Fast ice
Fast is

Sohjova
Windrow
Siamovell

Halkama
Crack
Spricka

Raio
Lead
Rik

Jään kokonaiskonsentraatio (1/10)		Total ice concentration (in tenth)	
C	0	0	0
C	1	1	1
C	2	2	2
C	3	3	3
C	4	4	4
C	5	5	5
C	6	6	6
C	7	7	7
C	8	8	8
C	9	9	9
C	10	10	10

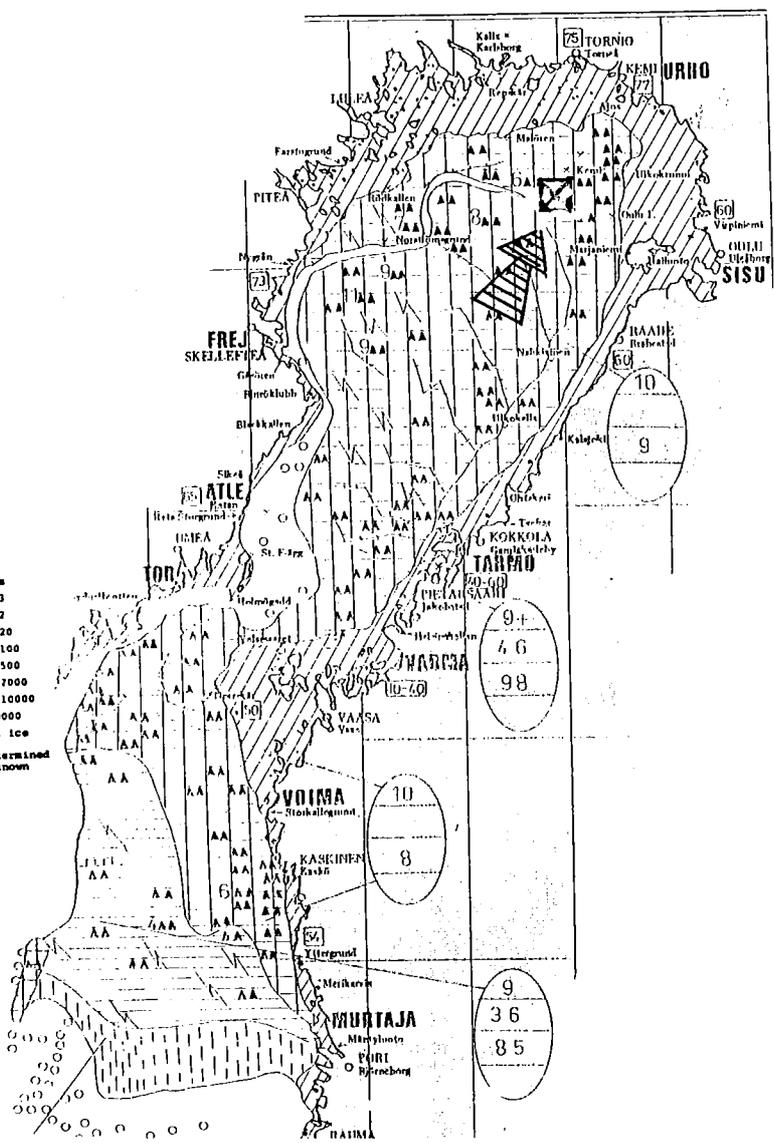
Osittaiskonsentraatio		Partial concentration	
C _a C _b C _c	1	1	1
C _a C _b C _c	2	2	2
C _a C _b C _c	3	3	3
C _a C _b C _c	4	4	4
C _a C _b C _c	5	5	5
C _a C _b C _c	6	6	6
C _a C _b C _c	7	7	7
C _a C _b C _c	8	8	8
C _a C _b C _c	9	9	9
C _a C _b C _c	10	10	10

Jään paksuus		Stage of development	
S _a S _b S _c	1	1	1
S _a S _b S _c	2	2	2
S _a S _b S _c	3	3	3
S _a S _b S _c	4	4	4
S _a S _b S _c	5	5	5
S _a S _b S _c	6	6	6
S _a S _b S _c	7	7	7
S _a S _b S _c	8	8	8
S _a S _b S _c	9	9	9
S _a S _b S _c	10	10	10

Jään muoto/lautojen koko		Form of ice/Floesize	
F _a F _b F _c	1	1	1
F _a F _b F _c	2	2	2
F _a F _b F _c	3	3	3
F _a F _b F _c	4	4	4
F _a F _b F _c	5	5	5
F _a F _b F _c	6	6	6
F _a F _b F _c	7	7	7
F _a F _b F _c	8	8	8
F _a F _b F _c	9	9	9
F _a F _b F _c	10	10	10

peksuin jää (a) of thickest ice (a)
 toiseksi peksuin jää (b) second (b)
 kolmanneksi peksuin jää (c) third (c)

grövssta isen (a)
 nätt (b)
 tredie (c)



ICE CONDITIONS ON 27TH OF MARCH 1985 WHEN SHIP N:O 13 WAS DAMAGED

Wind 7 m/s from S

T_{air} = - 1 °C

MERENTUTKIMUSLAITOS
HAVSFORSKNINGSINSTITUTET
INSTITUTE OF MARINE RESEARCH

	Yhennettyä, yhtäsuurua tai hyvin tiheää ajojää Consolidated, compact or very close ice (9 - 10/10) Sammanflyttad, kompakt eller mycket tät drivis		Ahtauslumi tai röykkiöitynyt jää (f=ehtauslumi/mäki) Ridged or hummocked ice (f=number of ridges/m) Vallor och upptornad is (f=vetar/sjömt)
	Pääletään ajautunut jää Rifted ice (C=concentration) Hopskuten is		Avovesi Open water c/1/10 Öppet vatten
	Tiheä ajojää Close ice (7 - 8/10) Tät drivis		Uusi jää New ice Nyis
	Harva ajojää Open ice (4 - 6/10) Spridd drivis		Tasainen jää Level ice Jämn is
	Hyvin harva ajojää Very open ice (1 - 3/10) Mycket spridd drivis		Kiintojää Fast ice Fast is
	Jään reuna tai jään raja Ice edge or ice boundary Iskant eller gräns		Sohjovo Windrow Stamovall
	Arvioitu jään reuna tai jään raja Estimated ice edge or ice boundary Uppskattad iskant eller gräns		Halkeama Crack Spricka
	Veden lämpötilan tasa-arvoikäyrä, °C Waters temperature isotherm, °C		Räsk Load
	Värittemperatuur isotherm i °C		
	Mittattu jään paksuus, cm Upmätti isjocklek i cm		

Jään kokonaiskonsentraatio (1/10)
Total ice concentration (in tenth)
Total iskoncentration

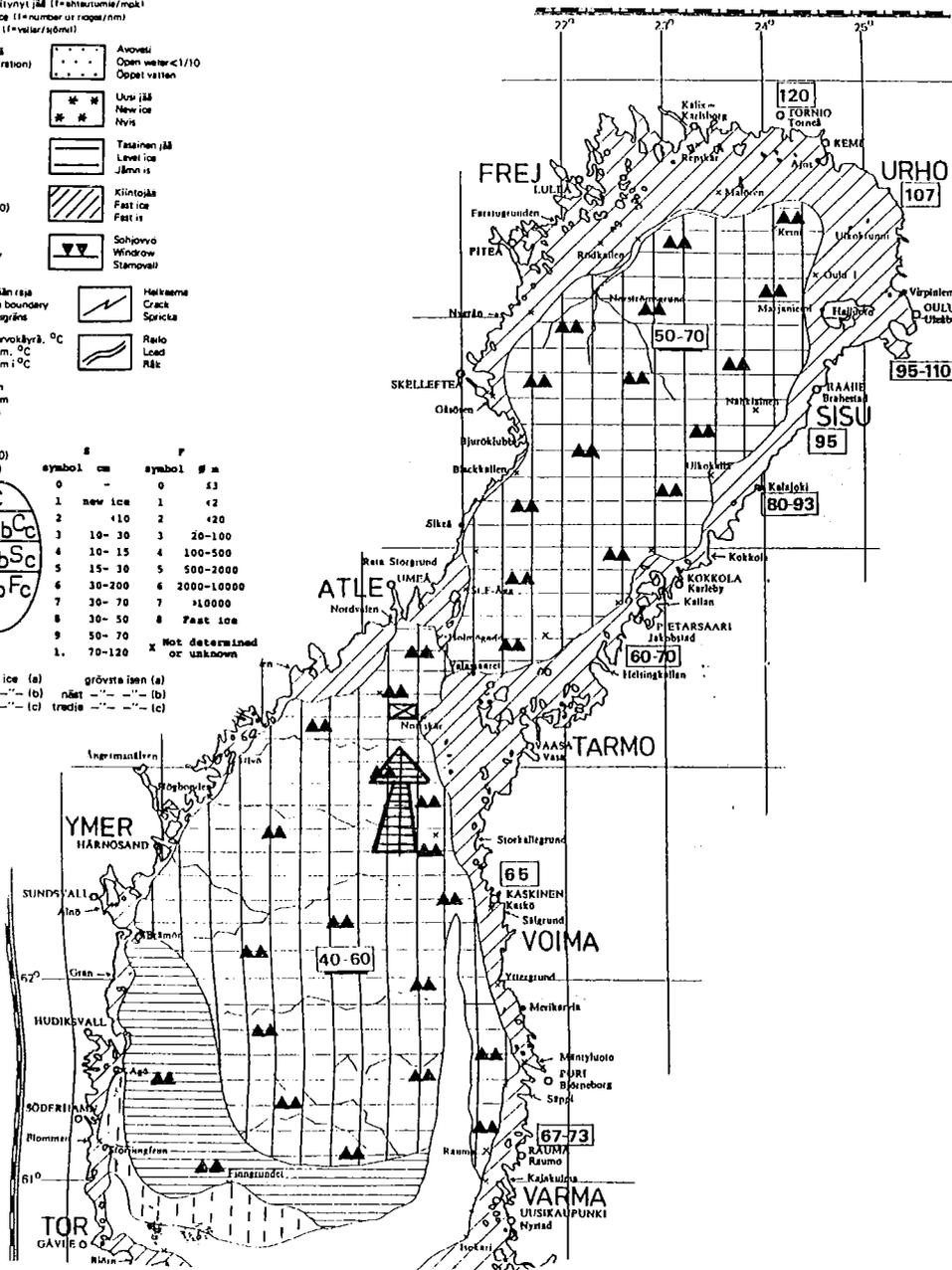
symbol	cm	symbol	cm
0	-	0	0-10
1	new ice	1	10-20
2	10-30	2	20-30
3	30-40	3	30-40
4	40-50	4	40-50
5	50-60	5	50-60
6	60-70	6	60-70
7	70-80	7	70-80
8	80-90	8	80-90
9	90-100	9	90-100
10	100-110	10	100-110
11	110-120	11	110-120
X	Not determined or unknown		

Osittaiskonsentraatio
Partial concentration
Delkoncentration

Jään paksuus
Stage of development
Isjocklek

Jään muoto/auttojen koko
Form of ice/Floesize
Form av is/Floesize

1. 70-120 X Not determined or unknown



ICE CONDITIONS ON 1ST OF MAY 1985 WHEN SHIP N:O 13 WAS DAMAGED

Wind 7 m/s from NE

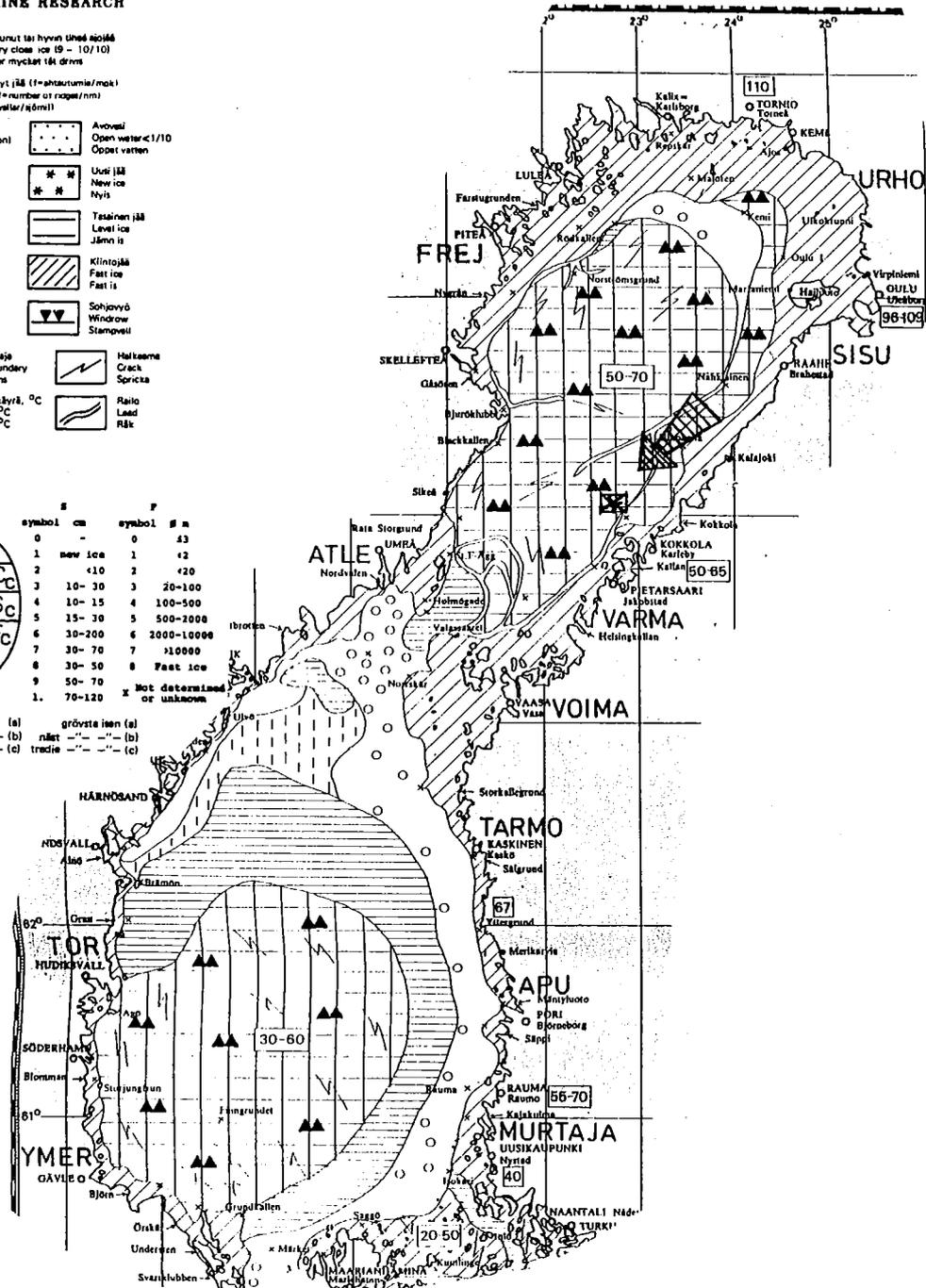
T_{air} = + 2 °C

MERENTUTKIMUSLAITOS
HAVSFORSKNINGSINSTITUTET
INSTITUTE OF MARINE RESEARCH

	Yhteisjäätynyt, yhteisjäätynyt tai hyvin tiheä ajojää Consolidated, compact or very close ice (9 - 10/10) Sammenfrosset, kompakt eller mykkelig is		Avovann Open water (1/10) Öppet vatten
	Ahtautunut tai rökkiöitynyt jää (1 = ahtautuma/mokki) Rigid or hummocked ice (1 = number of ridges/m) Väljar och upplömda is (1 = välar/sjömm)		Uusi jää New ice
	Päättökään ajautunut jää Rifted ice (10 = concentration) Höskjuken is		Level ice Jäänsä
	Tiheä ajojää Close ice (17 - 8/10) Tät drivis		Tasainen jää Fast ice
	Harva ajojää Open ice (14 - 8/10) Spödd drivis		Sohjainvö Windrow Stampvöl
	Hyvin harva ajojää Very open ice (11 - 3/10) Mycket spridd drivis		Halkama Crack Spricka
	Jään reuna tai jään raja Ice edge or ice boundary Iskant eller isgräns		Raio Lead Räb
	Arvioitu jään reuna tai jään raja Estimated ice edge or ice boundary Uppskattad iskant eller isgräns		
	Veden lämpötilan tase arvolukijä, °C Vattentemperatur isoterm, °C		
	Mittattu jään paksuus, cm Uppmättad isstjocklek, i cm		

C	Jään kokonaiskonsentraatio (1/10) Total ice concentration (in tenth) Total iskoncentration	symbol	cm	symbol	m
C _a C _b C _c	Oritaiskonsentraatio Partial concentration Delkoncentration	0	0	1	1
S _a S _b S _c	Jään paksuus Stage of development Isstjocklek	2	<10	2	<20
F _a F _b F _c	Jään muoto/lauttojen koko Form of ice/Flakstorlek	3	10-30	3	20-100
		4	10-15	4	100-500
		5	15-30	5	500-2000
		6	30-200	6	2000-10000
		7	30-70	7	10000
		8	30-50	8	Fast ice
		9	50-70	9	Not determined or unknown
		1.	70-120	X	Not determined or unknown

pakaisin jää (a) of thickest ice (a) grövste isen (a)
 toiseksi pakaisin jää (b) second " (b) näst " (b)
 kolmanneksi pakaisin jää (c) third " (c) tredje " (c)



ISBN 951-47-5203-1

The Finnish Government Printing Centre
Kampin VALTIMO
Helsinki 1991