SSC-310

A RATIONAL BASIS FOR THE SELECTION OF ICE STRENGTHENING CRITERIA FOR SHIPS VOLUME II-APPENDICES

SHIP STRUCTURE COMMITTEE

1981

SSC-310 A RATIONAL BASIS FOR THE SELECTION OF ICE STRENGTHENING CRITERIA FOR SHIPS-VOL.II — APPENDICES 1981

SHIP STRUCTURE COMMITTEE

The SHIP STRUCTURE COMMITTEE is constituted to prosecute a research program to improve the hull structures of ships and other marine structures by an extension of knowledge pertaining to design, materials and methods of construction.

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Ship Structure Committee

An Interagency Advisory Committee
Dedicated to Improving the Structure of Ships

Address Correspondence to:

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SR-1267

1981

As marine activity in ice covered waters is expected to increase in the foreseeable future, the design of ships to meet the varying conditions will have an expanding role for the naval architect.

The Ship Structure Committee has undertaken a program to acquire the necessary knowledge to permit a rational design for vessels which will be operating in various ice conditions. This first effort in the program surveyed the various classification societies and government regulations in order to discern the similarities and differences of their requirements, and further to recommend a procedure for selecting appropriate ice strengthening criteria. The results of this project are being published in two volumes. Volume I (SSC-309) contains the analytical portion of the work and Volume II (SSC-310) contains the appendices.

Clyde T. Lusk, Jr.
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

Technical Report Documentation Pc.

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15. Supplementary Notes SHIP STRUCTURE COMMITTEE PROJECT SR 1267		

16. Abstract

This report, Volume II, contains the appendices, A, B, and C, to Volume I of the same title. **Volume I** describes sources and differences between the ice strengthening criteria in use by various classification societies, and government regulations such as Canadian Arctic Pollution Prevention Regulations, and Swedish-Finnish Winter Navigation Board Regulations. A comparison of the different criteria is presented on the basis of a relative weight and relative cost. Effectiveness of the criteria is evaluated on the basis of statistical ice damage data and on a sample of individual ice damage cases. In addition, a comparison of different materials and fabrication techniques used for ice strengthening is presented. Deficiencies in current ice strengthening procedures are identified and a rational procedure for selecting appropriate ice strengthening criteria is presented.

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METRIC CONVERSION FACTORS

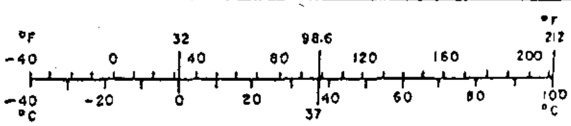
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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VOLUME I

CONTENTS (Continued)

APPENDIX A

MAXIMUM AND AVERAGE ICE CONDITIONS BY MONTH

Abbreviations used in this Appendix are as follows:

FY = first-year ice

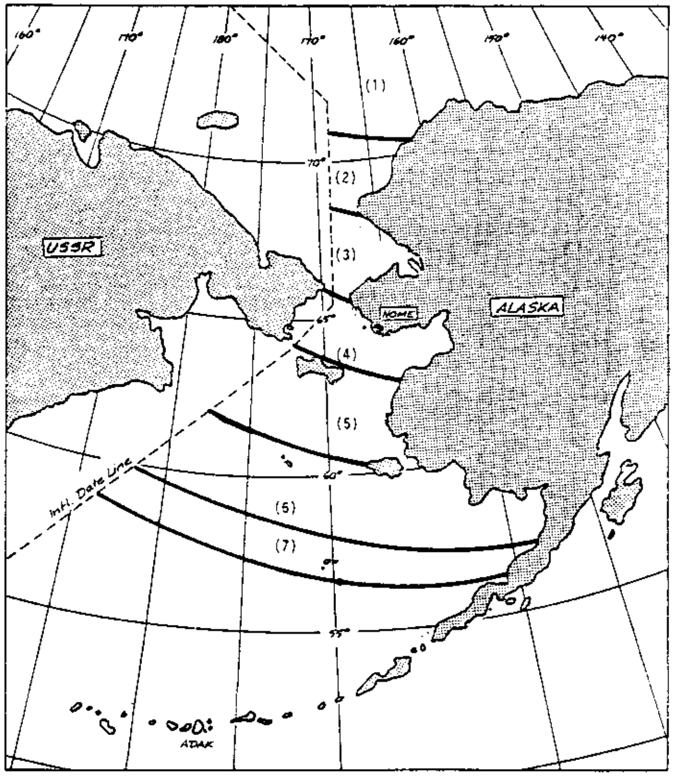
MY = multi-year ice

IB = iceberg, bergy bits, growlers, and any other fragments

IS = ice island or fragment therefrom

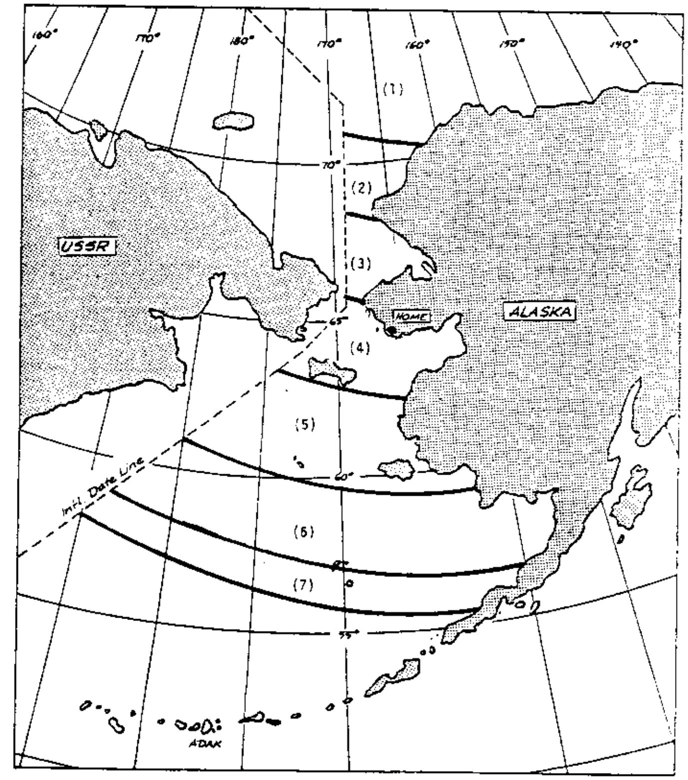
BI = broken ice

XX = level ice thickness. The corresponding pressure ridge depth (water surface to keel depth) contained within level ice floes is ten times the level ice thickness. The depth of consolidation within the first-year pressure ridge is assumed 25% of the depth; for multi-year ice 50% of the depth is assumed to be consolidated.



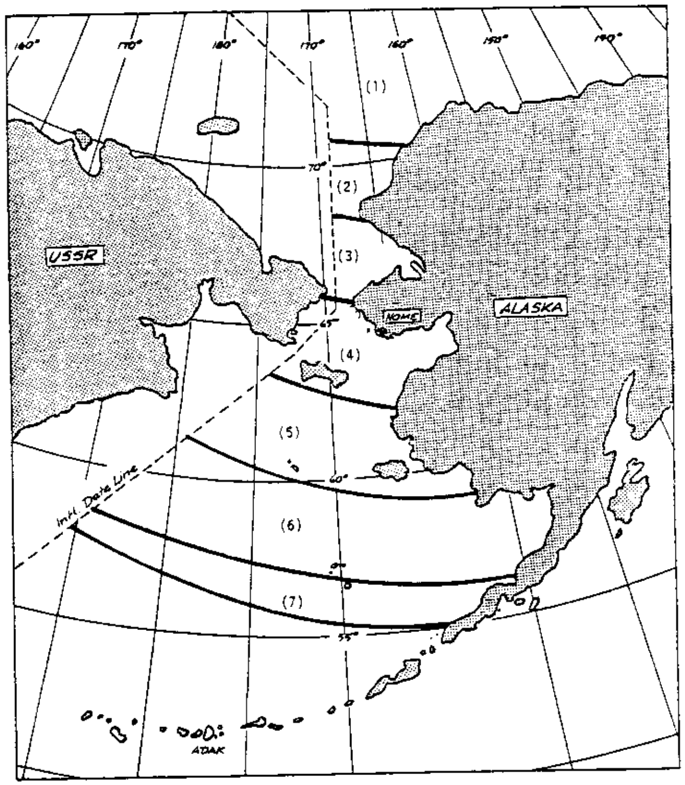
MAXIMUM ICE CONDITIONS, JANUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 4; MY 8.5; IS
2	FY 4; MY 8.5
3	FY 3; MY 8.5
4	FY 3
5	FY 2
6	FY 1
7	BI 1



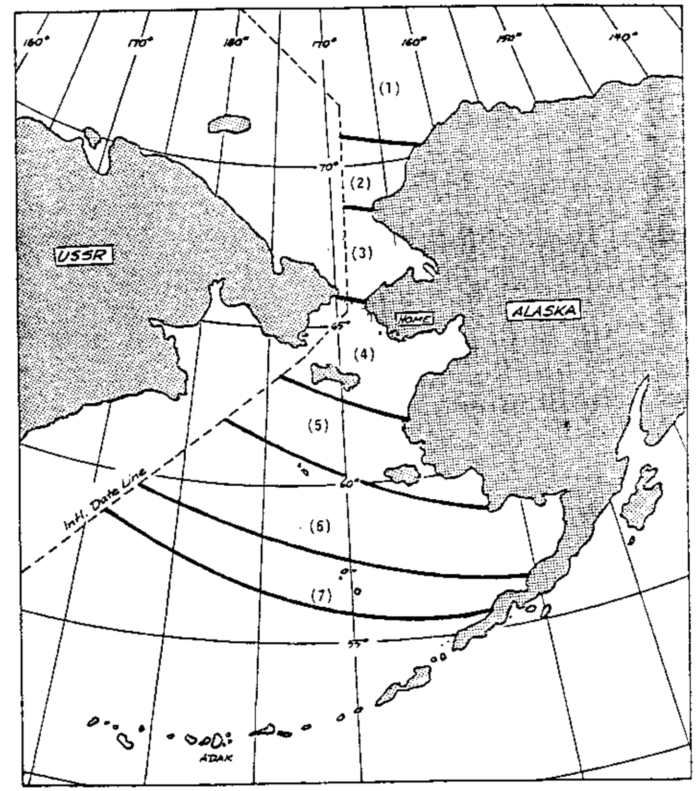
MAXIMUM ICE CONDITIONS, FEBRUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 5; MY 9; IS
2	FY 4.5; MY 9
3	FY 4; MY 9
4	FY 3
5	FY 2
6	FY 1
7	BI 1



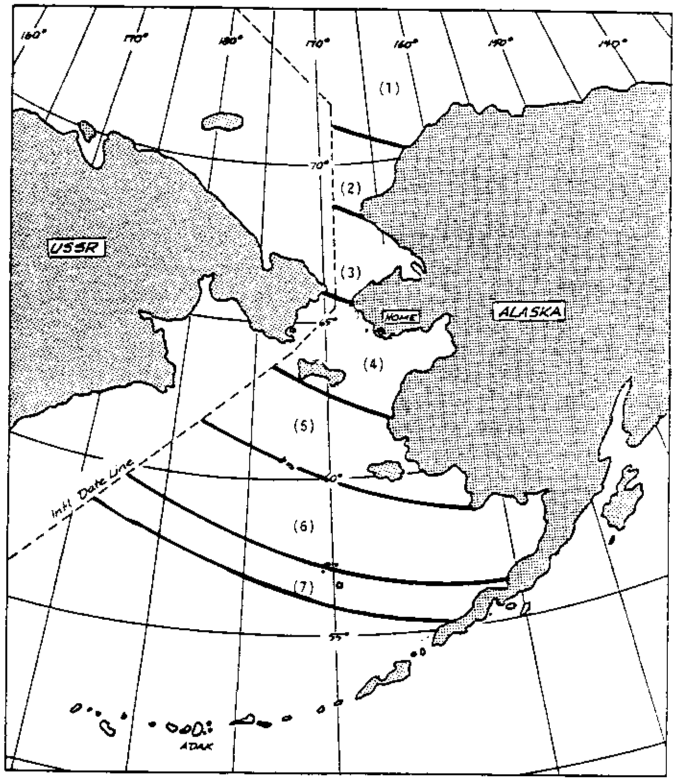
MAXIMUM ICE CONDITIONS, MARCH

ICE AREA	ICE CHARACTERISTICS
1	FY 5.5; MY 10; IS
2	FY 5; MY 10
3	FY 4.5; MY 10
4	FY 4
5	FY 3
6	FY 2
7	BI 2



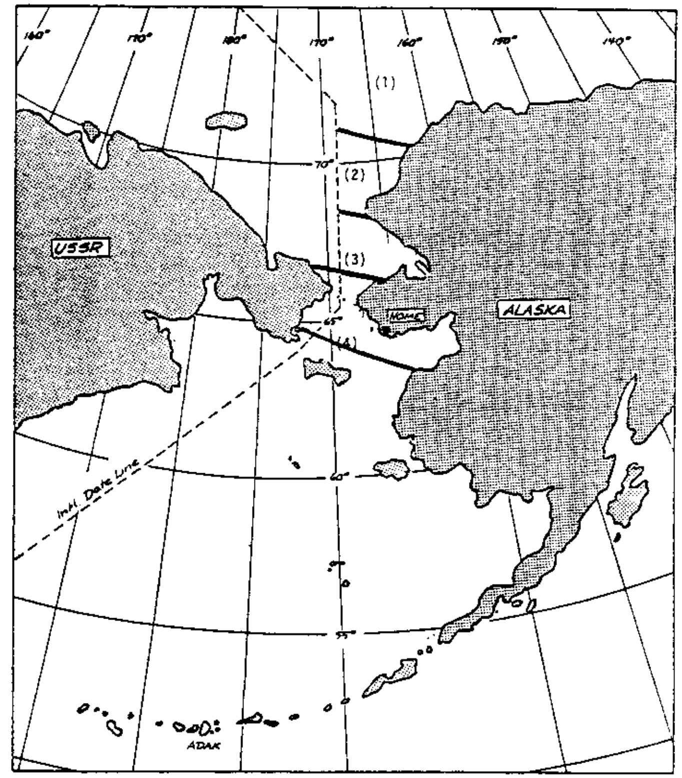
MAXIMUM ICE CONDITIONS, APRIL

ICE AREA	ICE CHARACTERISTICS
1	FY 6.5; MY 11; IS
2	FY 6; MY 10
3	FY 5; MY 10
4	FY 4
5	FY 3
6	FY 2
7	BI 2



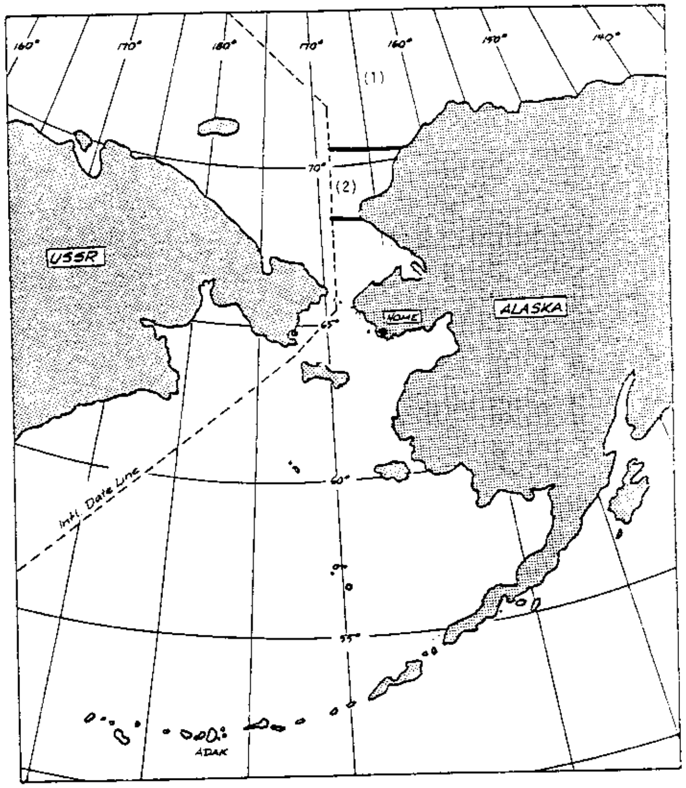
MAXIMUM ICE CONDITIONS, MAY

ICE AREA	ICE CHARACTERISTICS
1	FY 7; MY 11.5; IS
2	FY 6; MY 10
3	FY 5; MY 10
4	FY 4
5	FY 3
6	FY 2
7	BI 2



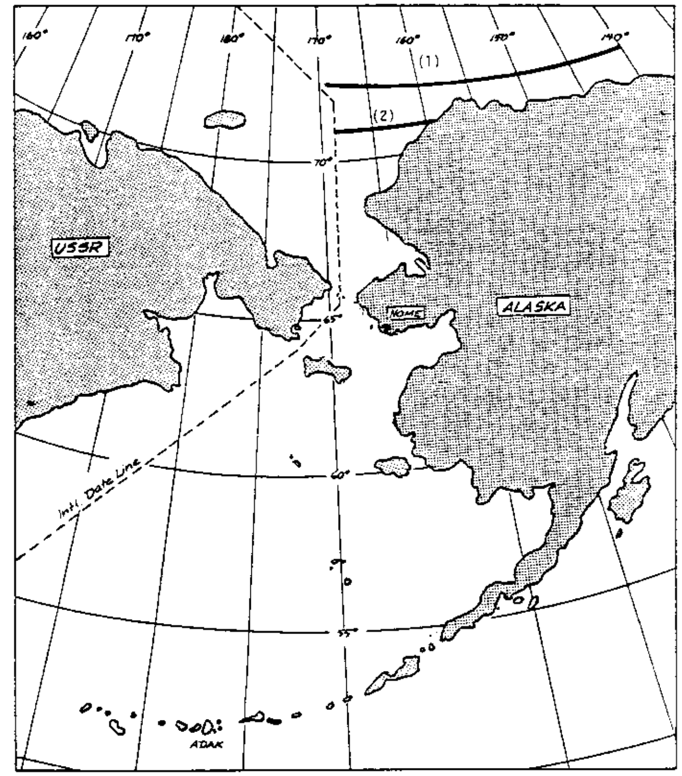
MAXIMUM ICE CONDITIONS, JUNE

ICE AREA	ICE CHARACTERISTICS
1	FY 7; MY 11.5; IS
2	FY 6; MY 10
3	FY 4; MY 6
4	FY 3; BI 2



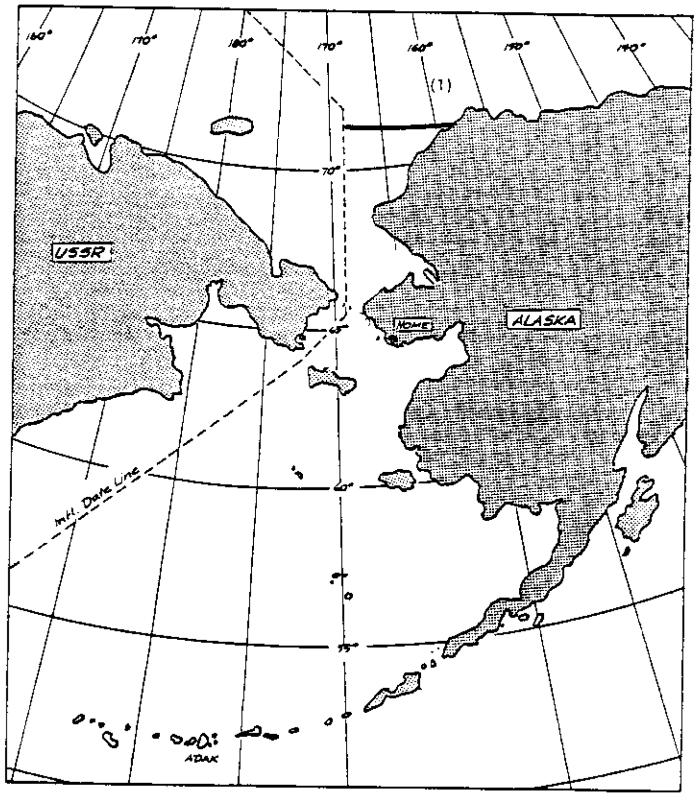
MAXIMUM ICE CONDITIONS, JULY

ICE AREA	ICE CHARACTERISTICS
1	FY 5.5; MY 10; IS
2	MY 8; BI 4



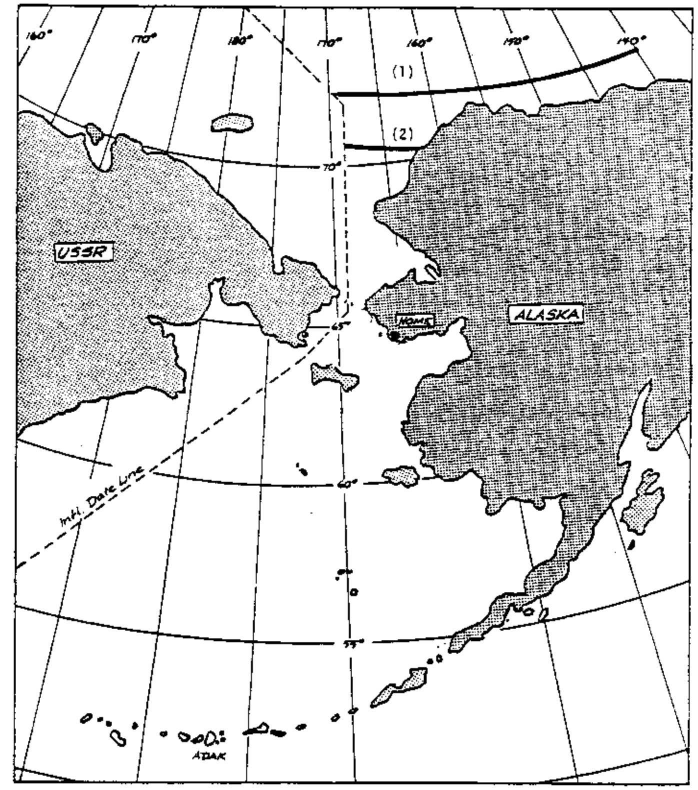
MAXIMUM ICE CONDITIONS, AUGUST

ICE AREA	ICE CHARACTERISTICS
1	FY 4.5; MY 8; IS
2	BI 4



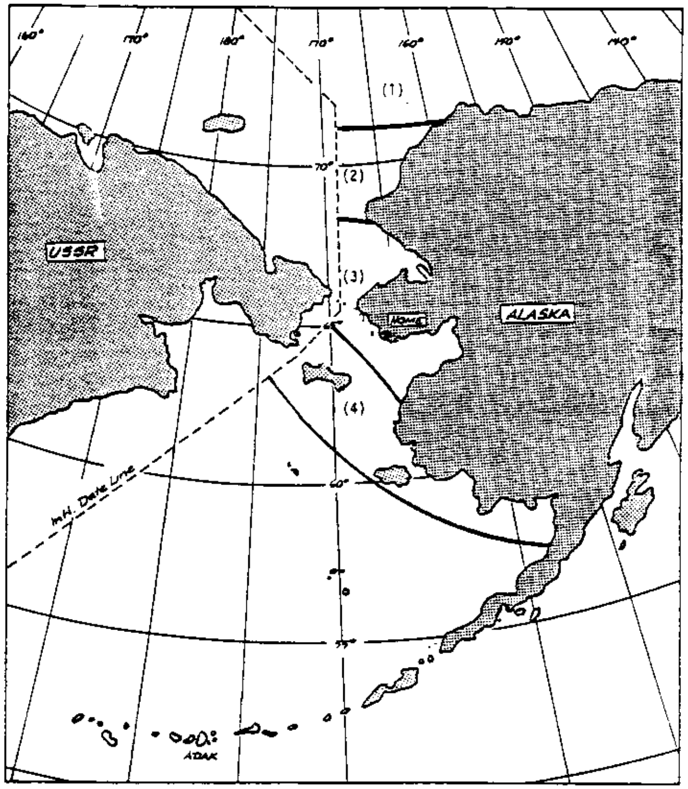
MAXIMUM ICE CONDITIONS, SEPTEMBER

ICE AREA	ICE CHARACTERISTICS
1	MY 6; BI 6; IS



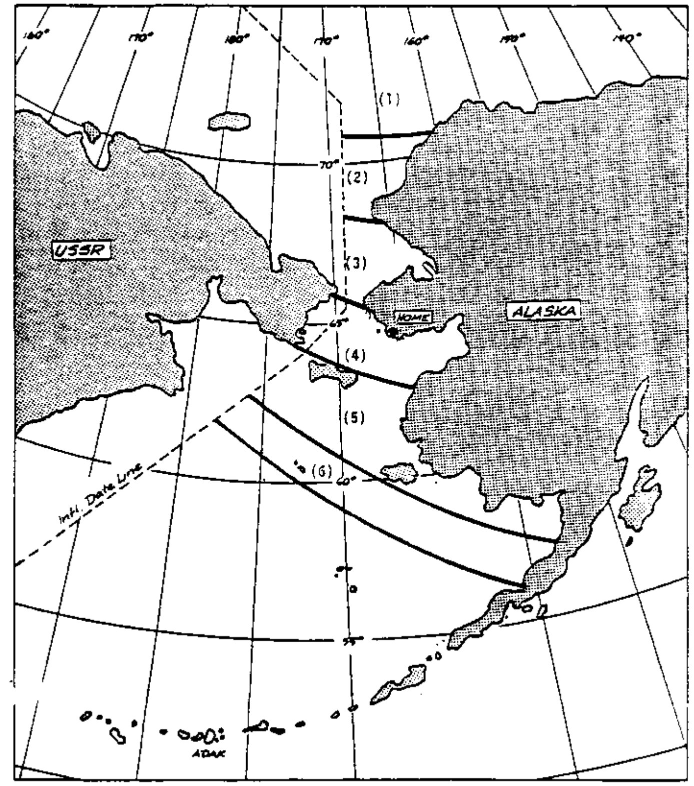
MAXIMUM ICE CONDITIONS, OCTOBER

ICE AREA	ICE CHARACTERISTICS
1	FY 1; MY 6; IS
2	BI 1
3	FY 0.5



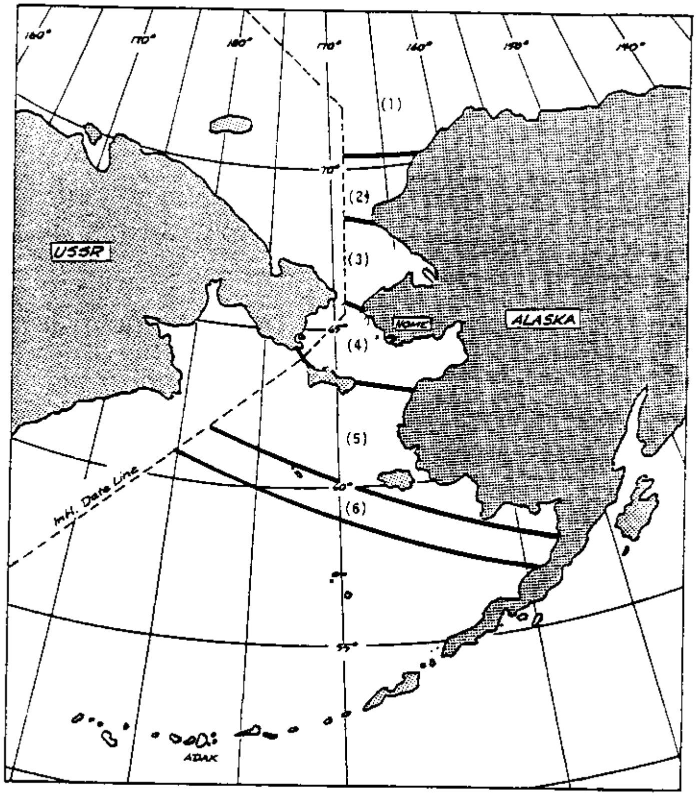
MAXIMUM ICE CONDITIONS, NOVEMBER

ICE AREA	ICE CHARACTERISTICS
1	FY 2; MY 7; IS
2	FY 2; MY 7
3	FY 1
4	BI 1



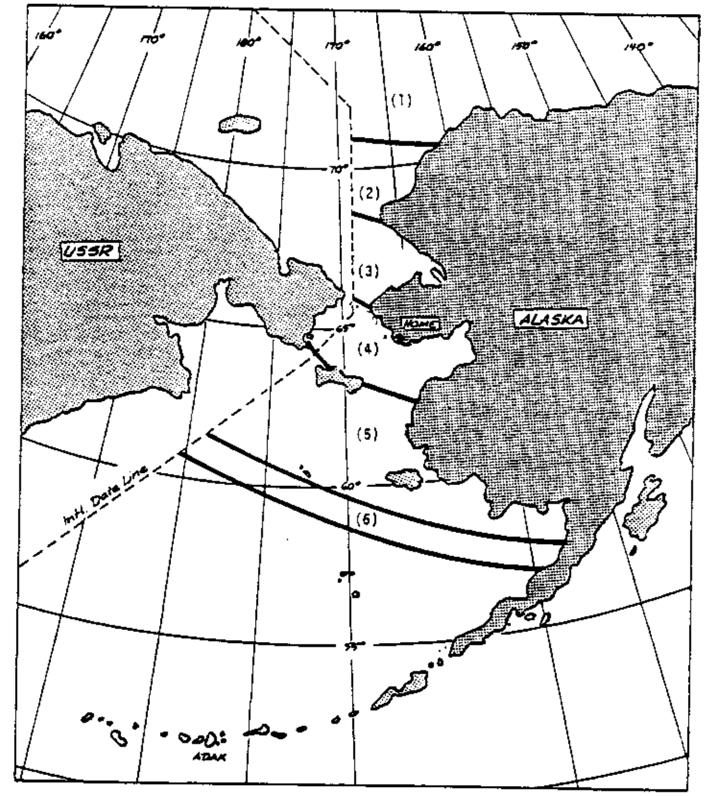
MAXIMUM ICE CONDITIONS, DECEMBER

ICE AREA	ICE CHARACTERISTICS
1	FY 3; MY 8; IS
2	FY 3; MY 8
3	FY 2.5
4	FY 2
5	FY 1
6	BI 1



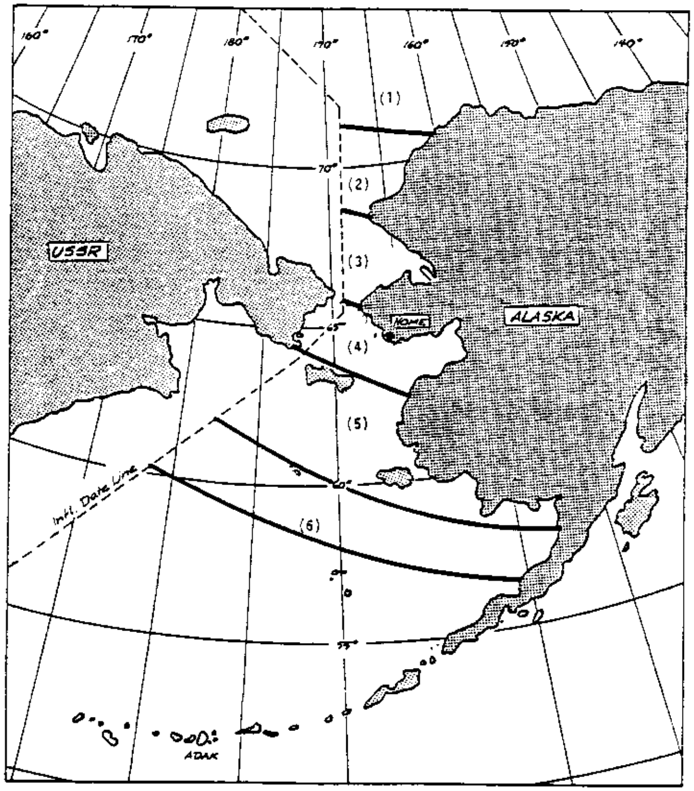
AVERAGE ICE CONDITIONS, JANUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 3.5; MY 8.5; IS
2	FY 3.0; MY 8.5
3	FY 2.5
4	FY 1.75
5	FY 1.25
6	BI 1



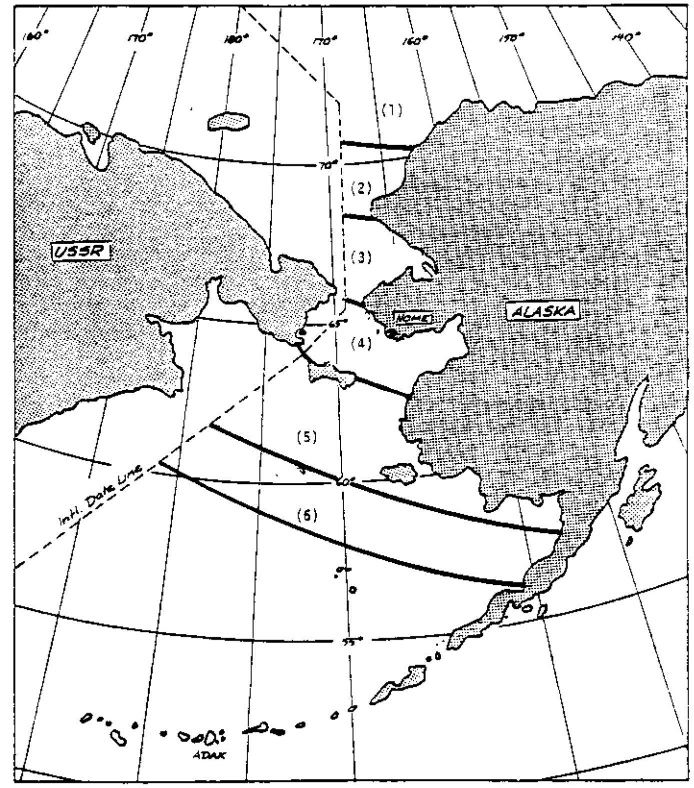
AVERAGE ICE CONDITIONS, FEBRUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 4; MY 9; IS
2	FY 3.5; MY 9
3	FY 3.25
4	FY 2.75
5	FY 2.25
6	BI 1



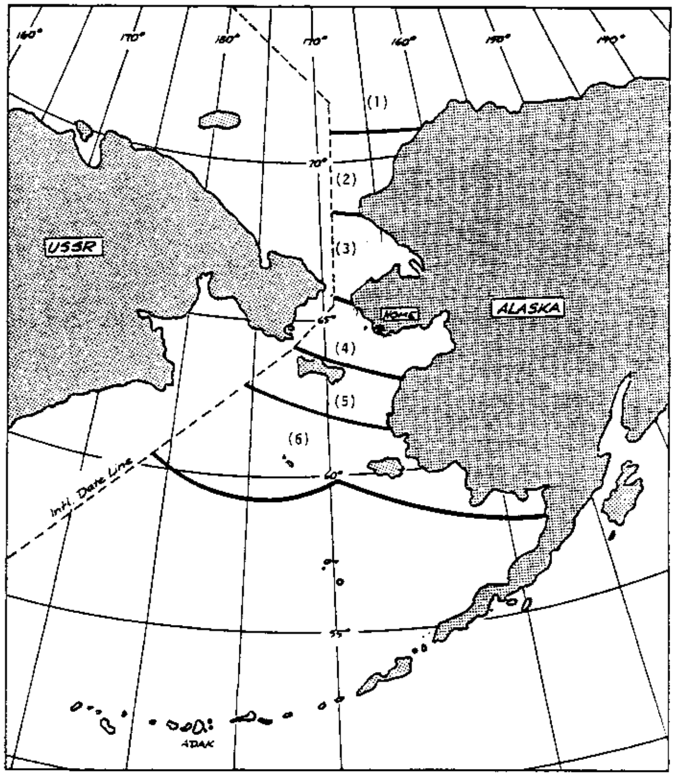
AVERAGE ICE CONDITIONS, MARCH

ICE AREA	ICE CHARACTERISTICS
1	FY 4.5; MY 10; IS
2	FY 4.5; MY 10
3	FY 4
4	FY 3.25
5	FY 2.5
6	BI 1.5



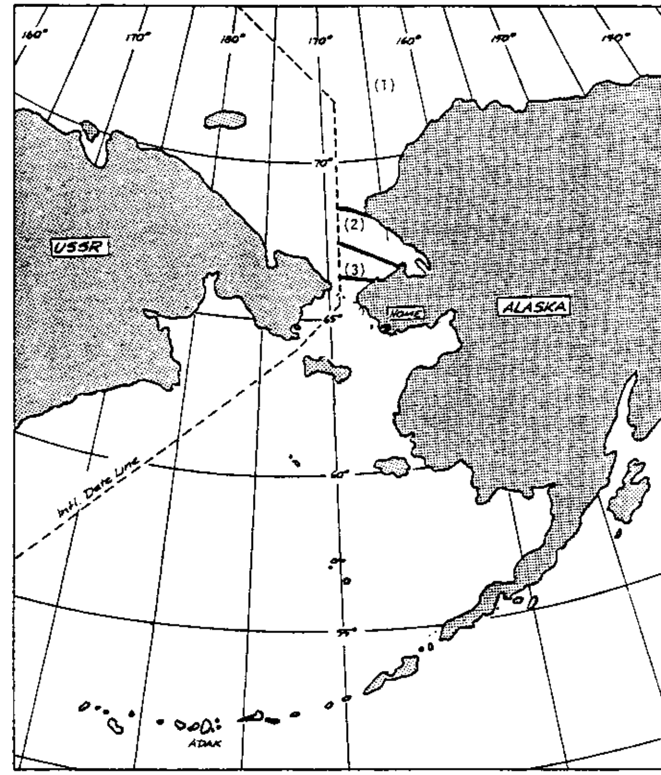
AVERAGE ICE CONDITIONS, APRIL

ICE AREA	ICE CHARACTERISTICS
1	FY 5; MY 10; IS
2	FY 5; MY 10
3	FY 4.5
4	FY 3.25
5	FY 2.5
6	BI 1.5



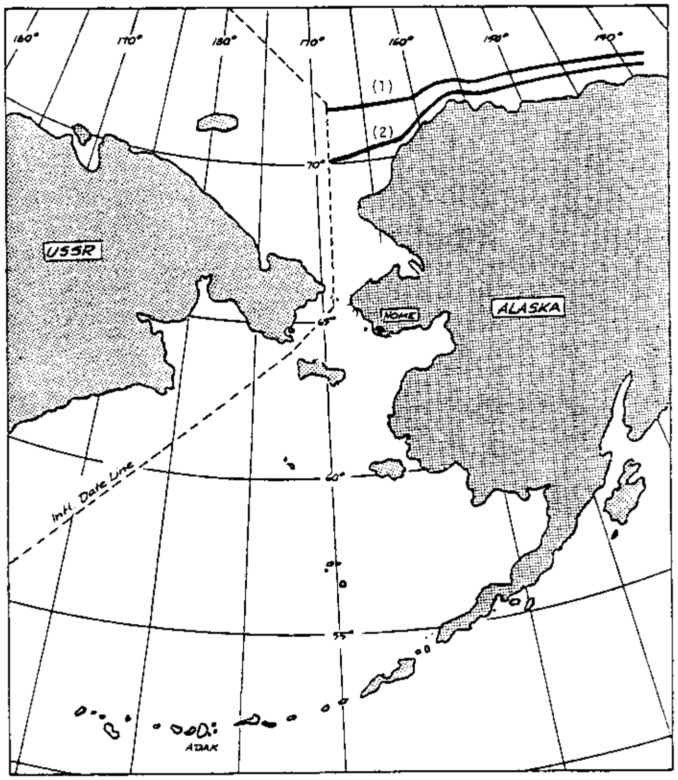
AVERAGE ICE CONDITIONS, MAY

ICE AREA	ICE CHARACTERISTICS
1	FY 5.5; MY 10.5; IS
2	FY 5.5; MY 10.5
3	FY 4.5
4	FY 3.0
5	FY 2.5
6	BI 1.5



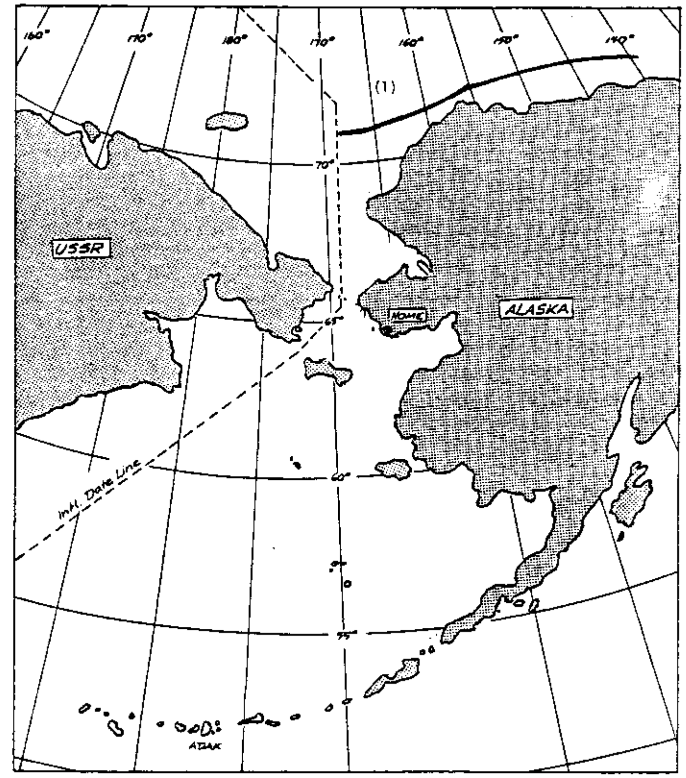
AVERAGE ICE CONDITIONS, JUNE

ICE AREA	ICE CHARACTERISTICS
1	FY 5.5; MY 8.5, IS
2	FY 4.5
3	BI 3.0



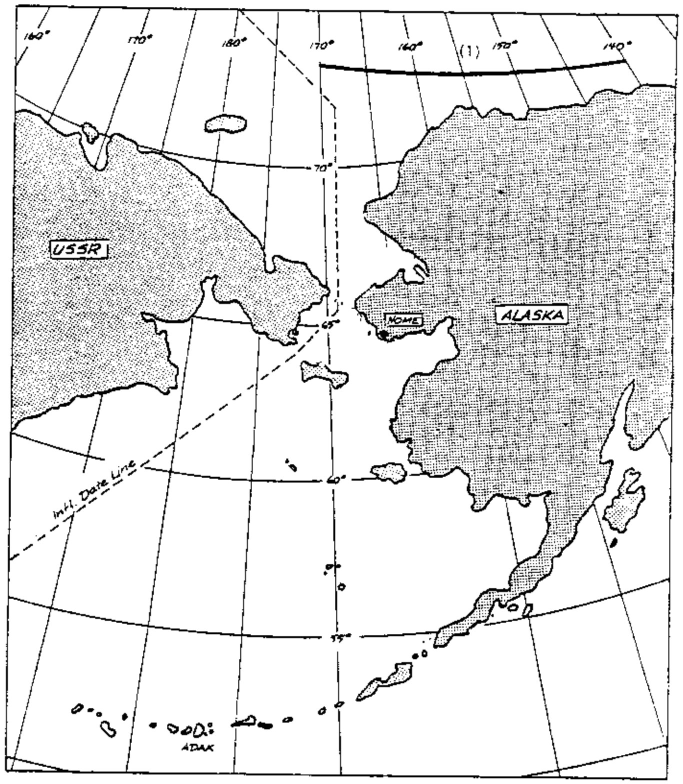
AVERAGE ICE CONDITIONS, JULY

ICE AREA	ICE CHARACTERISTICS
1	FY 4.5; MY 6.5; IS
2	BI 3.0



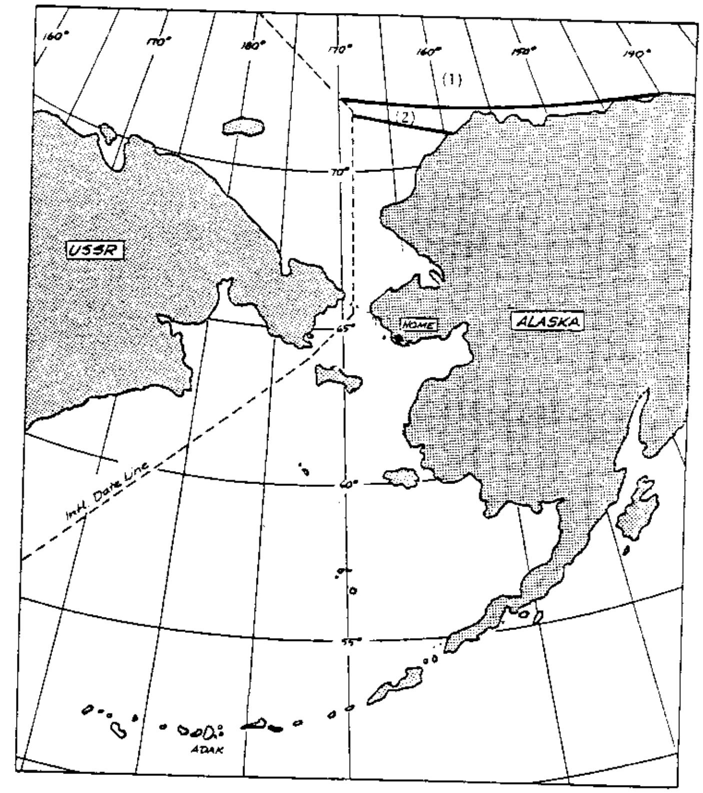
AVERAGE ICE CONDITIONS, AUGUST

ICE AREA	ICE CHARACTERISTICS
1	FY 3; MY 7; IS



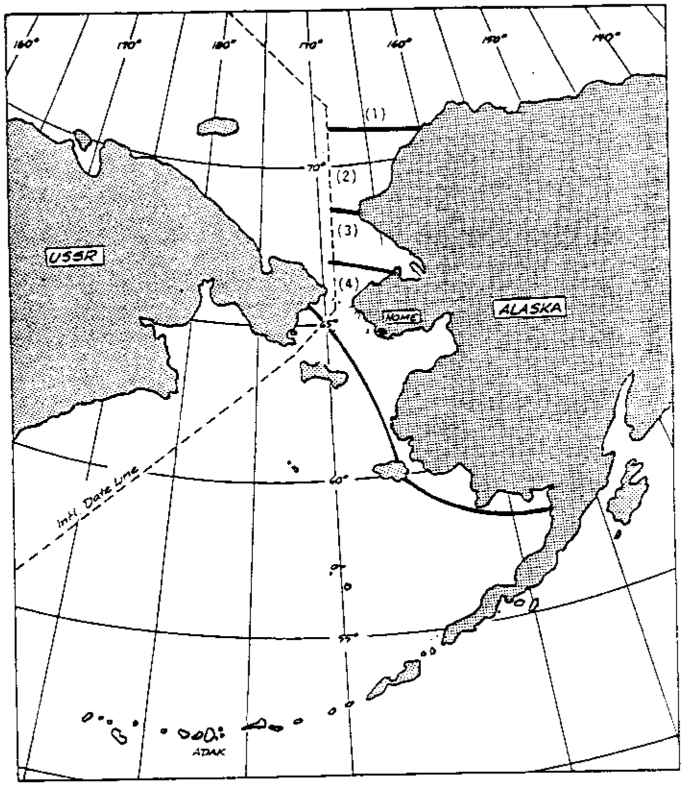
AVERAGE ICE CONDITIONS, SEPTEMBER

ICE AREA	ICE CHARACTERISTICS
1	MY 6; BI 6; IS



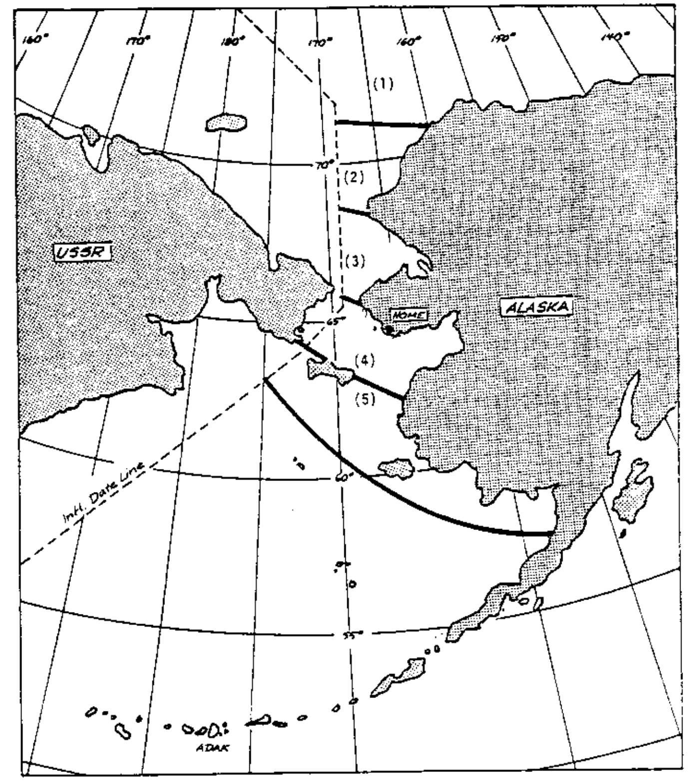
AVERAGE ICE CONDITIONS, OCTOBER

ICE AREA	ICE CHARACTERISTICS
1	FY 1; M 6; IS
2	BI 1



AVERAGE ICE CONDITIONS, NOVEMBER

ICE AREA	ICE CHARACTERISTICS
1	FY 1.5; MY 7; IS
2	FY 1.5; MY 7
3	FY 0.75
4	BI 1

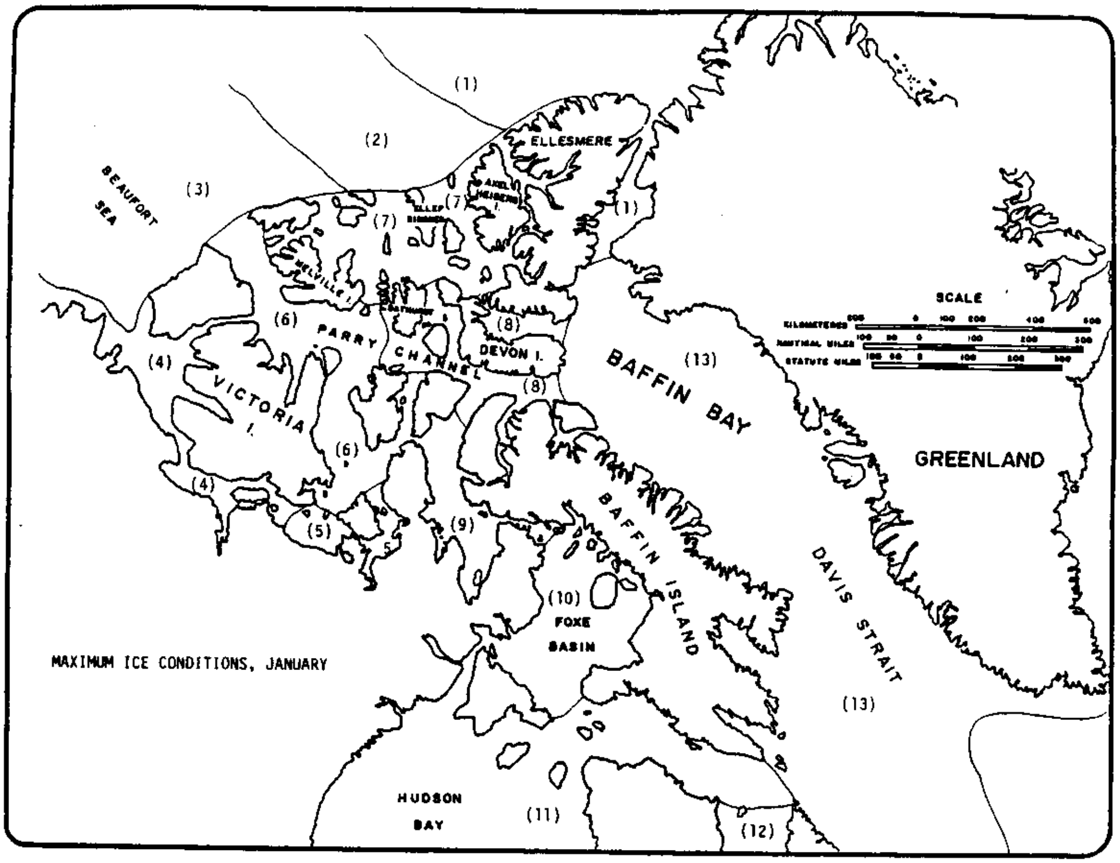


AVERAGE ICE CONDITIONS, DECEMBER

ICE AREA	ICE CHARACTERISTICS
1	FY 2.5; MY 7; IS
2	FY 2.5; MY 7
3	FY 2.0
4	FY 1.25
5	BI 1

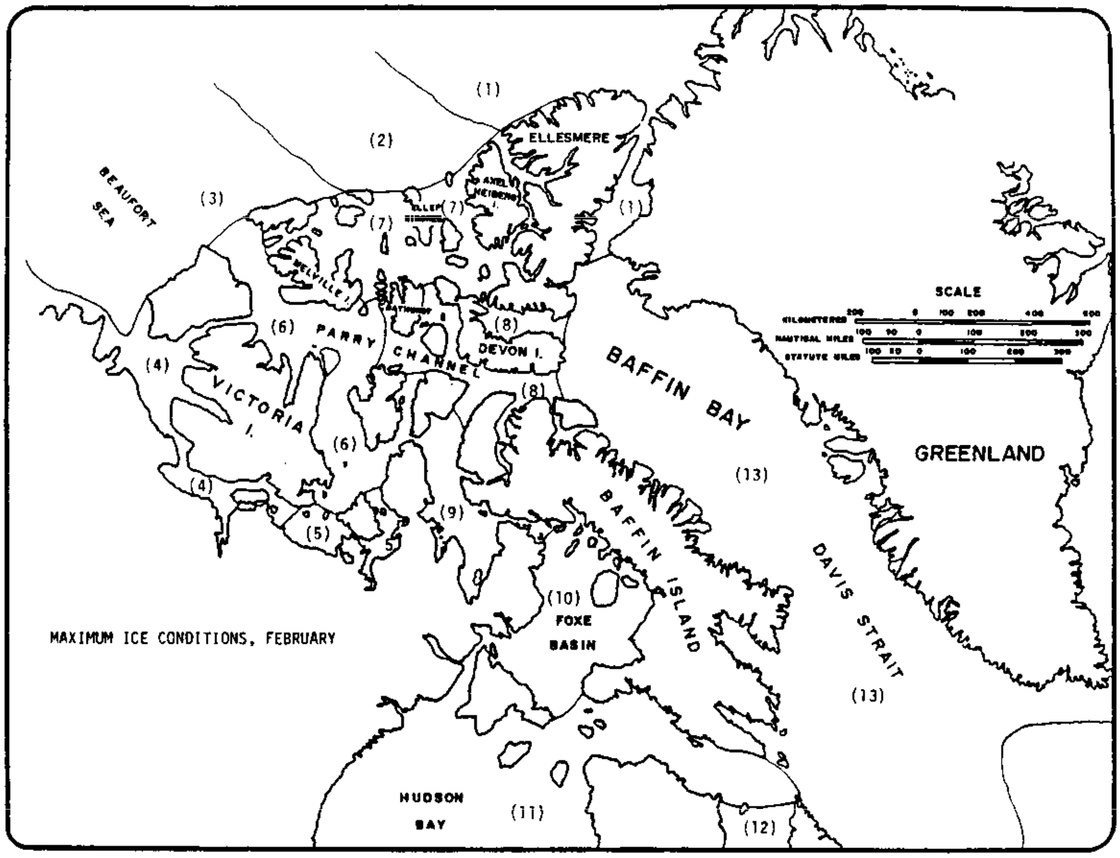
APPENDIX A.2

CANADA - MAXIMUM AND AVERAGE ICE CONDITIONS BY MONTH

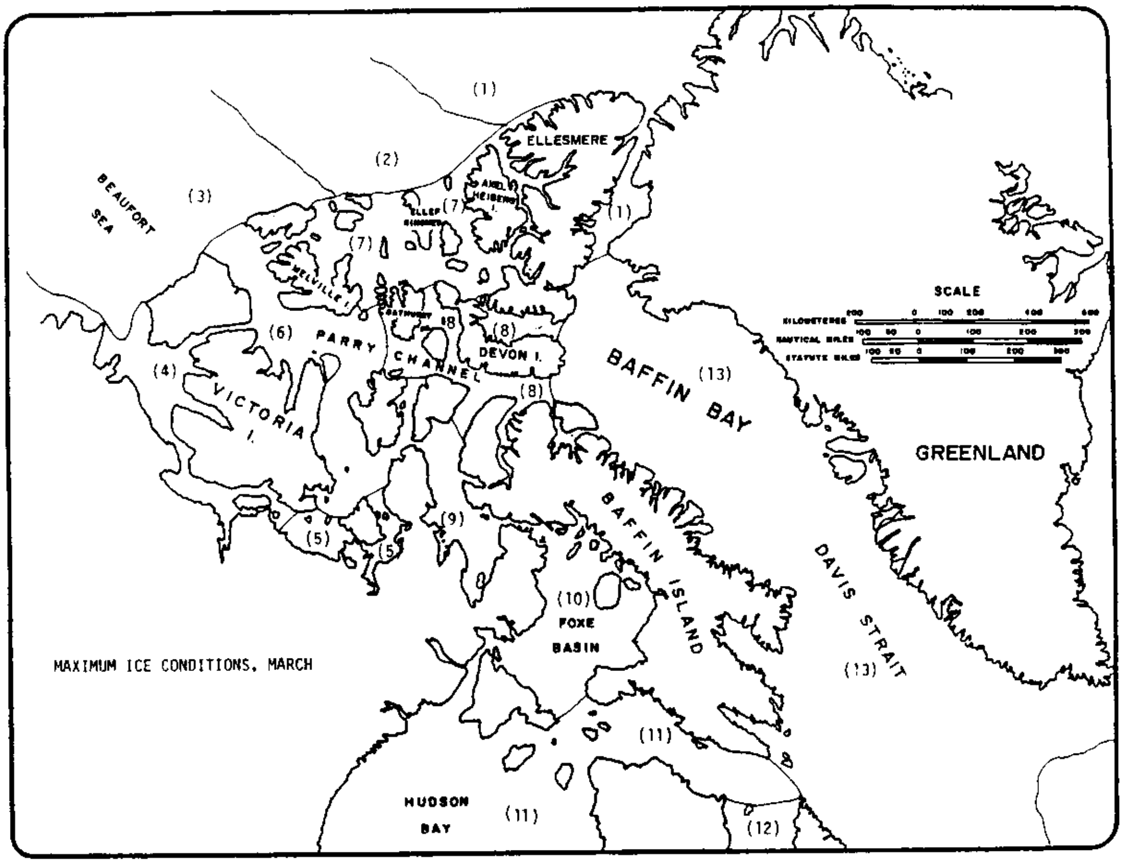


MAXIMUM ICE CONDITIONS, JANUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 5.1-60; MY 20-110; ice islands, icebergs
2	FY 5.1-60; MY 20-100; ice islands
3	FY 5.1-40; MY 20-90; ice islands
4	FY 4.9-40; MY 10-40
5	FY 5.2-40
6	FY 4.8-40; MY 18-40; ice islands
7	FY 5.2-30; MY 18-40; ice islands
8	FY 4.5-40; icebergs, ice islands
9	FY 5.3-40; MY 18-40
10	FY 5.5-40; MY 12-40
11	FY 4.0-30; icebergs
12	FY 4.2-25; icebergs
13	BI 3.9-4.0; icebergs

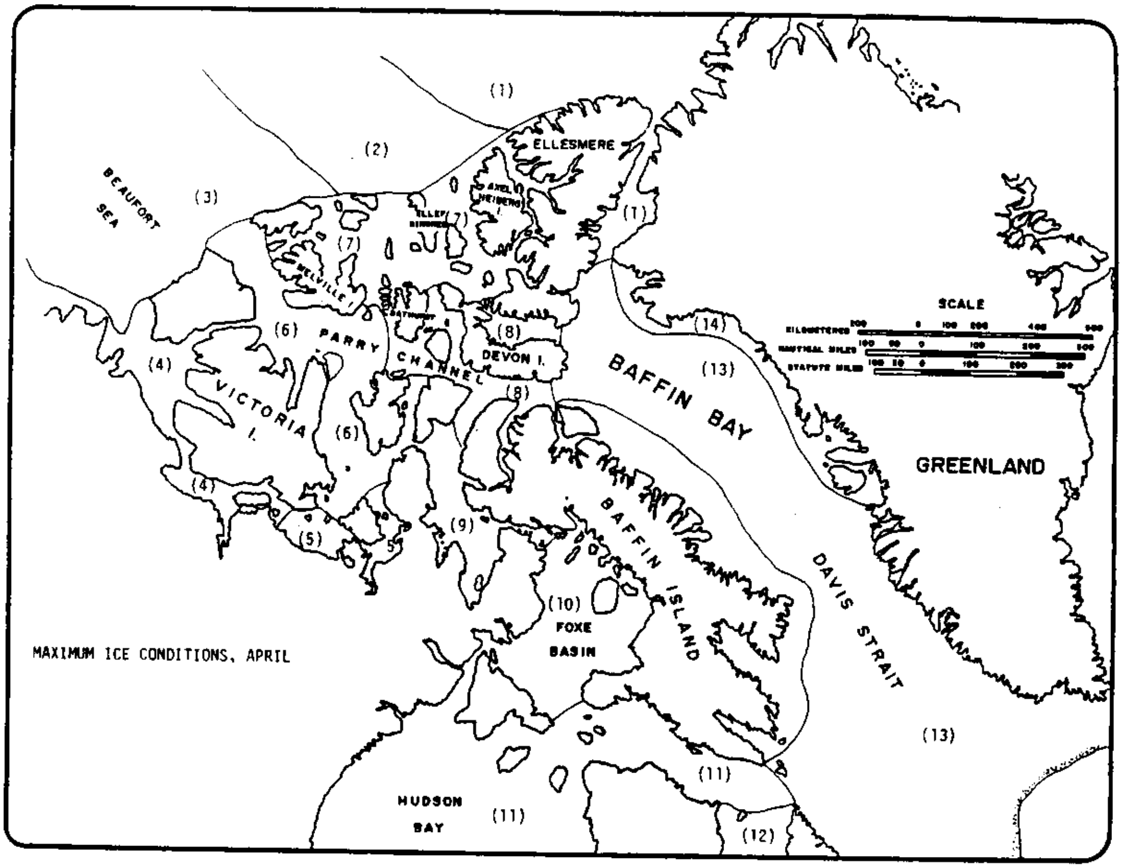


ICE AREA	ICE CHARACTERISTICS
1	FY 5.7-60; MY 20-110; ice islands, icebergs
2	FY 6.5-60; MY 20-100; ice islands
3	FY 6.2-40; MY 20-90; ice islands
4	FY 5.4-40; MY 18-40
5	FY 6.1-40
6	FY 5.6-40; MY 18-40; ice islands
7	FY 5.4-30; MY 18-40; ice islands
8	FY 5.4-40; icebergs, ice islands
9	FY 5.1-40; MY 18-40
10	FY 5.7-40; MY 12-40
11	FY 5.0-30; icebergs
12	FY 4.6-25; icebergs
13	BI 0.9-4.3; icebergs



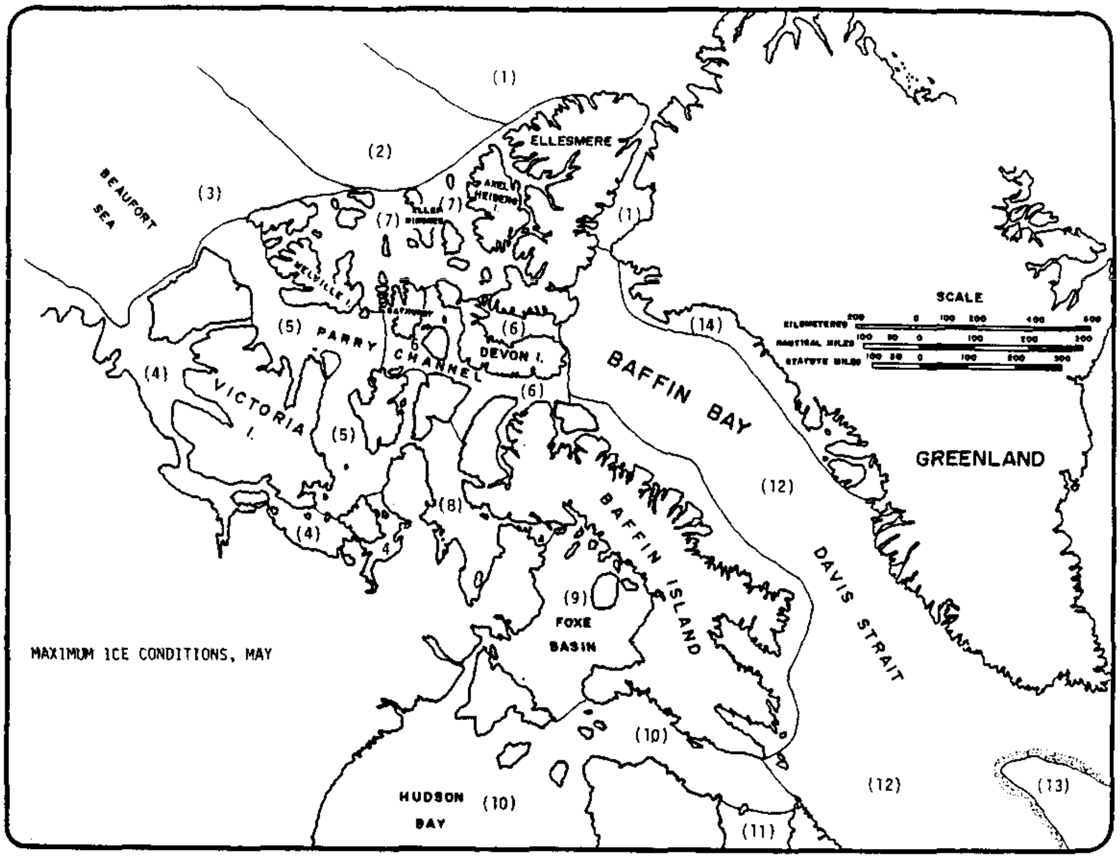
MAXIMUM ICE CONDITIONS, MARCH

ICE AREA	ICE CHARACTERISTICS
1	FY 6.7-60; MY 22-110; ice islands, icebergs
2	FY 7.7-60; MY 22-100; ice islands
3	FY 6.2-40; MY 22-90; ice islands
4	FY 6.0-40; MY 19-40
5	FY 5.6-40
6	FY 5.8-40; MY 19-40; ice islands
7	FY 7.3-30; MY 19-40; ice islands
8	FY 5.2-40; icebergs, ice islands
9	FY 7.0-40; MY 19-40
10	FY 6.5-40; MY 13-40
11	FY 5.4-30; icebergs
12	FY 5.1-25; icebergs
13	BI 0.3-5.5; icebergs



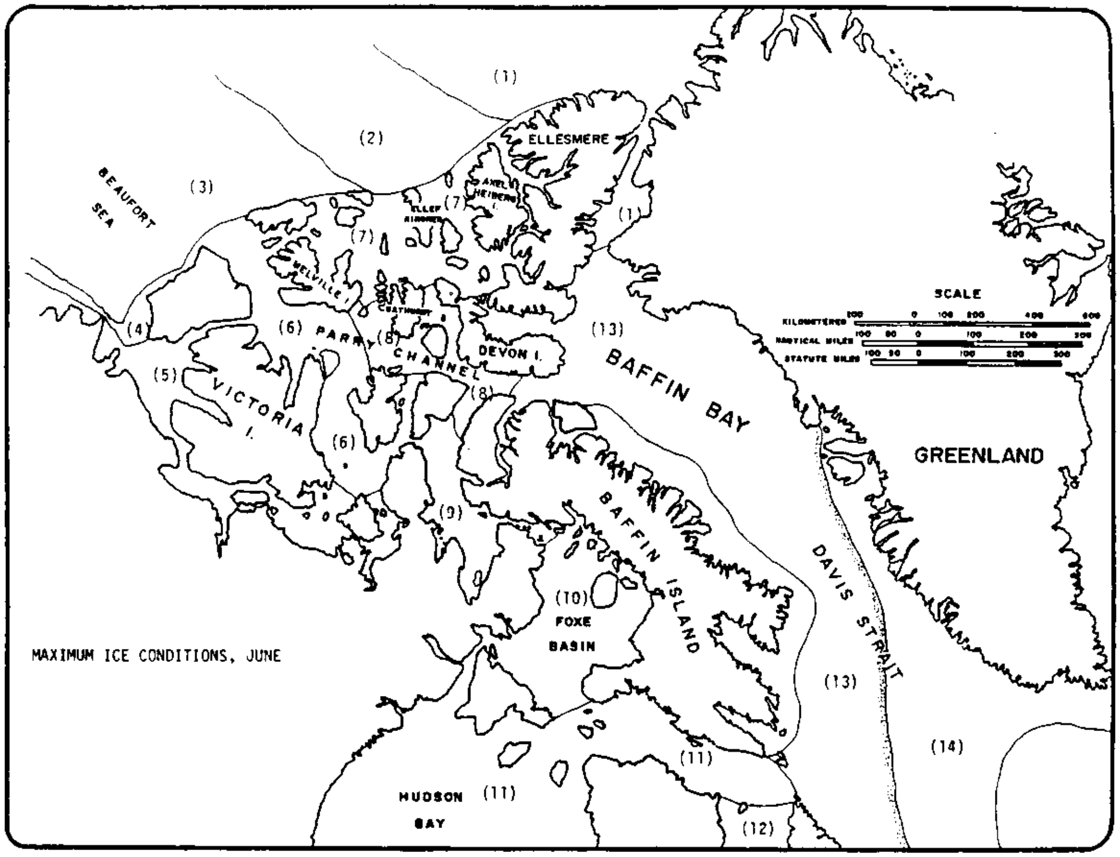
MAXIMUM ICE CONDITIONS, APRIL

ICE AREA	ICE CHARACTERISTICS
1	FY 7.0-60; MY 22-110; ice islands, icebergs
2	FY 8.0-60; MY 22-100; ice islands
3	FY 6.8-40; MY 22-90; ice islands
4	FY 7.2-40; MY 19-40
5	FY 7.3-40
6	FY 6.9-40; MY 19-40; ice islands
7	FY 7.9-30; MY 19-40; ice islands
8	FY 6.7-40; icebergs, ice islands
9	FY 7.4-40; MY 19-40
10	FY 8.1-40; MY 13-40
11	FY 5.8-30; icebergs
12	FY 5.6-25; icebergs
13	BI 0.9-5.8; icebergs
14	FY 6.0-40; icebergs



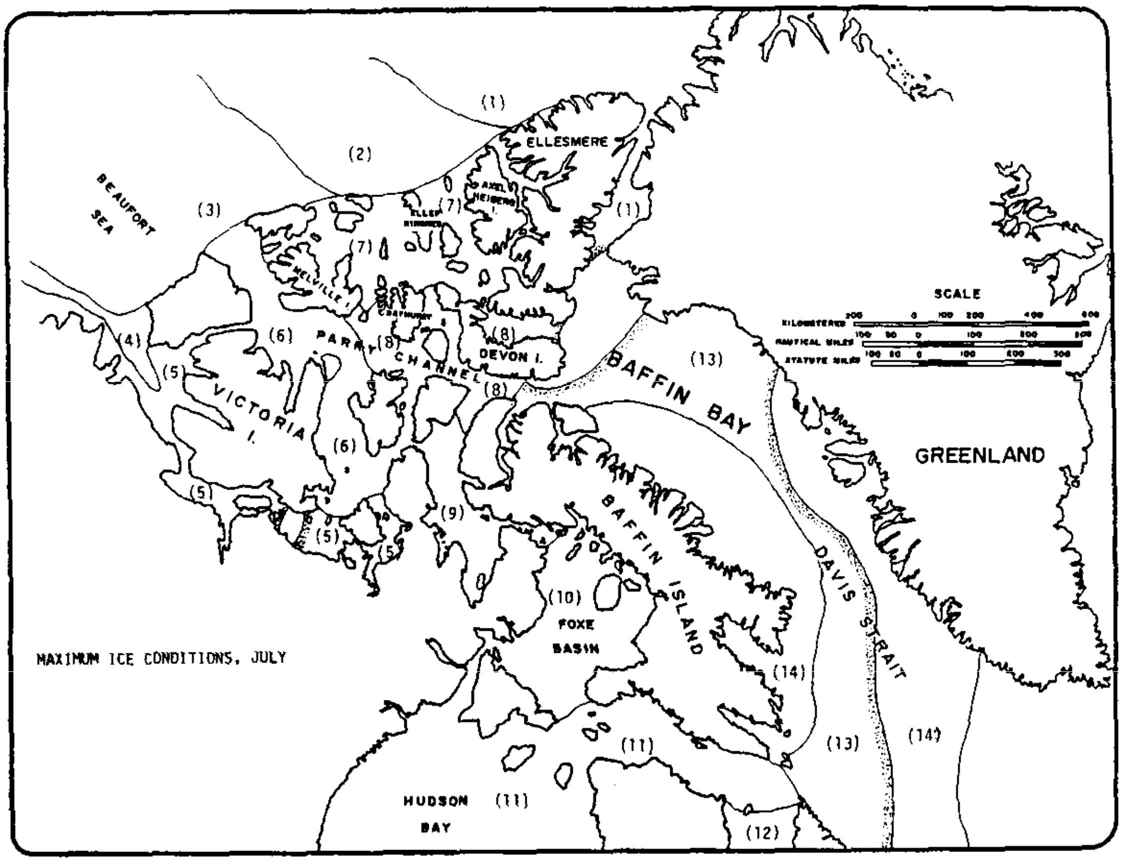
MAXIMUM ICE CONDITIONS, MAY

ICE AREA	ICE CHARACTERISTICS
1	FY 8.3-60; MY 22-110; ice islands, icebergs
2	FY 8.3-60; MY 22-100; ice islands
3	FY 7.5-40; MY 22-90; ice islands
4	FY 7.1-40; MY 19-40
5	FY 7.1-40; MY 19-40
6	FY 6.6-40; icebergs, ice islands
7	FY 8.5-30; MY 19-40; ice islands
8	FY 7.5-40; MY 19-40
9	FY 8.2-40; MY 13-40
10	FY 6.2-30; icebergs
11	FY 5.5-25; icebergs
12	9I 0.9-5.0; icebergs
13	Icebergs
14	FY 5.5-40; icebergs



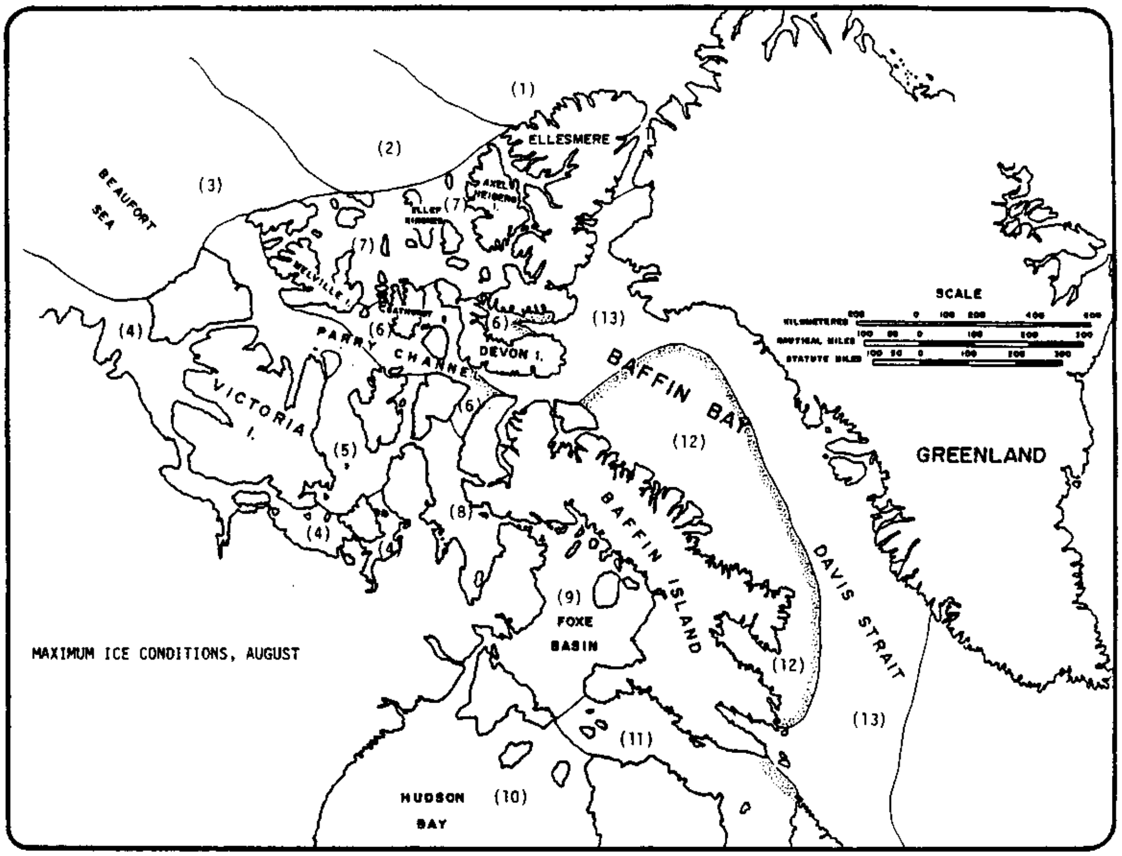
MAXIMUM ICE CONDITIONS, JUNE

ICE AREA	ICE CHARACTERISTICS
1	FY 7.7-60; MY 22-110; ice islands, icebergs
2	FY 8.2-60; MY 22-100; ice islands
3	FY 7.5-40; MY 22-90; ice islands
4	BI 0.9-6.5
5	FY 7.0-40; MY 19-40
6	FY 7.5-40; MY 19-40; icebergs, ice islands
7	FY 8.0-30; MY 19-40; ice islands
8	FY 7.2-40; ice islands
9	FY 6.2-40; MY 19-40
10	FY 7.5-40; MY 19-40
11	FY 6.0-30; icebergs
12	FY 5.4-25; icebergs
13	BI 0.3-5.0; icebergs
14	Icebergs



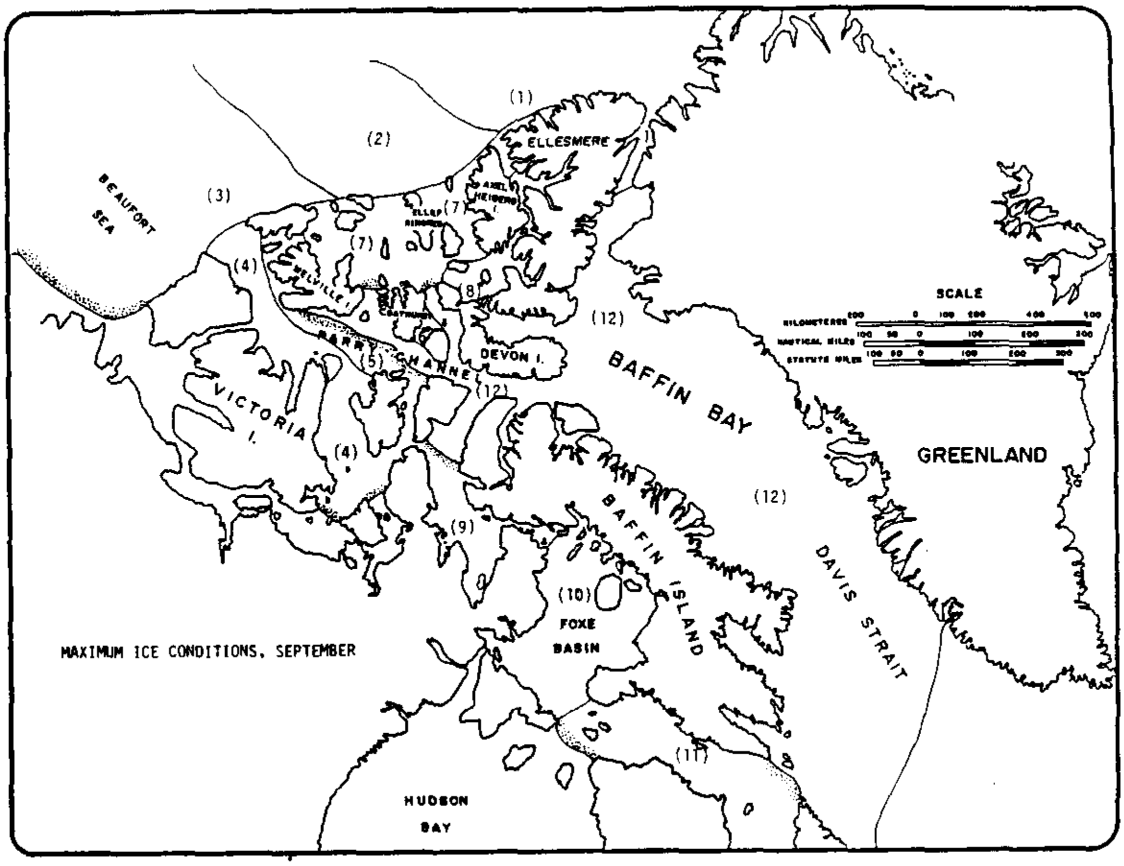
MAXIMUM ICE CONDITIONS, JULY

ICE AREA	ICE CHARACTERISTICS
1	FY 6.0-60; MY 22-110; ice islands, icebergs
2	FY 7.5-60; MY 22-100; ice islands
3	FY 6.8-40; MY 22-90; ice islands
4	SI 0.8-4.8
5	FY 3.8-30; MY 19-40
6	FY 5.0-30; MY 19-40; icebergs, ice islands
7	FY 7.2-30; MY 19-40; ice islands
8	FY 3.3-30; ice islands
9	FY 4.2-30; MY 19-40
10	FY 5.0-30; MY 19-40
11	SI 0.6-3.0; icebergs
12	SI 0.8-2.0; icebergs
13	SI 0.7-3.5; icebergs
14	SI 0.8-3.5; icebergs



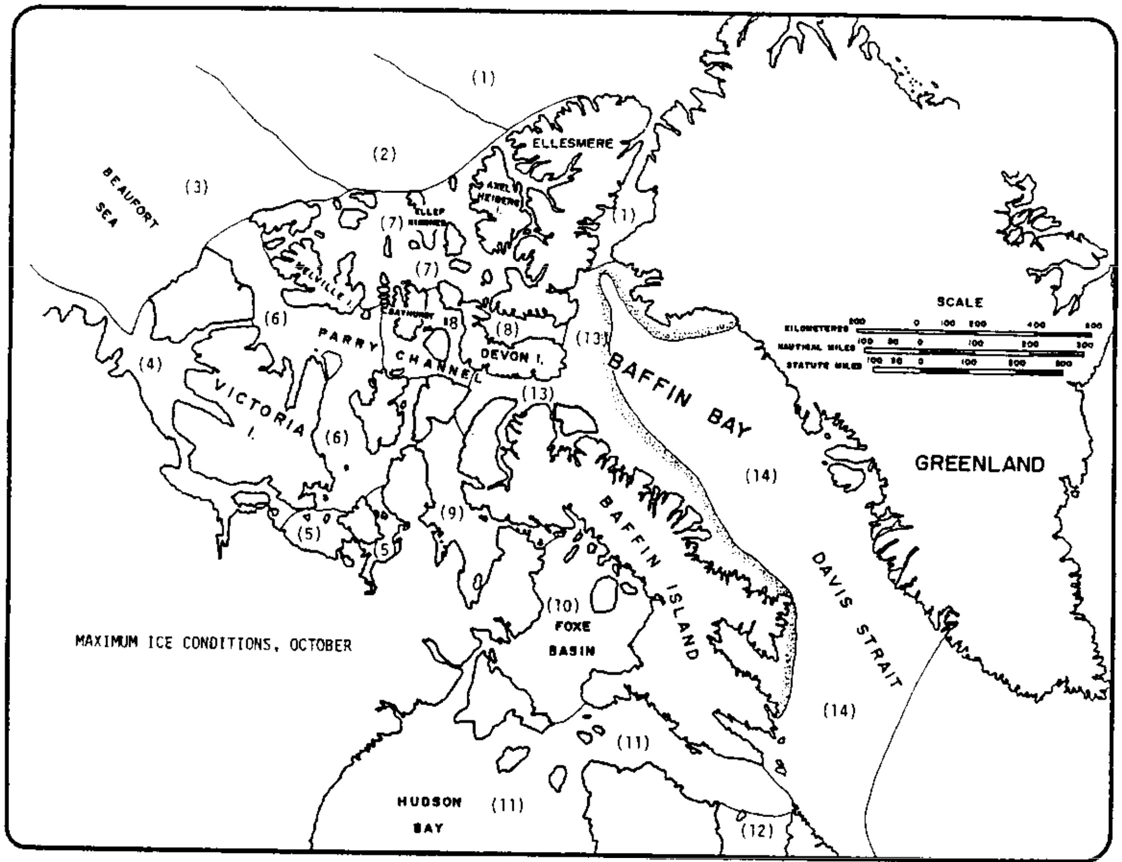
MAXIMUM ICE CONDITIONS, AUGUST

ICE AREA	ICE CHARACTERISTICS
1	FY 4.0-60; MY 20-110; ice islands, icebergs
2	FY 5.8-60; MY 20-100; ice islands
3	FY 5.5-40; MY 20-90; ice islands
4	BI 0.6-2.6; icebergs
5	BI 0.9-5.0; icebergs, ice islands
6	BI 0.7-2.0; icegargs, ice islands
7	FY 4.5-30; MY 17-40; ice islands
8	FY 2.0-20; MY 17-40
9	FY 2.5-20; MY 17-40
10	BI 0.5-1.5; icebergs
11	BI 0.7-1.8; icebergs
12	BI 0.7-2.0; icebergs
13	icebergs

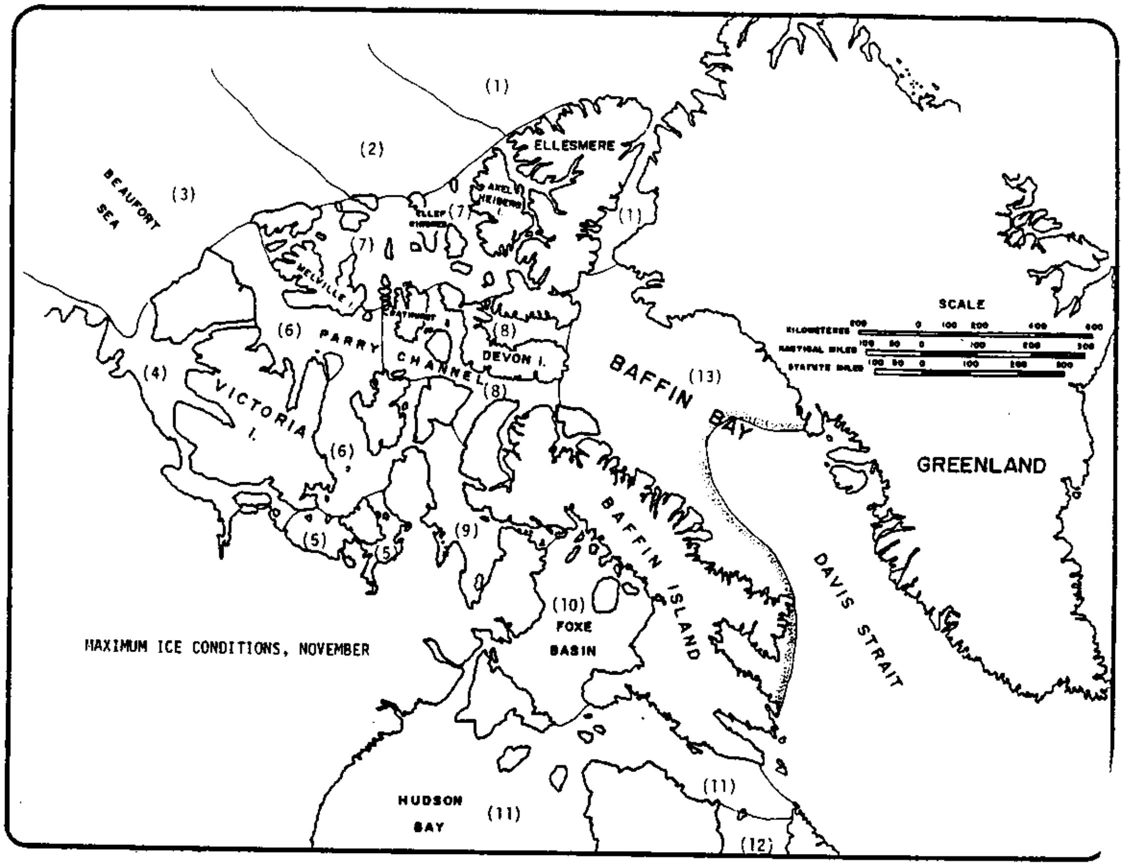


MAXIMUM ICE CONDITIONS, SEPTEMBER

ICE AREA	ICE CHARACTERISTICS
1	FY 1.0-60; MY 20-110; icebergs, ice islands
2	FY 1.1-60; MY 20-100; ice islands
3	FY 0.5-40; MY 20-90; ice islands
4	BI 0.7-5.0; ice islands
5	BI 0.5-4.0; icebergs
6	BI 0.4-2.0; icebergs
7	FY 0.8-30; MY 17-40; ice islands
8	BI 0.8-4.5; ice islands
9	FY 1.0-30; MY 17-40
10	BI 0.7-1.5; icebergs
11	BI 0.4-1.0; icebergs
12	Icebergs

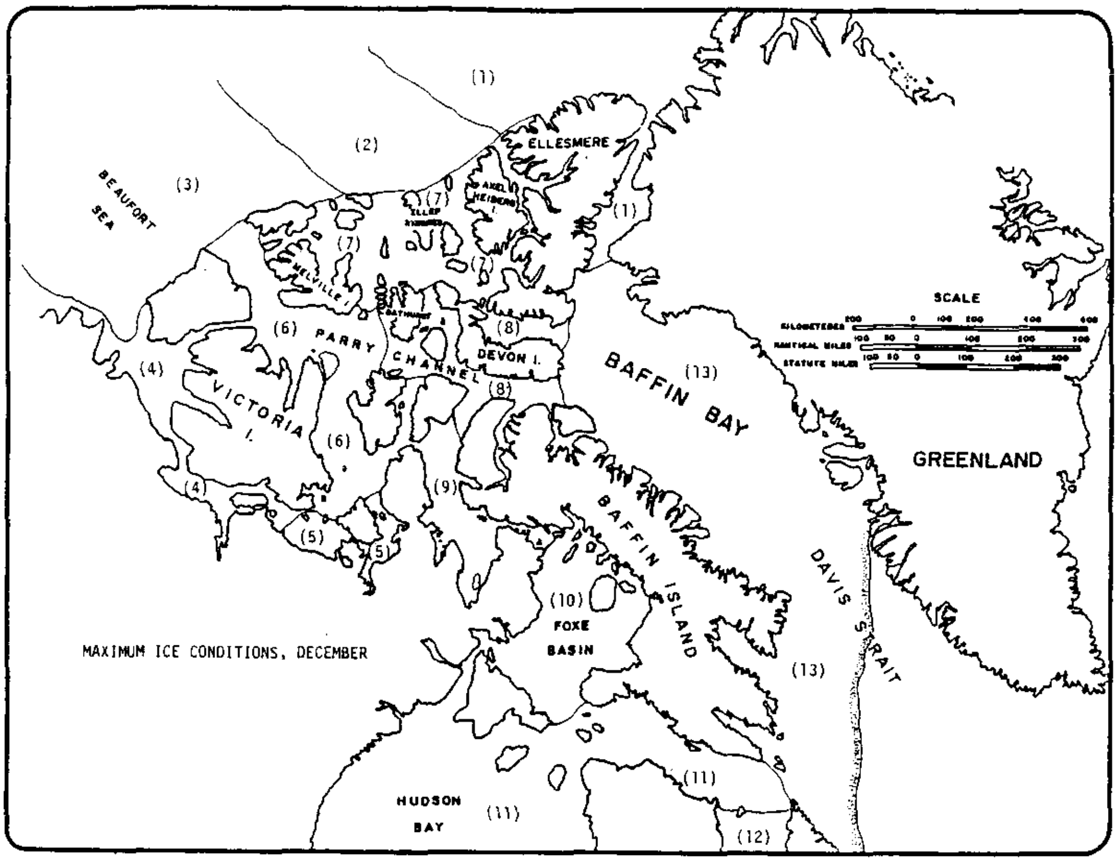


ICE AREA	ICE CHARACTERISTICS
1	FY 2.7-60; MY 18-110; ICE ISLANDS, ICEBERGS
2	FY 3.6-60; MY 18-100; ICE ISLANDS
3	FY 1.5-40; MY 18-90; ICE ISLANDS
4	FY 1.0-30; MY 16-40
5	FY 1.1-30
6	FY 1.3-30; MY 16-40; ICE ISLANDS
7	FY 2.0-30; MY 16-40; ICE ISLANDS
8	FY 1.2-40; MY 16-40
9	FY 1.2-30; MY 16-40
10	FY 0.8-30; ICEBERGS
11	FY 0.5-20; ICEBERGS
12	FY 0.8-20; ICEBERGS
13	BI 0.3-20; ICEBERGS
14	ICEBERGS

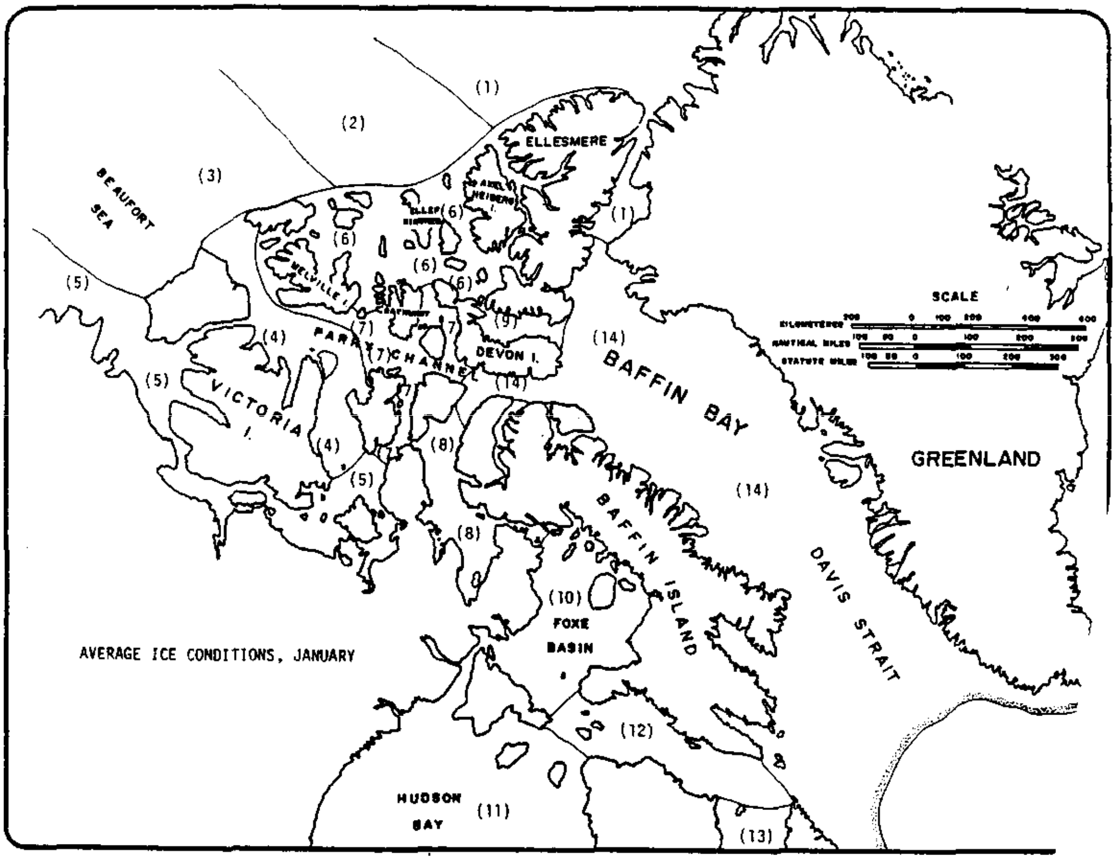


MAXIMUM ICE CONDITIONS, NOVEMBER

ICE AREA	ICE CHARACTERISTICS
1	FY3.7-60; MY 18-110; ICE ISLANDS, ICEBERGS
2	FY4.3-60; MY 18-100; ICE ISLANDS
3	FY2.7-40; MY 18-90; ICE ISLANDS
4	FY2.4-40;MY 16-40
5	FY3.0-40
6	FY2.7-40; MY 16-40; ICE ISLANDS
7	FY3.7-30; MY 16-40; ICE ISLANDS
8	FY2.7-40; ICEBERGS, ICE ISLANDS
9	FY2.6-40; MY 16-40
10	FY3.0-40; MY 10-40
11	FY1.5-30; ICEBERGS
12	FY1.5-25; ICEBERGS
13	BIO.9-1.4; ICEBERGS

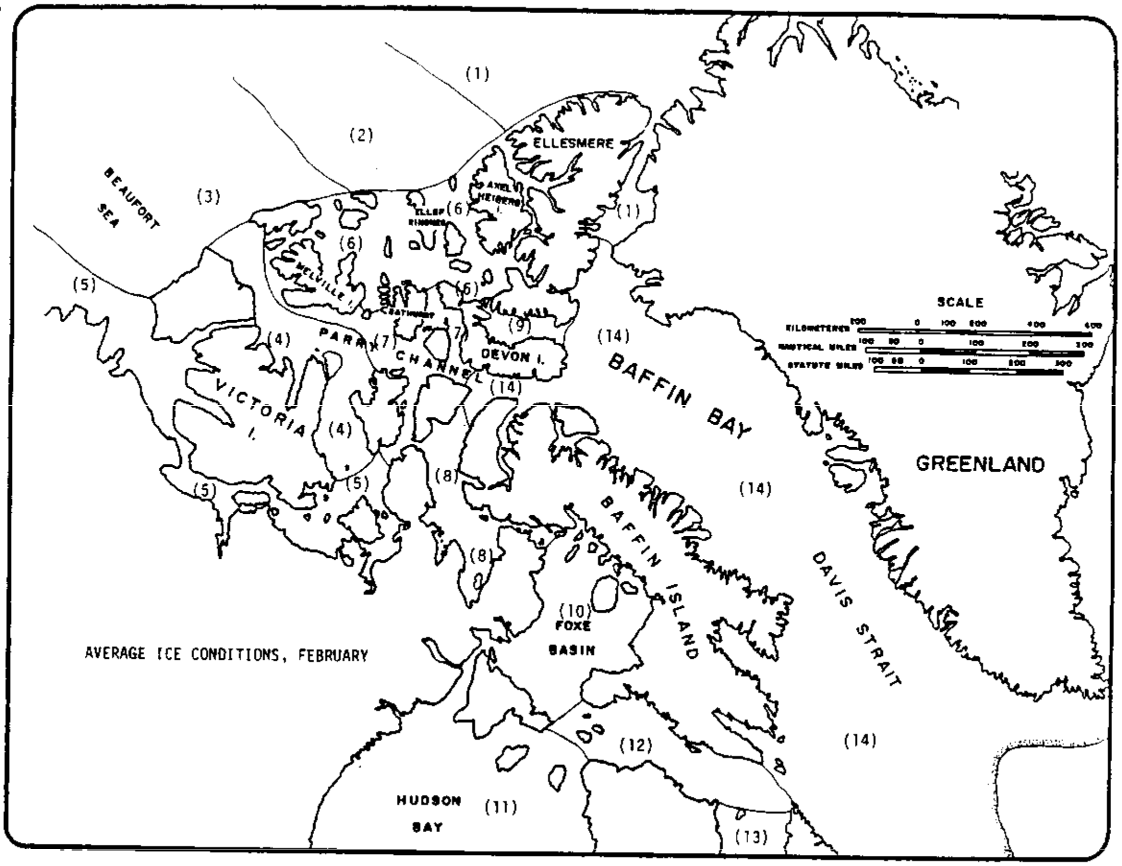


ICE AREA	ICE CHARACTERISTICS
1	FY 4.2-60; MY 20-110; ICE ISLANDS, ICEBERGS
2	FY 4.8-60; MY 20-100; ICE ISLANDS
3	FY 4.1-40; MY 20-90; ICE ISLANDS
4	FY 3.8-40; MY 18-40
5	FY 3.8-40
6	FY 3.8-40; MY 18-40; ICE ISLANDS
7	FY 4.3-30; MY 18-40; ICE ISLANDS
8	FY 3.6-40; ICEBERGS, ICE ISLANDS
9	FY 3.6-40; ICEBERGS, ICE ISLANDS
10	FY 4.0-40; MY 12-40
11	FY 2.5-30; ICEBERGS
12	FY 2.0-25; ICEBERGS
13	BI 0.9-2.8; ICEBERGS



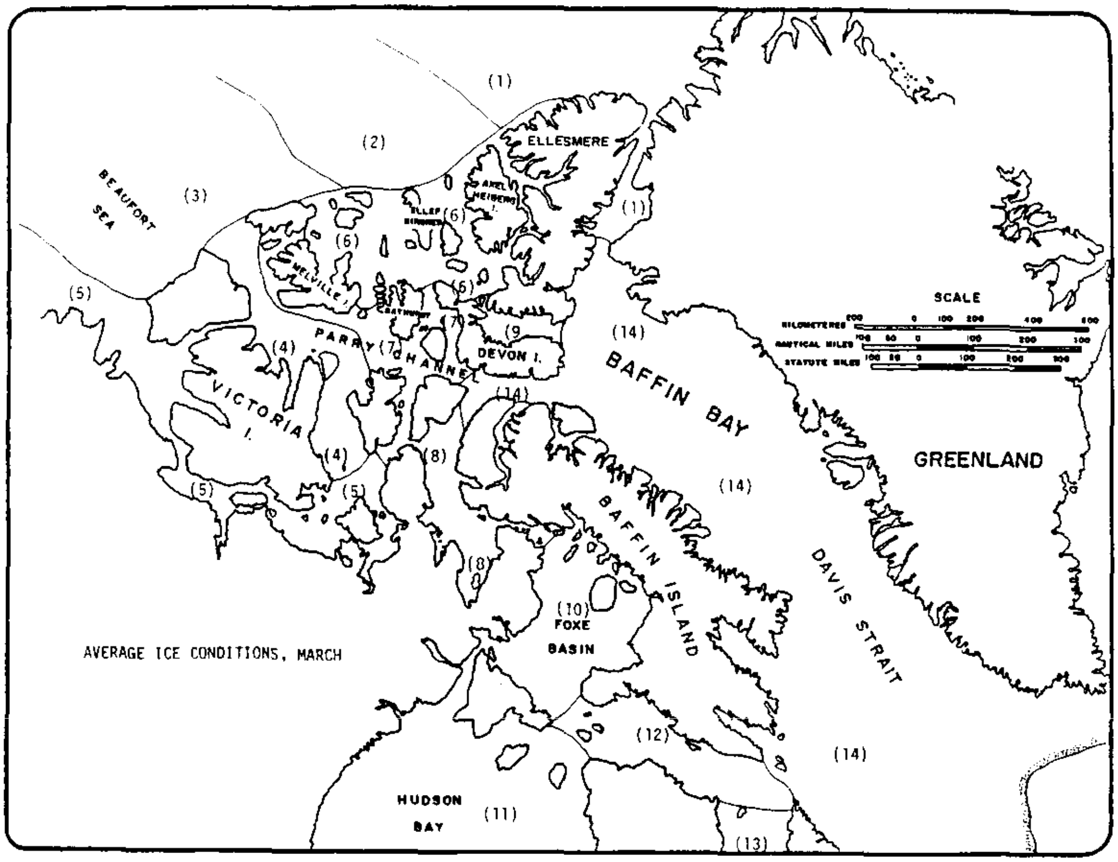
AVERAGE ICE CONDITIONS, JANUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 4.5-60; MY 15.0-100; ice islands
2	FY 4.2-60; MY 15.0-110; ice islands
3	FY 4.0-40; MY 15.0-60.0; ice islands
4	FY 3.9-40; MY 12.0-60.0
5	FY 3.6-25.0; MY 12.0-40.0
6	FY 4.5-25.0; MY 12.0-40.0
7	FY 3.9-30.0; MY 10.0-40.0
8	FY 4.8-40.0
9	FY 4.3-25.0
10	FY 3.8-30.0; MY 15.0-40.0
11	FY 3.5-20.0
12	FY 2.5-25.0; icebergs
13	FY 3.5-25.0; icebergs
14	BI 0.9-3.0; icebergs



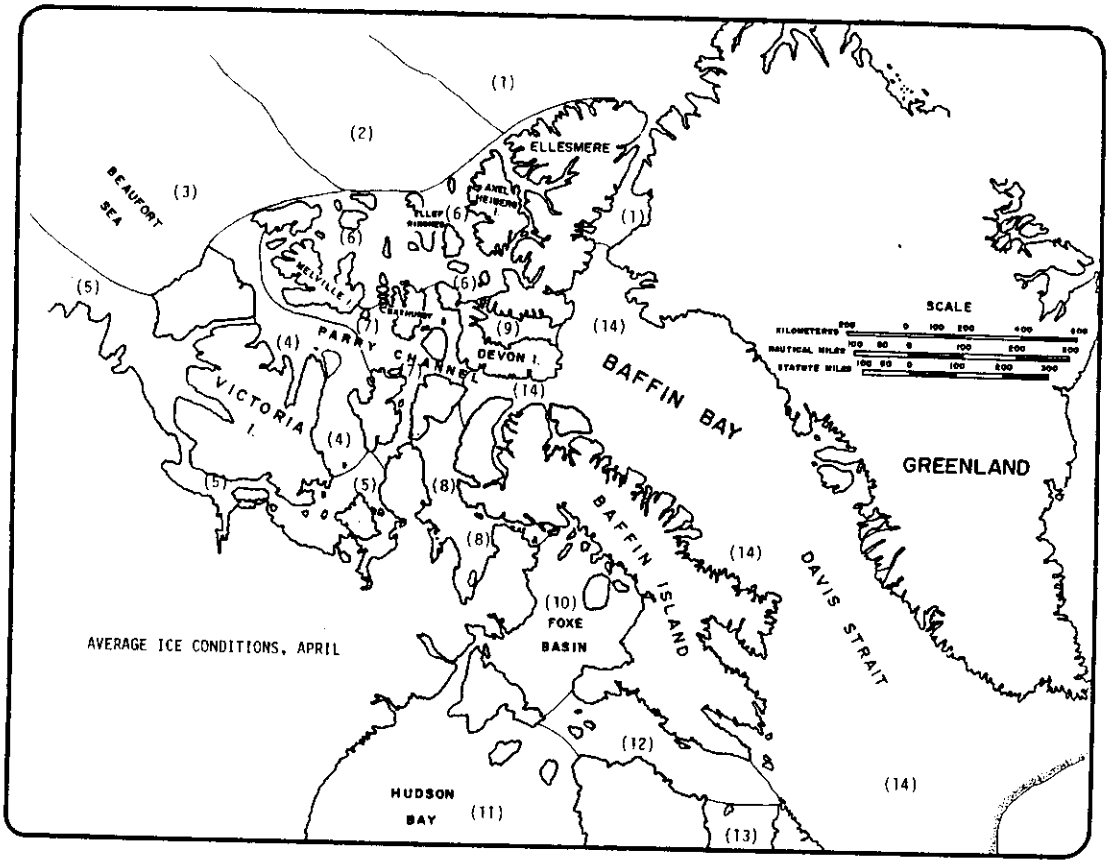
AVERAGE ICE CONDITIONS, FEBRUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 5.1-60.0; MY 15.0-100.0; ice islands
2	FY 5.3-60.0; MY 15.0-110.0; ice islands
3	FY 4.9-40.0; MY 15.0-60.0; ice islands
4	FY 4.7-40.0; MY 12.0-60.0
5	FY 4.5-25.0; MY 12.0-40.0
6	FY 5.3-25.0; MY 12.0-40.0
7	FY 4.6-30.0; MY 10.0-40.0
8	FY 5.3-40.0
9	FY 5.0-25.0
10	FY 4.6-30.0; MY 15.0-40.0
11	FY 4.6-20.0
12	FY 4.0-25.0; icebergs
13	FY 4.4-25.0; icebergs
14	BI 0.9-3.4; icebergs



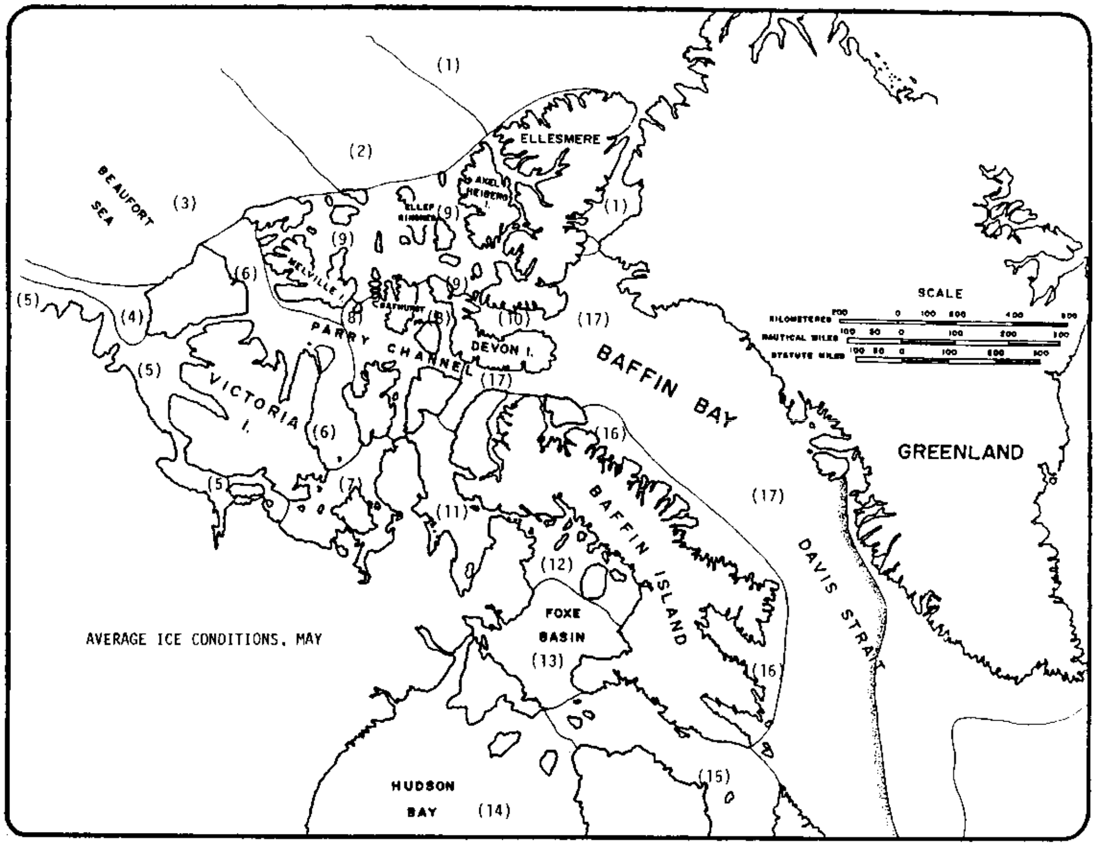
AVERAGE ICE CONDITIONS, MARCH

ICE AREA	ICE CHARACTERISTICS
1	FY 5.3-60.0; MY 17.0-100.0; ice islands
2	FY 6.1-60.0; MY 17.0-110.0; ice islands
3	FY 5.3-40.0; MY 17.0-60.0; ice islands
4	FY 5.2-40.0; MY 14.0-60.0;
5	FY 5.6-25.0; MY 14.0-40.0
6	FY 6.3-25.0; MY 14.0-40.0
7	FY 5.2-30.0; MY 12.0-40.0
8	FY 6.0-40.0;
9	FY 5.7-25.0
10	FY 5.4-30.0; MY 17.0-40.0
11	FY 4.9-20.0
12	FY 4.5-25.0; icebergs
13	FY 4.3-25.0; icebergs
14	BI 0.9-3.8; icebergs



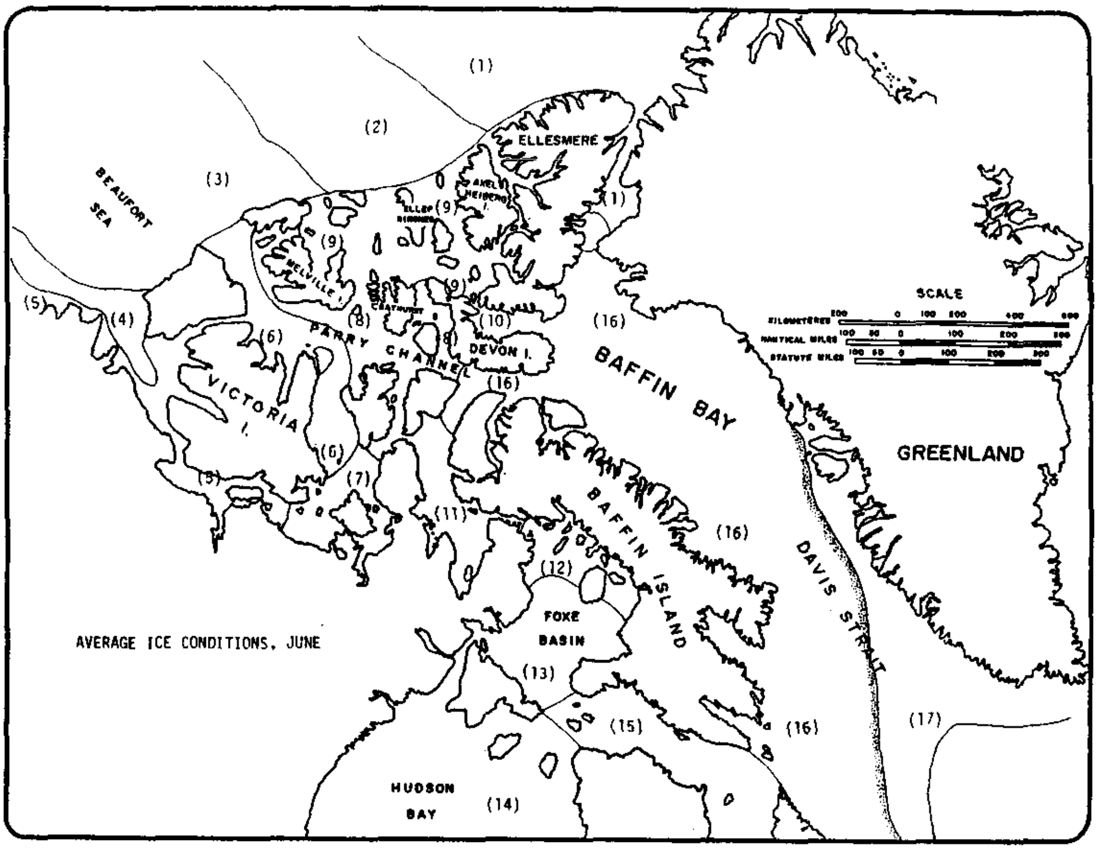
AVERAGE ICE CONDITIONS, APRIL

ICE AREA	ICE CHARACTERISTICS
1	FY 6.4-60.0; MY 17.0-100.0; ice islands
2	FY 6.8-60.0; MY 17.0-110.0; ice islands
3	FY 5.5-40.0; MY 17.0-60.0; ice islands
4	FY 5.4-40.0; MY 14.0-60.0
5	FY 6.0-25.0; MY 14.0-40.0
6	FY 6.9-25.0; MY 14.0-40.0
7	FY 5.7-30.0 MY 12.0-40.0
8	FY 6.7-40.0
9	FY 6.2-25.0
10	FY 5.1-30.0; MY 17.0-40.0
11	FY 5.5-20.0
12	FY 5.1-25.0; icebergs
13	FY 5.3-25.0; icebergs
14	3I 0.0-4.2; icebergs



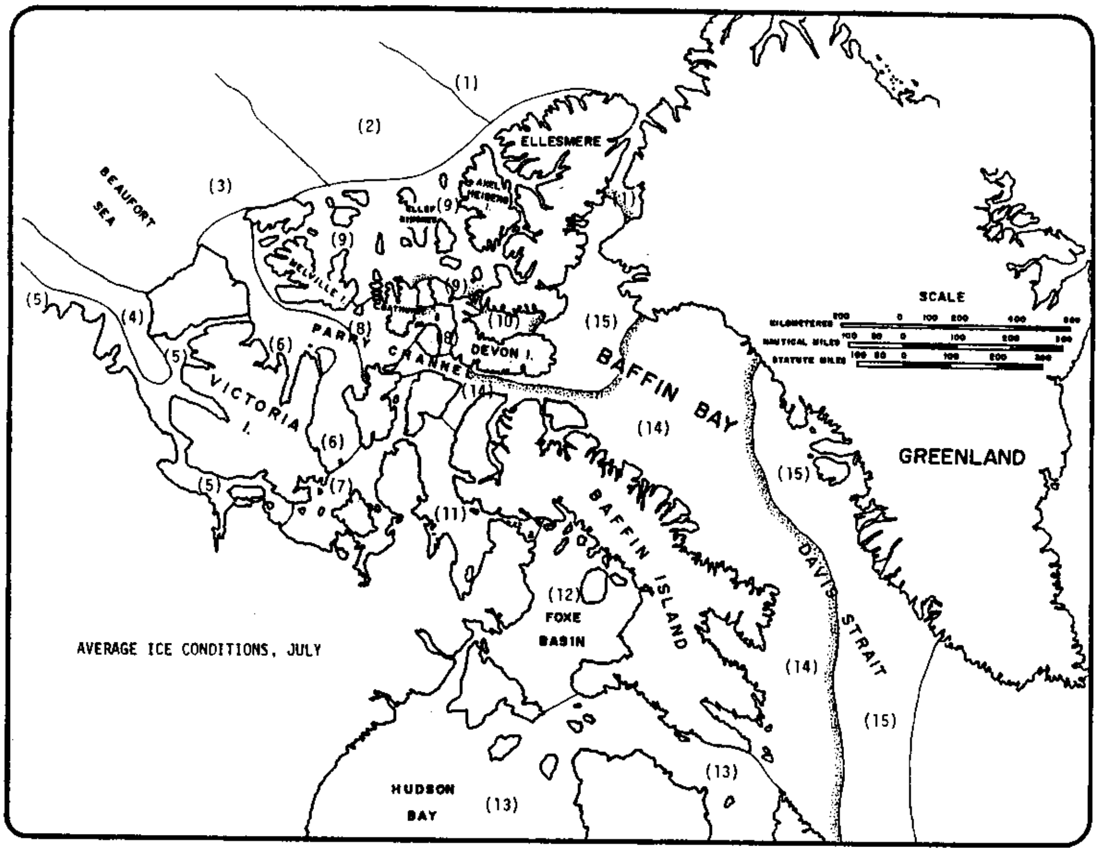
AVERAGE ICE CONDITIONS, MAY

ICE AREA	ICE CHARACTERISTICS
1	FY 6.7-60; MY 18.0-100.0; ice islands
2	FY 7.3-60; MY 18.0-110.0; ice islands
3	FY 6.1-40.0; MY 18.0-60.0; ice islands
4	3I 0.9-6.0
5	FY 6.7-25.0; MY 15.0-40.0
6	FY 6.5-40.0; MY 15.0-60.0
7	FY 7.0-40.0; MY 15.0-40.0
8	FY 6.0-30.0; MY 12.5-40.0
9	FY 7.4-25.0; MY 16.0-40.0
10	FY 5.5-25.0
11	FY 7.0-40.0
12	FY 6.4-40.0
13	3I 0.9-5.4
14	3I 0.9-5.5
15	3I 0.9-4.7; icebergs
16	FY 4.8-25.0
17	3I 0.8-4.5; icebergs
18	icebergs

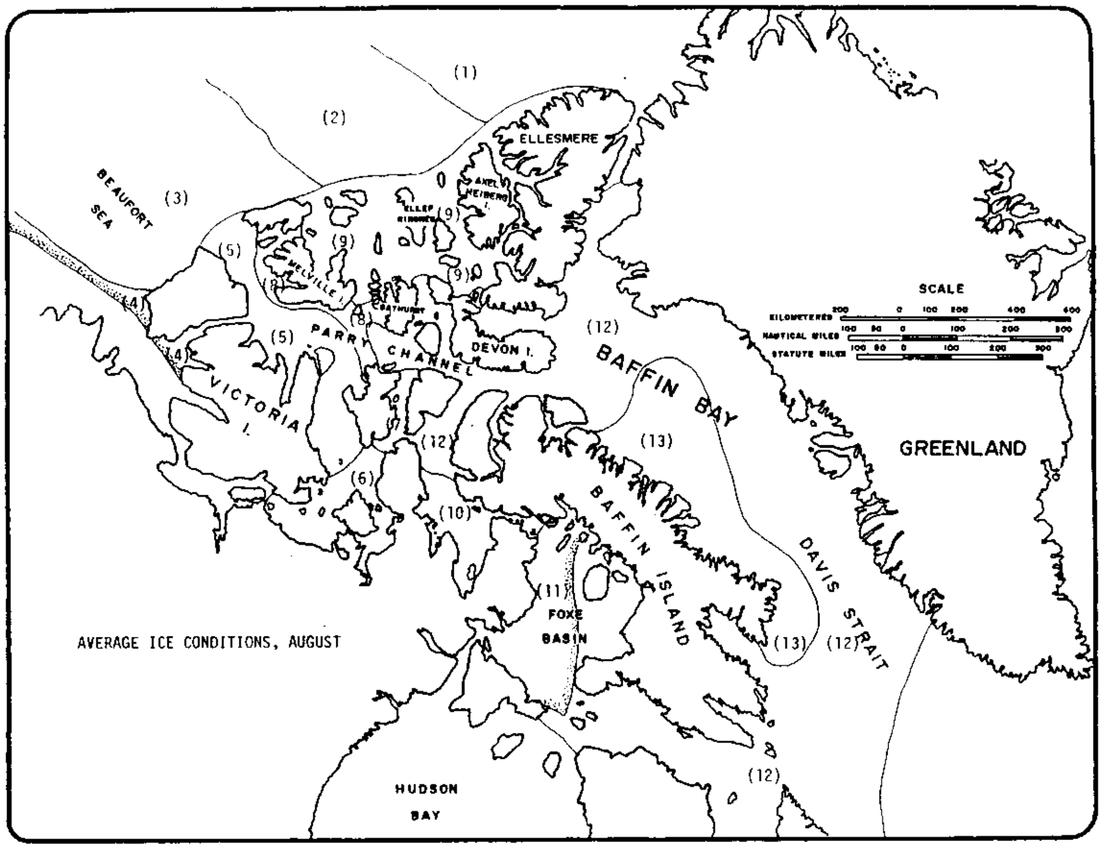


AVERAGE ICE CONDITIONS, JUNE

ICE AREA	ICE CHARACTERISTICS
1	FY 6.2-60; MY 18-100; ice islands
2	FY 7.4-60; MY 18-110; ice islands
3	FY 6.8-40; MY 18-60; ice islands
4	BI 0.9-4.5
5	FY 5.9-25.0; my 15-40
6	FY 6.3-40; MY 15-60
7	FY 6.0-40; MY 15-40
8	FY 6.5-30; MY 12.5-40
9	FY .73-25; MY 16-40
10	FY 6.5-25
11	FY 5.8-40
12	FY 6.2-40
13	BI 0.8-5.0
14	BI 0.7-5.0
15	BI 0.7-4.2; icebergs
16	BI 0.8-5.0; icebergs
17	Icebergs

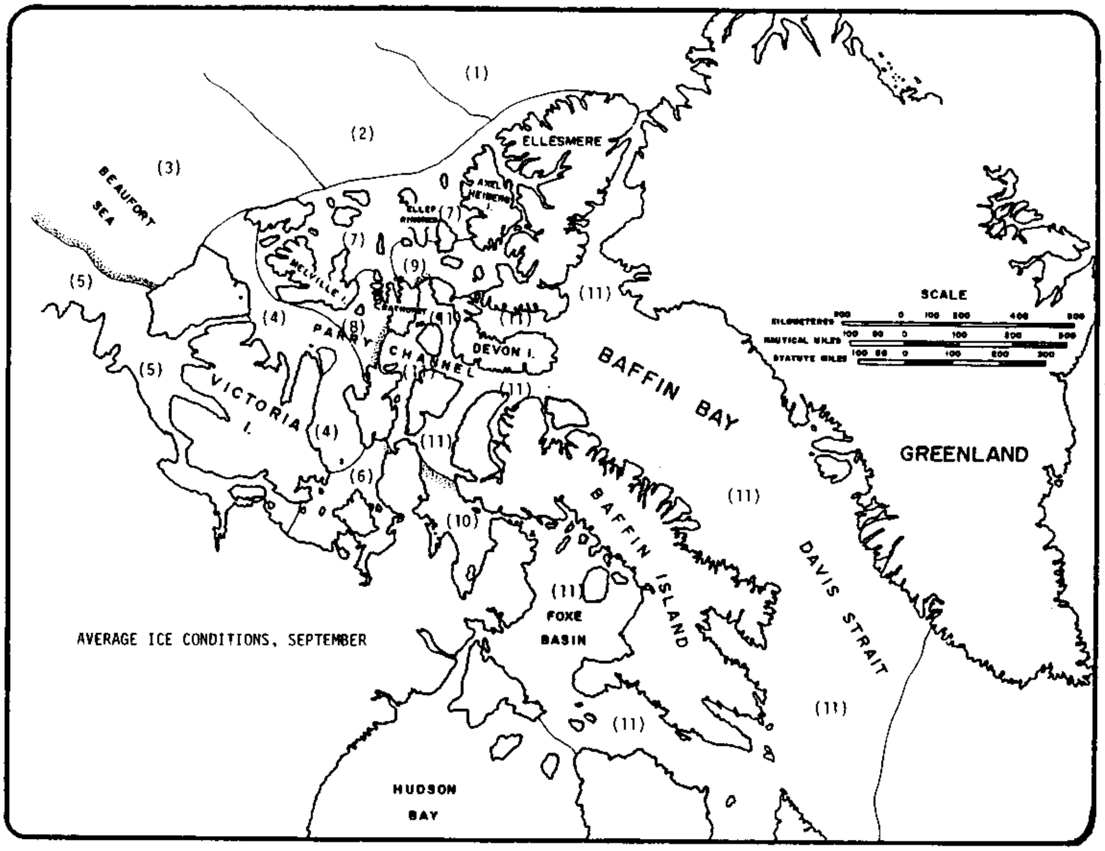


ICE AREA	ICE CHARACTERISTICS
1	FY 5.2-60; MY 18-100; ice islands
2	FY 6.7-60; MY 18-110; ice islands
3	FY 5.8-40; MY 18-60; ice islands
4	BI 0.8-3.0
5	FY 3.0-25; MY 15-40
6	FY 4.7-40; MY 15-60
7	FY 4.0-40; MY 15-40
8	FY 4.5-30; MY 12.5-40
9	FY 6.0-25; MY 16-40
10	FY 4.7-25
11	FY 4.2-40
12	BI 0.8-4.0
13	BI 0.5-3.5
14	BI 0.7-3.0
15	icebergs



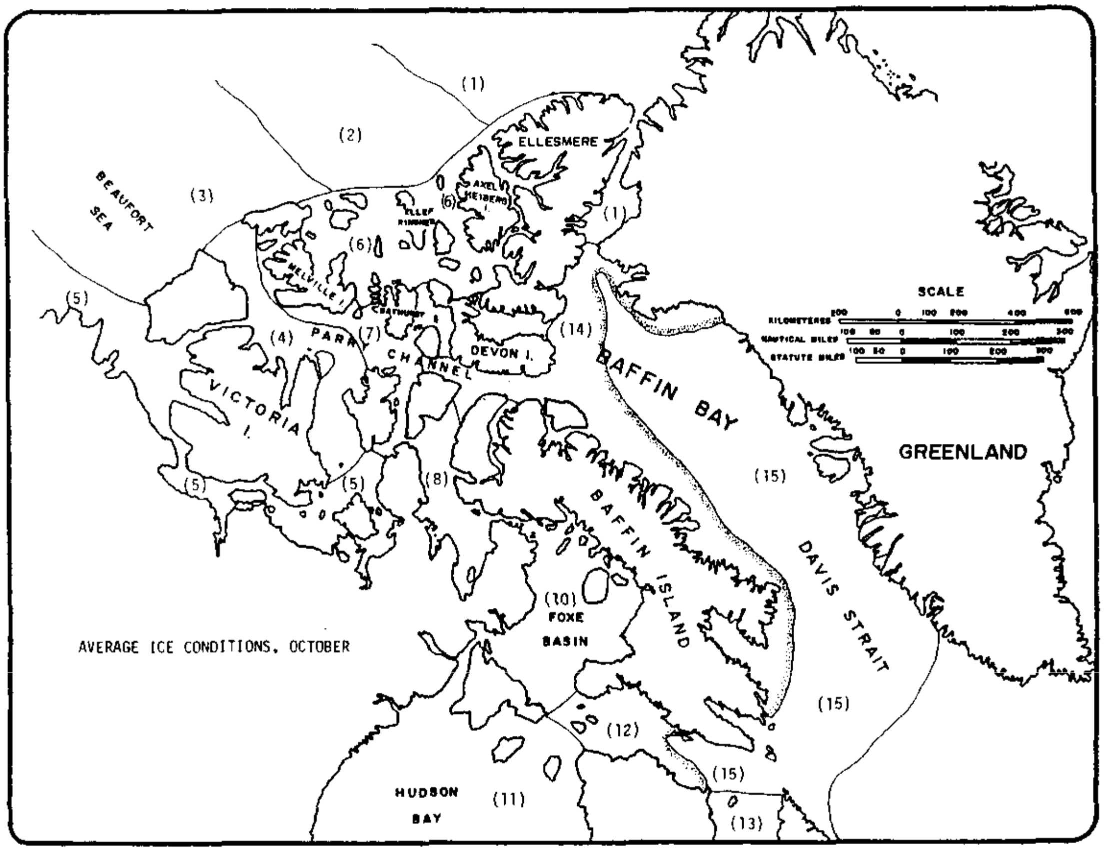
AVERAGE ICE CONDITIONS, AUGUST

ICE AREA	ICE CHARACTERISTICS
1	FY 4.3-60; MY 16-100; ice islands
2	FY 6.0-60; MY 16-110; ice islands
3	FY 5.5-40; MY 16-60; ice islands
4	BI 0.6-2.5; icebergs
5	FY 2.5-40; MY 15-60
6	BI 0.9-2.5; icebergs
7	FY 3.0-40
8	FY 3.2-30; MY 11-40
9	FY 4.0-25; MY 16-40
10	FY 2.2-40
11	BI 0.6-1.5
12	Icebergs
13	BI 0.5-2.0; icebergs

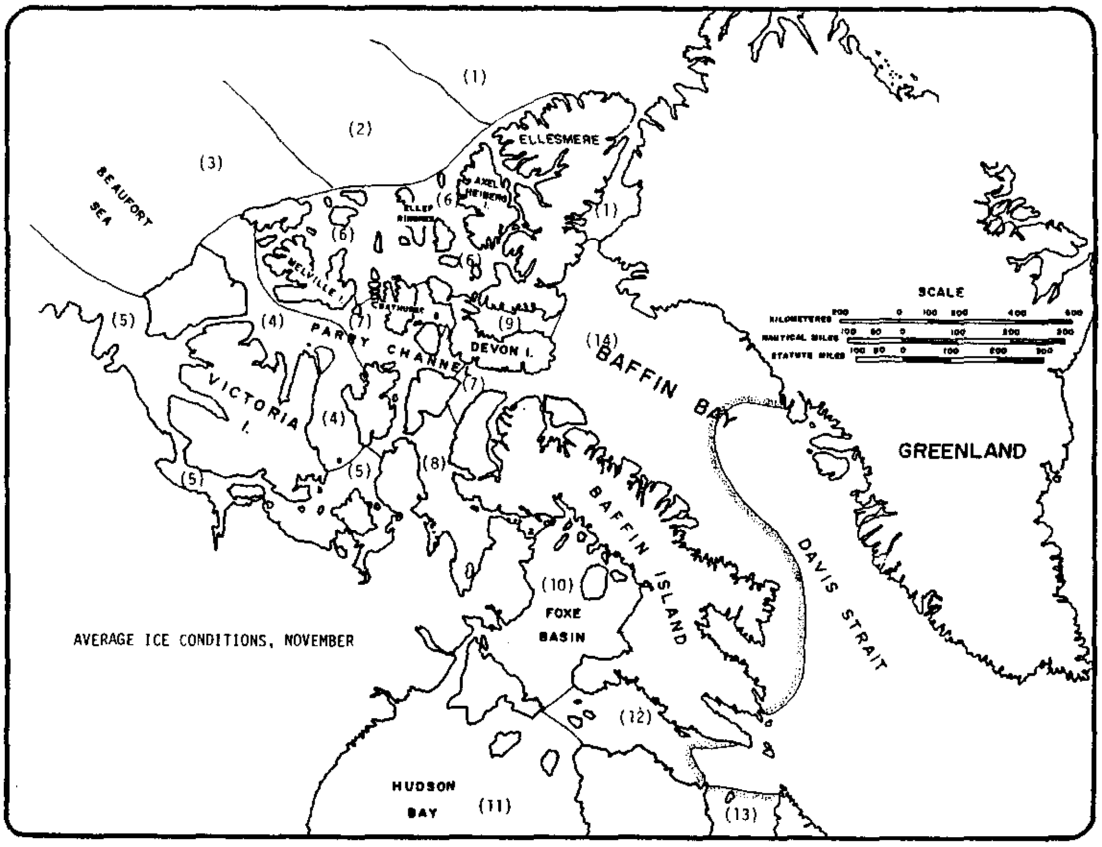


AVERAGE ICE CONDITIONS, SEPTEMBER

ICE AREA	ICE CHARACTERISTICS
1	FY 4.5-60; MY 16-100; ice islands
2	FY 5.5-60; MY 16-110; ice islands
3	FY 3.2-40; MY 16-60; ice islands
4	FY 2.0-40; MY 15-60
5	BI 0.3-1.0; icebergs
6	BI 0.6-1.5; icebergs
7	FY 2.5-25; MY 11-40
8	BI 0.8-1.7
9	BI 0.8-3.5
10	BI 0.8-1.5
11	Icebergs

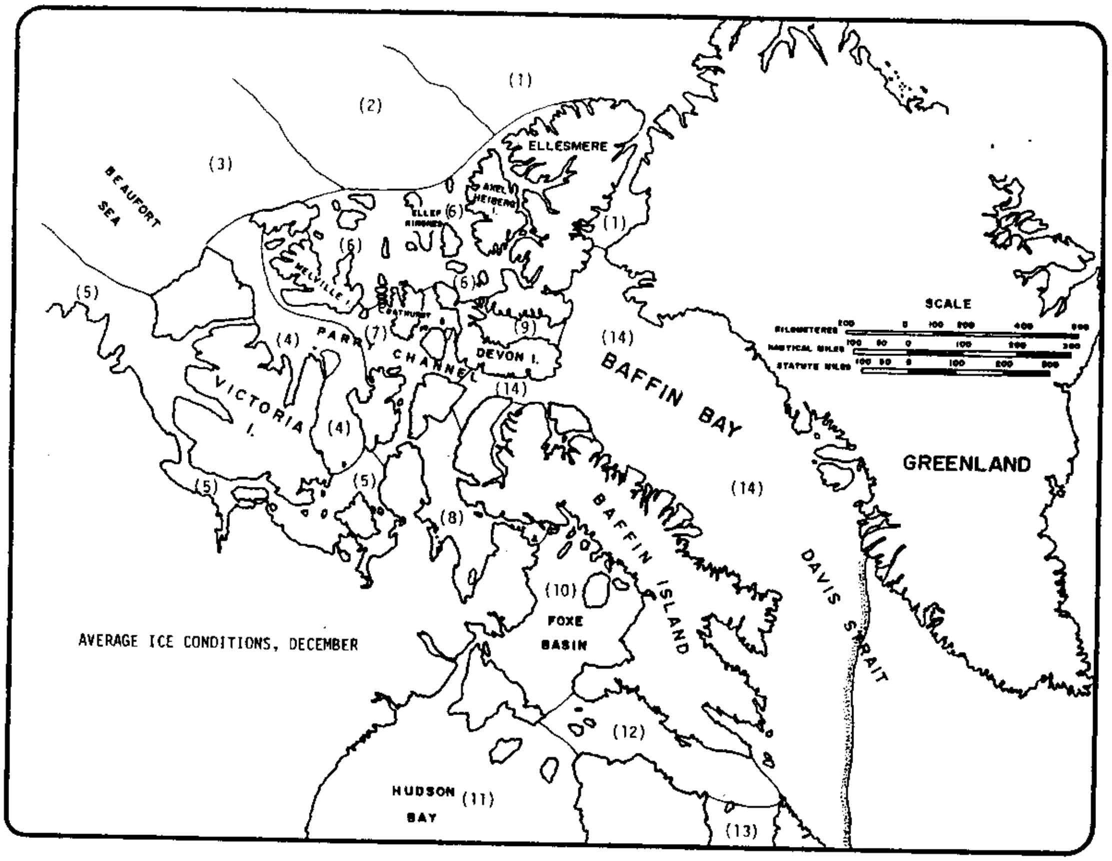


ICE AREA	ICE CHARACTERISTICS
1	FY 1.5-60; MY 12-100; ice islands
2	FY 1.8-60; MY 12-110; ice islands
3	FY 1.5-40; MY 10-60; ice islands
4	FY 1.1-40; MY 10-60
5	FY 0.8-30; MY 10-40
6	FY 1.4-20; MY 10-40
7	FY 0.8-20; MY 3.5-40
8	FY 0.9-20
9	FY 1.2-20
10	FY 0.5-10; MY 12-40
11	BI 0.7-0.8
12	BI 0.8-0.9
13	FY 0.7-10; icebergs
14	BI 0.8-0.3; icebergs
15	icebergs



AVERAGE ICE CONDITIONS, NOVEMBER

ICE AREA	ICE CHARACTERISTICS
1	FY 2.7-60; MY 15-100; ice islands
2	FY 2.7-60; MY 15-110; ice islands
3	FY 2.4-40; MY 15-60; ice islands
4	FY 2.2-40; MY 12-60
5	FY 1.9-30; MY 12-40
6	FY 2.7-25; MY 12-40
7	FY 2.1-30; MY 10-40
8	FY 2.2-40
9	FY 2.4-25
10	FY 1.7-20; MY 15-40
11	FY 1.2-15
12	FY 1.4-18; icebergs
13	FY 1.0-12; icebergs
14	BI 0.9-1.2; icebergs

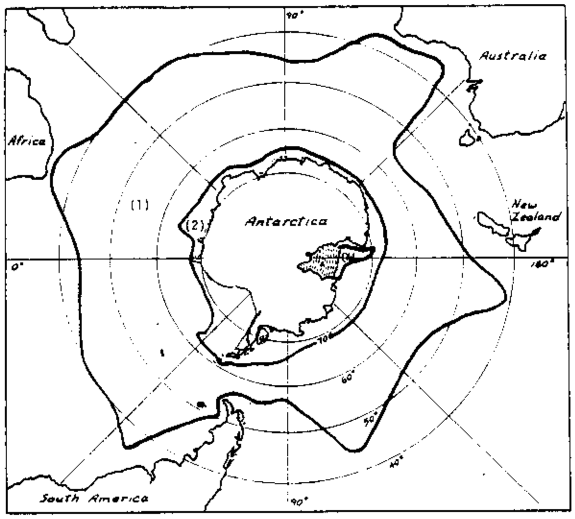


AVERAGE ICE CONDITIONS, DECEMBER

ICE AREA	ICE CHARACTERISTICS
1	FY 3.4-60; MY 15-100; ice islands
2	FY 3.5-60; MY 15-110; ice islands
3	FY 3.1-40; MY 15-60; ice islands
4	FY 3.0-40; MY 12-60;
5	FY 2.8-40; MY 12-40
6	FY 3.8-25; MY 12-40
7	FY 3.0-30; MY 10-40
8	FY 3.2-40
9	FY 3.3-25
10	FY 2.6-30; MY 15-40
11	FY 2.1-20
12	FY 2.5-25; icebergs
13	FY 2.0-25; icebergs
14	3I 0.9-2.0; icebergs

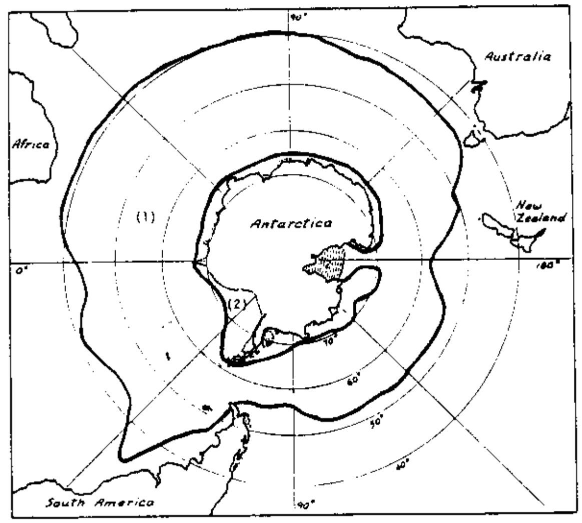
APPENDIX A.3

ANTARCTIC - MAXIMUM AND AVERAGE ICE CONDITIONS BY MONTH



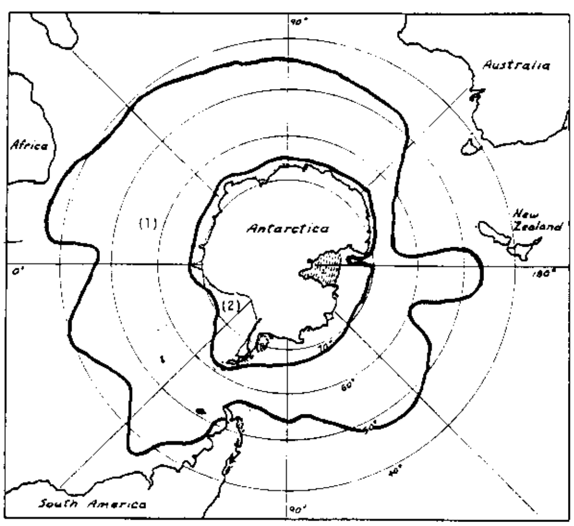
MAXIMUM ICE CONDITIONS, JANUARY

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 6 FT



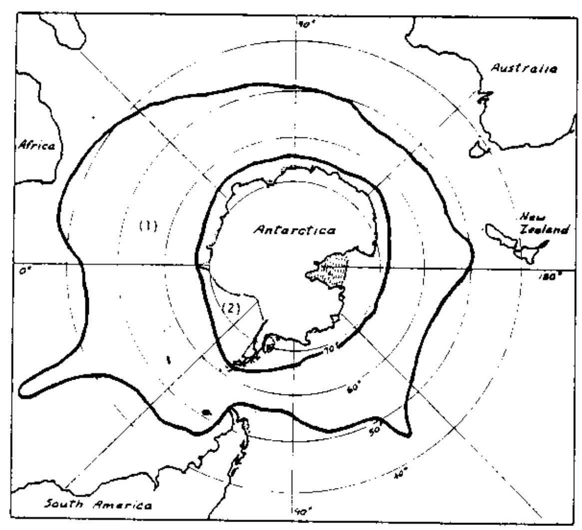
MAXIMUM ICE CONDITIONS, FEBRUARY

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3 FT



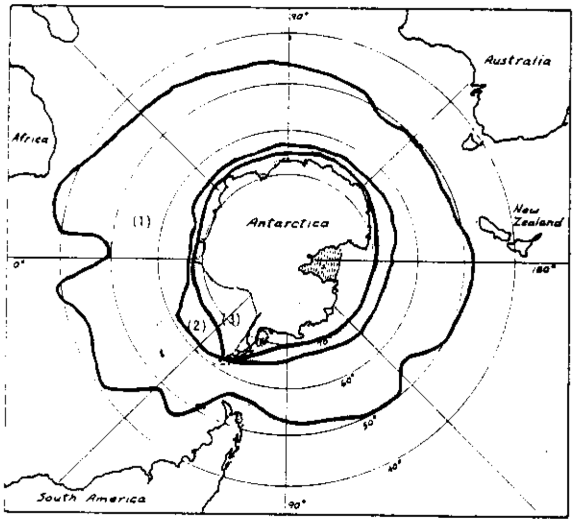
MAXIMUM ICE CONDITIONS, MARCH

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3.5 FT



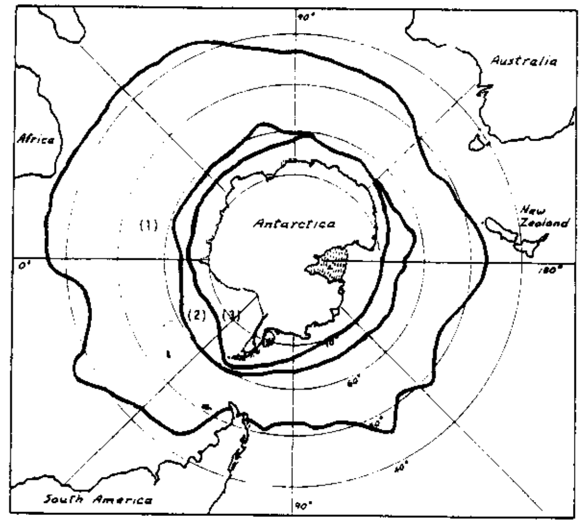
MAXIMUM ICE CONDITIONS, APRIL

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3.5 FT



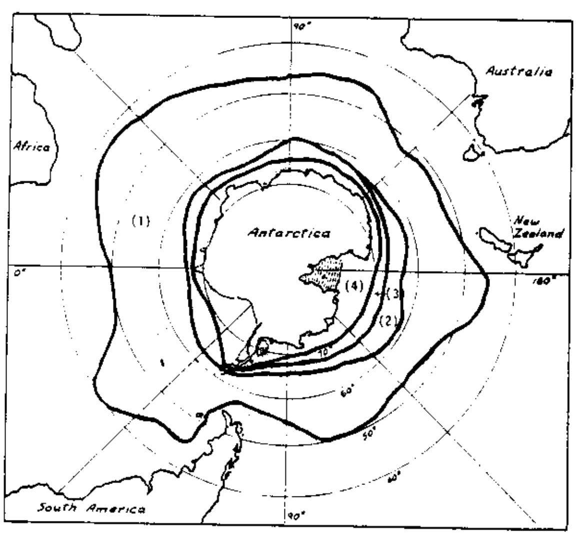
MAXIMUM ICE CONDITIONS, MAY

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 1 FT
3	IB, 4 FT



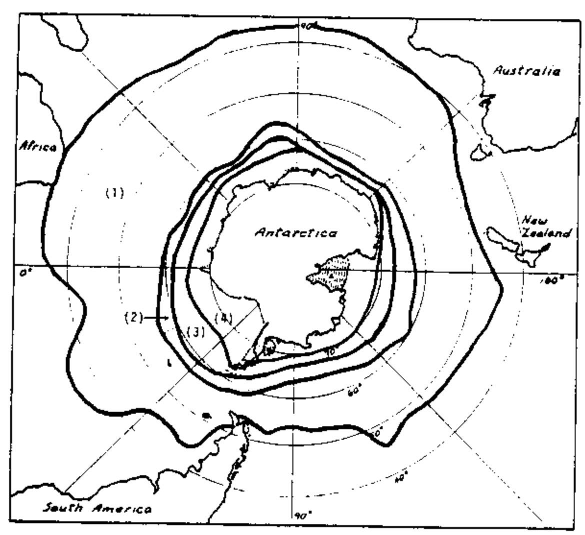
MAXIMUM ICE CONDITIONS, JUNE

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 2 FT
3	IB, 5 FT



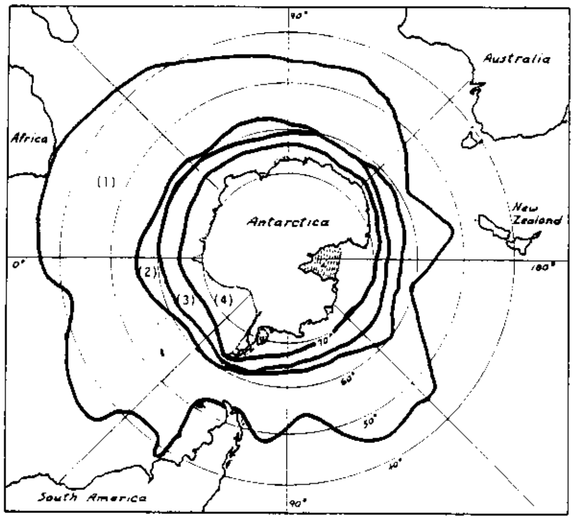
MAXIMUM ICE CONDITIONS, JULY

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 1 FT
3	IB, 3 FT
4	IB, 5 FT



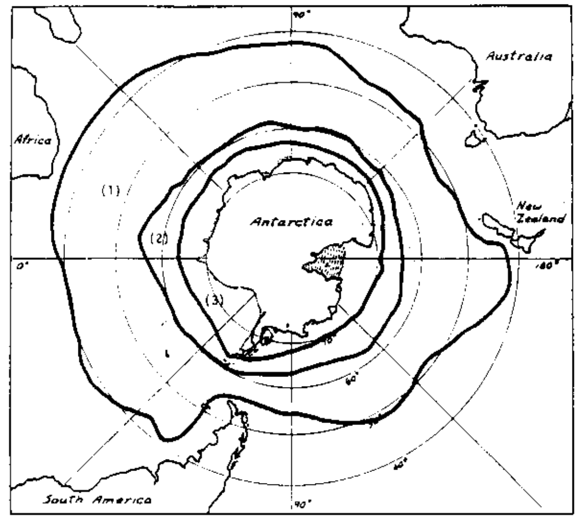
MAXIMUM ICE CONDITIONS, AUGUST

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 2 FT
3	IB, 4 FT
4	IB, 6 FT



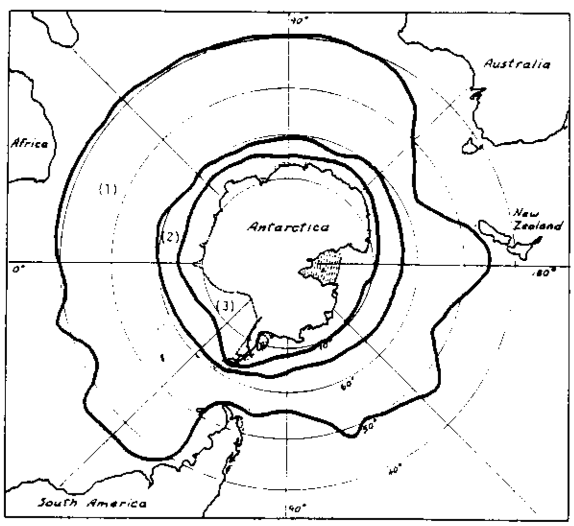
MAXIMUM ICE CONDITIONS, SEPTEMBER

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 2 FT
3	IB, 4 FT
4	IB, 6 FT



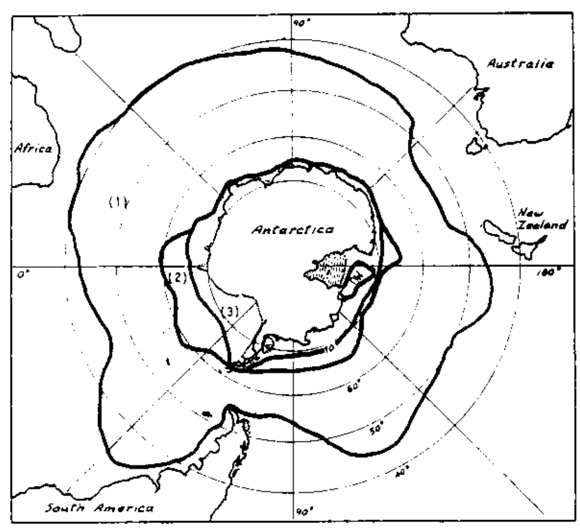
MAXIMUM ICE CONDITIONS, OCTOBER

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3 FT
3	IB, 6 FT



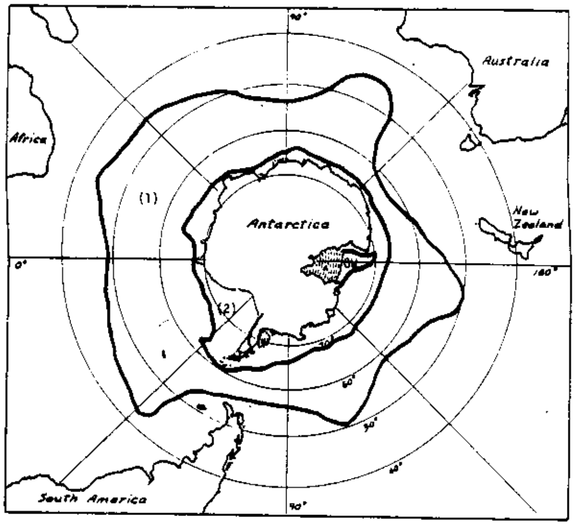
MAXIMUM ICE CONDITIONS, NOVEMBER

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3 FT
3	IB, 6 FT



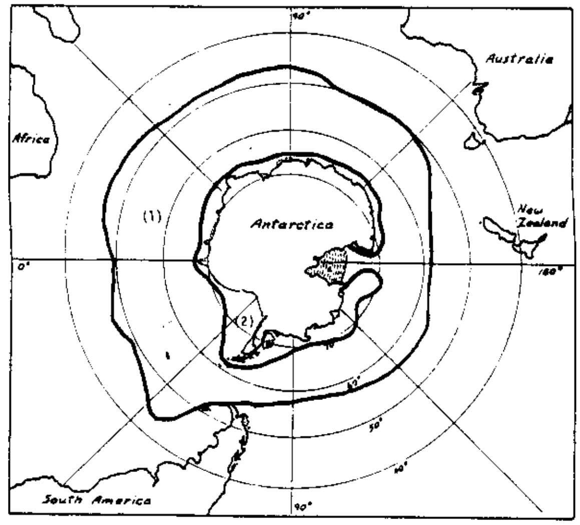
MAXIMUM ICE CONDITIONS, DECEMBER

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3 FT
3	IB, 6 FT



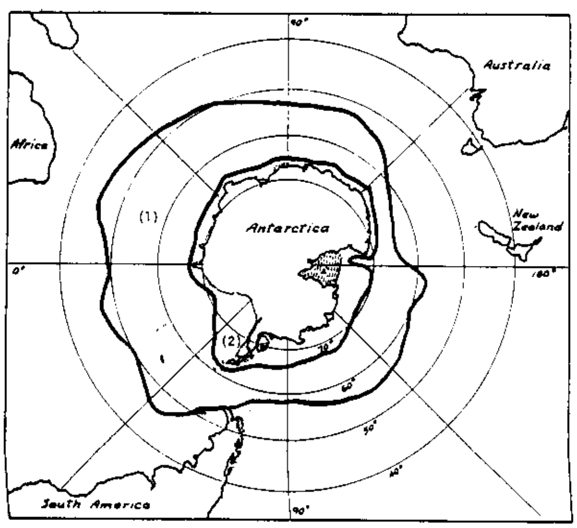
AVERAGE ICE CONDITIONS, JANUARY

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 6 FT



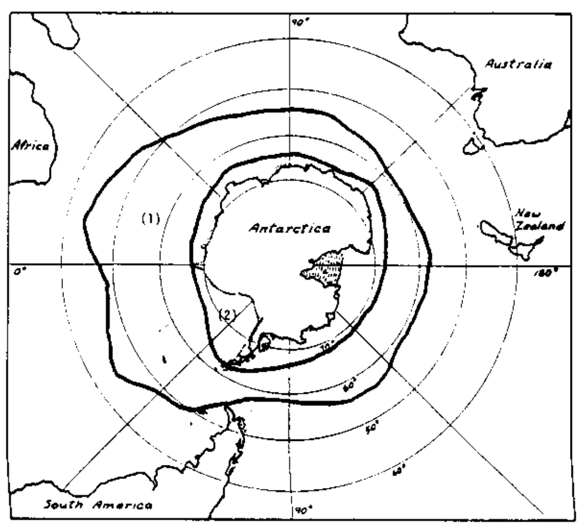
AVERAGE ICE CONDITIONS, FEBRUARY

ICE AREA	ICE CHARACTERISTICS
1	IB, open water
2	IB, 3 FT



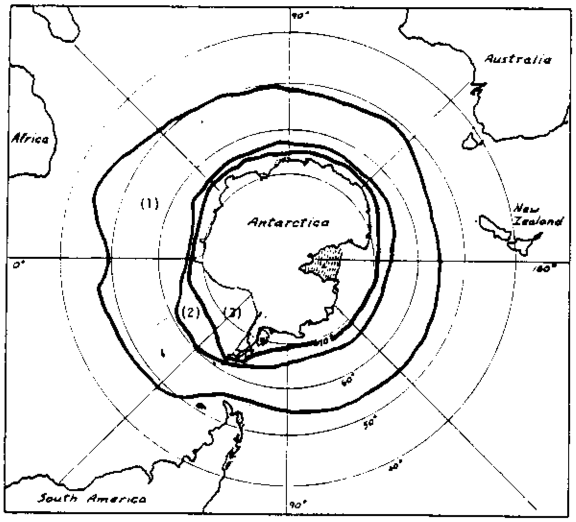
AVERAGE ICE CONDITIONS, MARCH

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3.5 FT



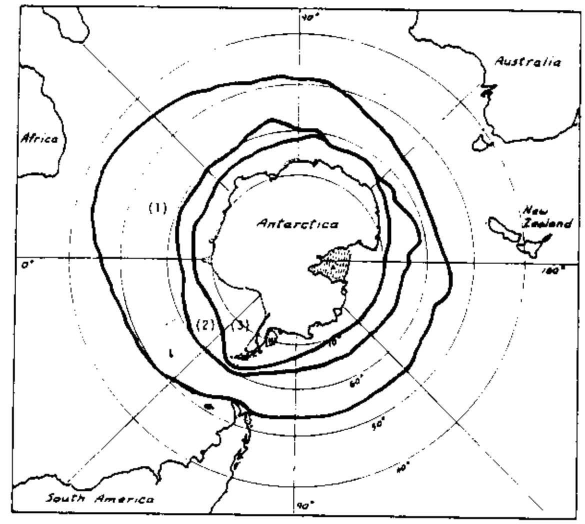
AVERAGE ICE CONDITIONS, APRIL

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3.5 FT



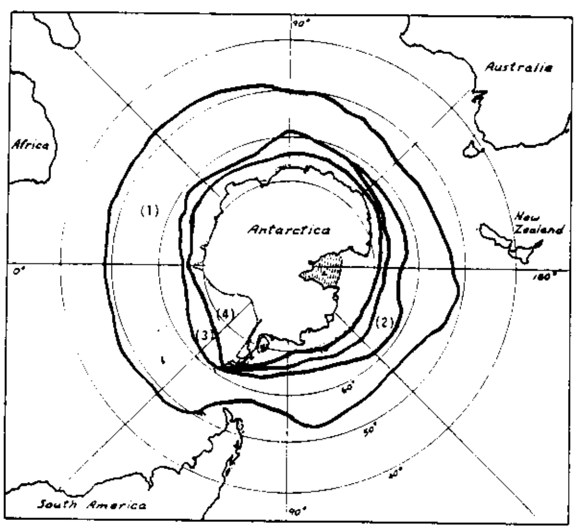
AVERAGE ICE CONDITIONS, MAY

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 1 FT
3	IB, 4 FT



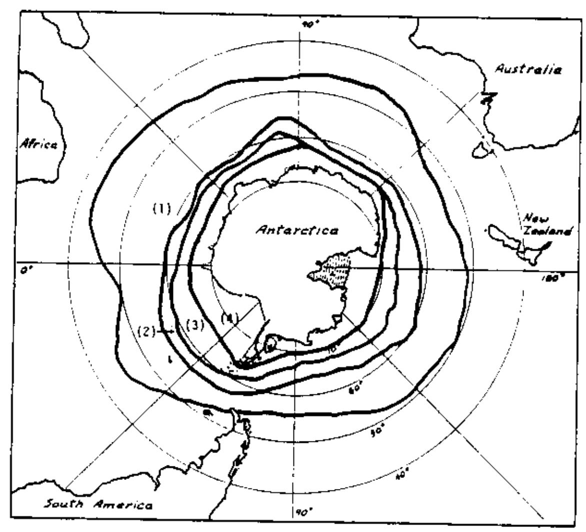
AVERAGE ICE CONDITIONS, JUNE

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 2 FT
3	IB, 5 FT



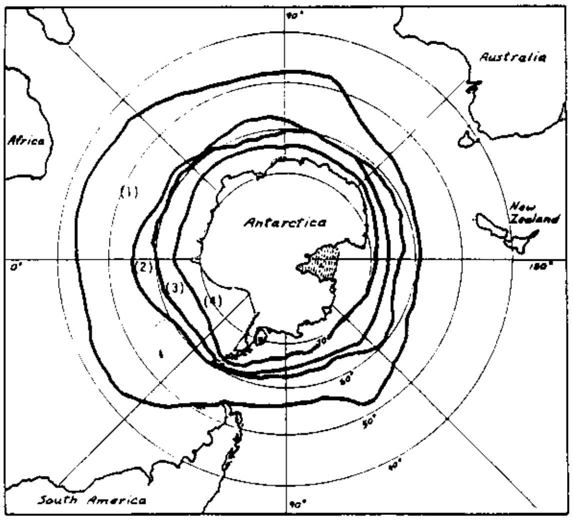
AVERAGE ICE CONDITIONS, JULY

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 1 FT
3	IB, 3 FT
4	IB, 5 FT



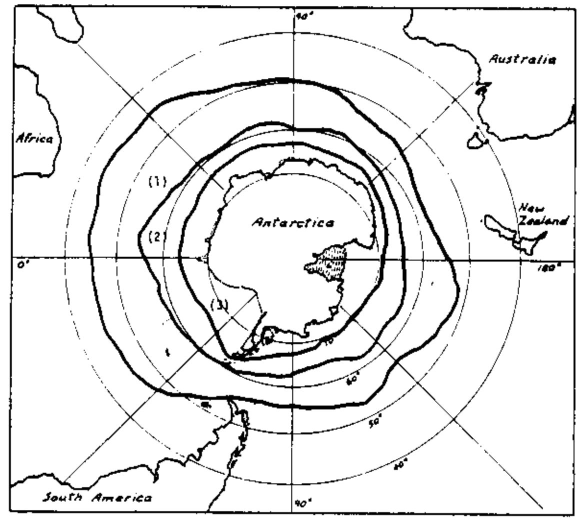
AVERAGE ICE CONDITIONS, AUGUST

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 2 FT
3	IB, 4 FT
4	IB, 6 FT



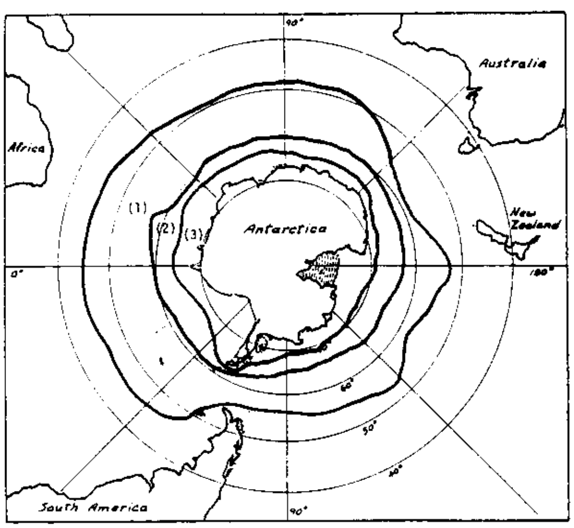
AVERAGE ICE CONDITIONS, SEPTEMBER

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 2 FT
3	IB, 4 FT
4	IB, 6 FT



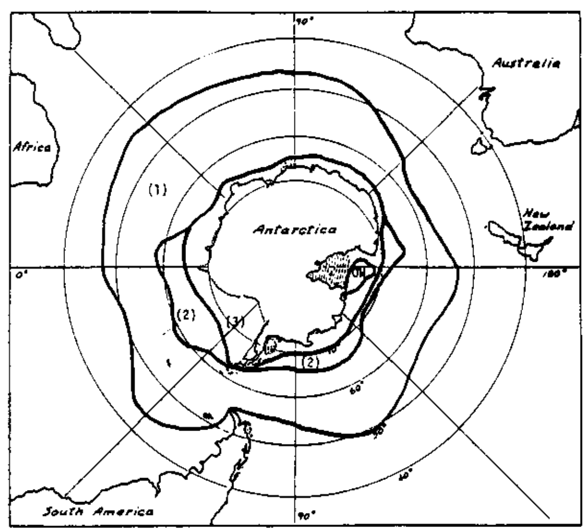
AVERAGE ICE CONDITIONS, OCTOBER

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3 FT
3	IB, 6 FT



AVERAGE ICE CONDITIONS, NOVEMBER

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3 FT
3	IB, 6 FT



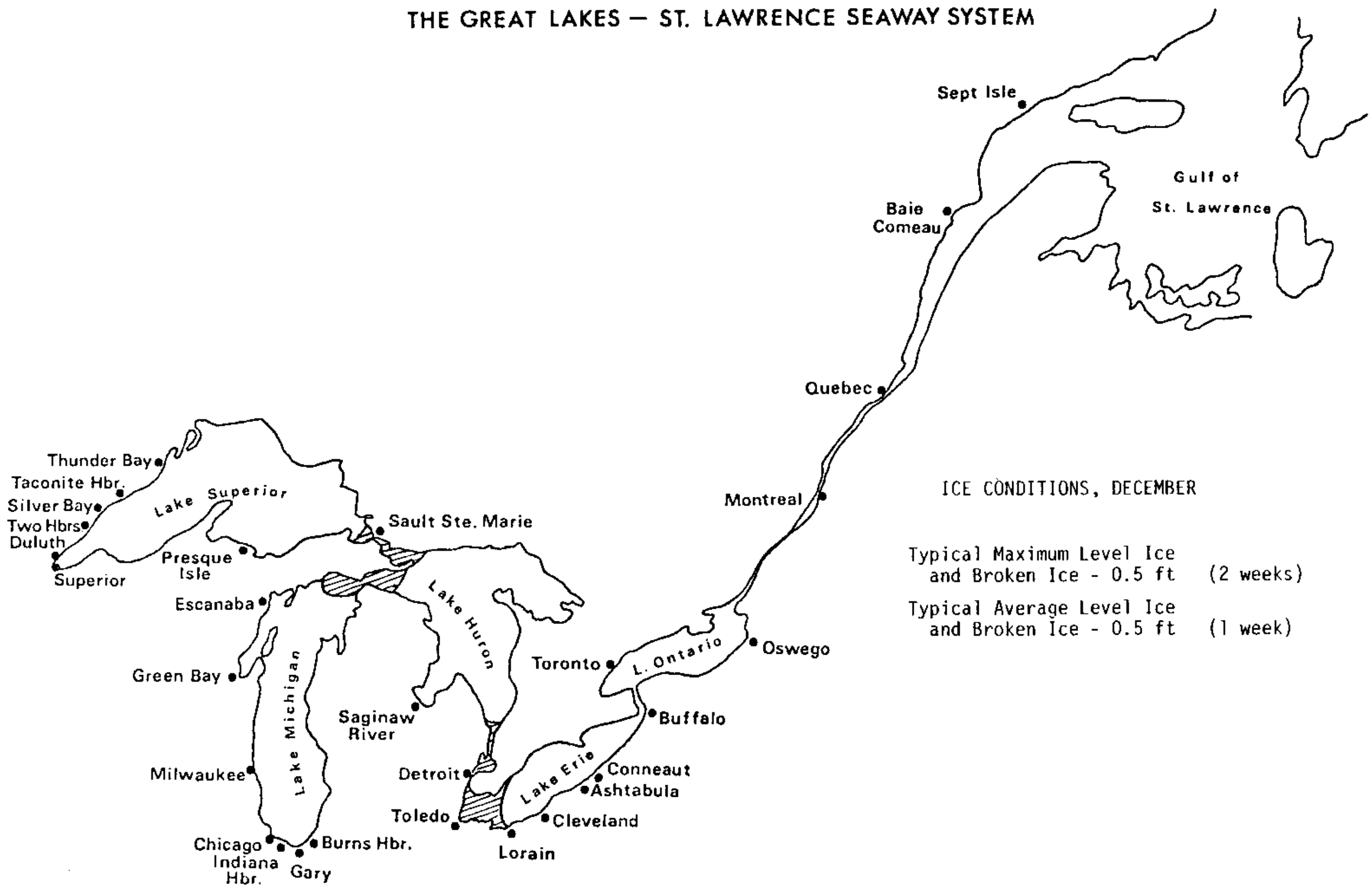
AVERAGE ICE CONDITIONS, DECEMBER

ICE AREA	ICE CHARACTERISTICS
1	IB, OPEN WATER
2	IB, 3 FT
3	IB, 6 FT

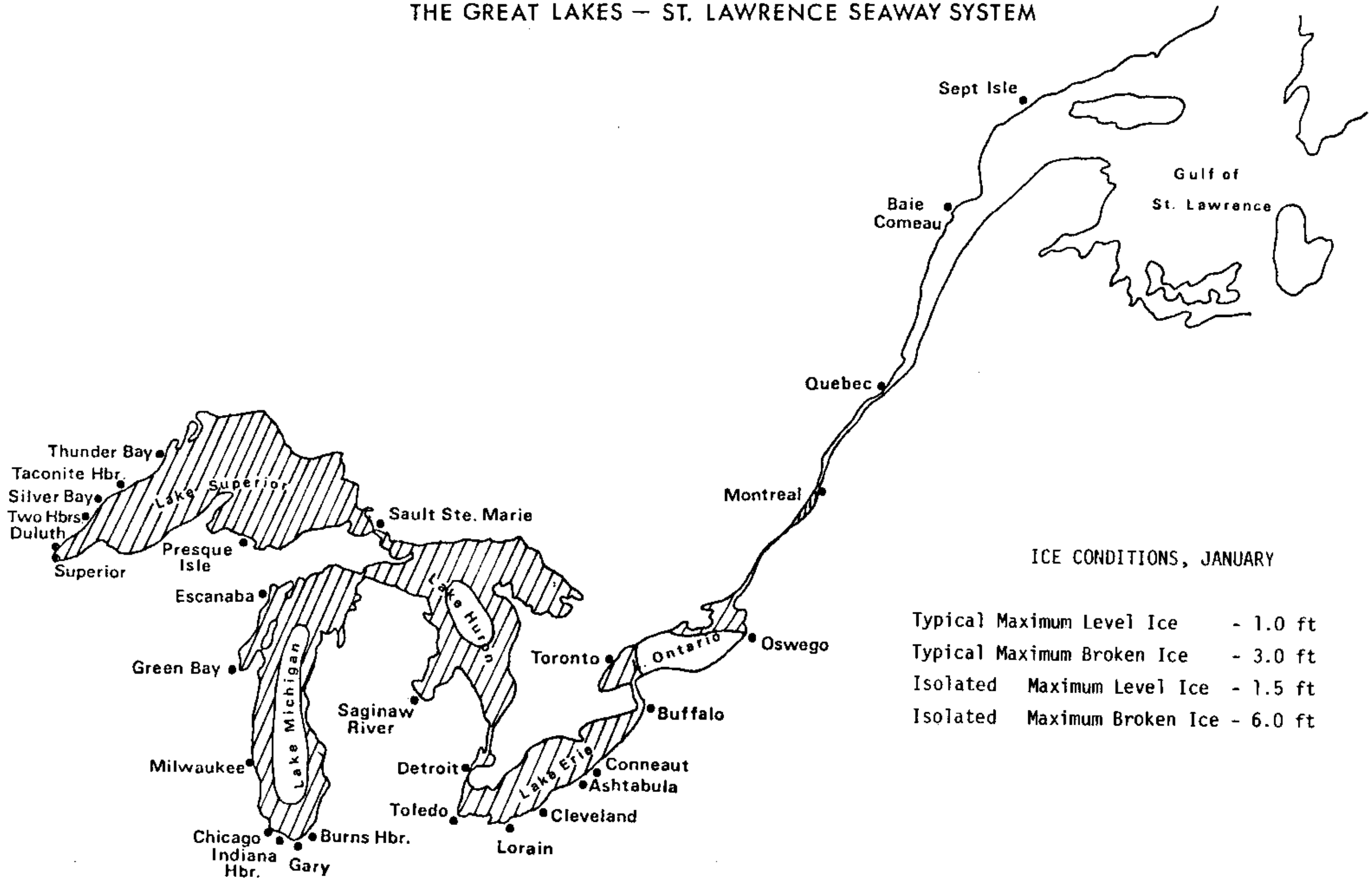
APPENDIX A.4

GREAT LAKES - MAXIMUM AND AVERAGE ICE CONDITIONS BY MONTH

THE GREAT LAKES — ST. LAWRENCE SEAWAY SYSTEM



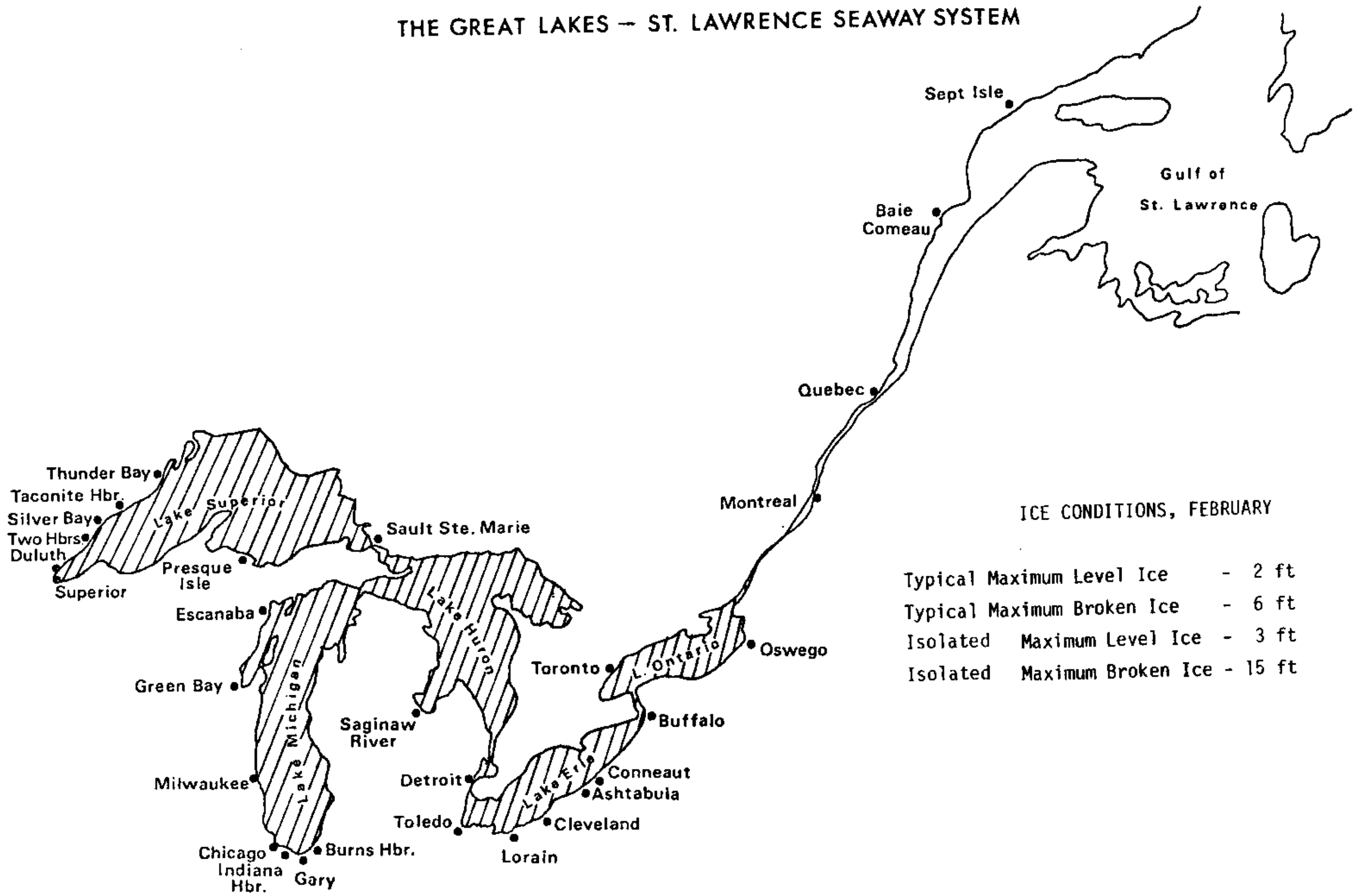
THE GREAT LAKES — ST. LAWRENCE SEAWAY SYSTEM



ICE CONDITIONS, JANUARY

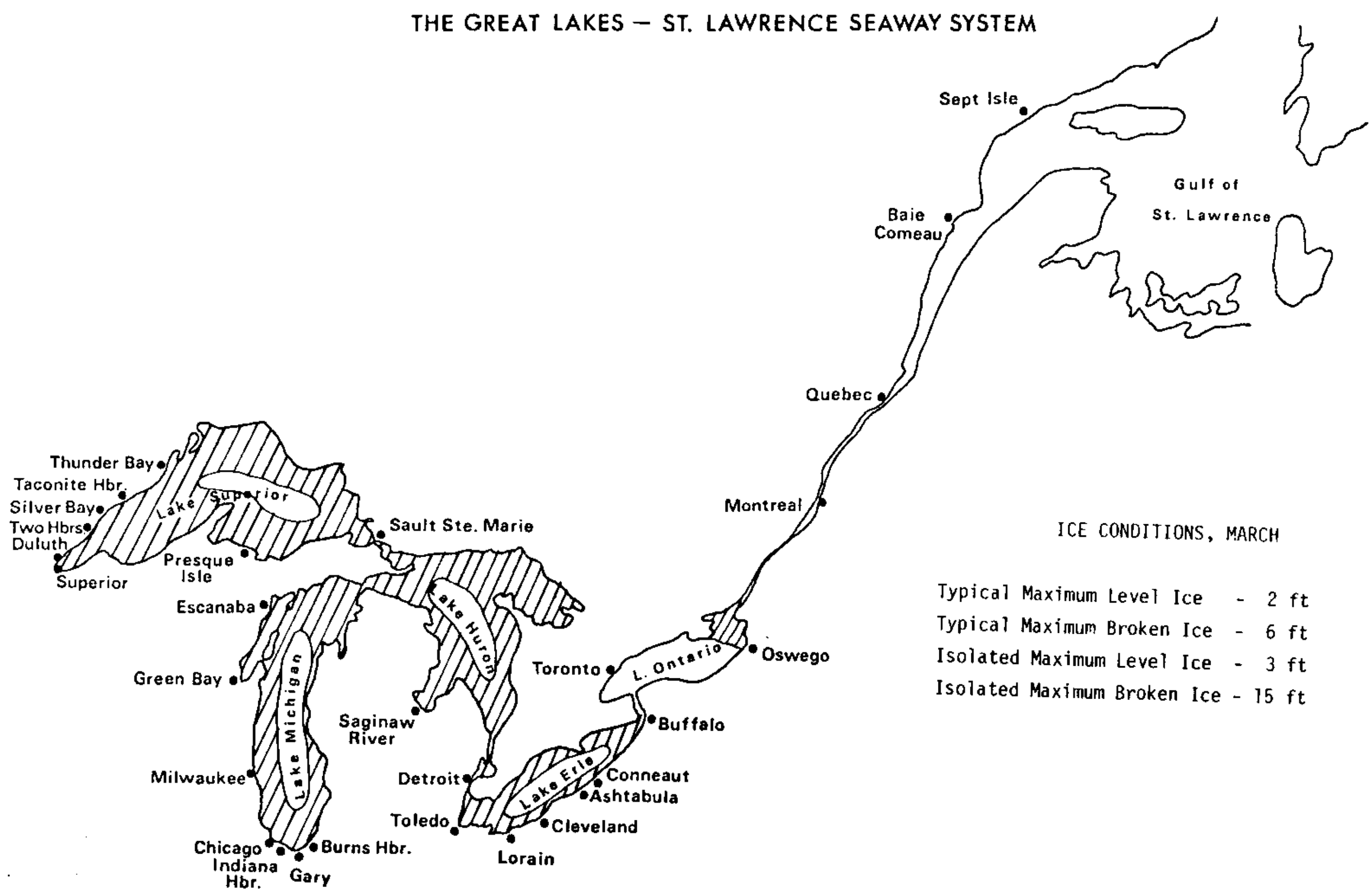
Typical Maximum Level Ice	- 1.0 ft
Typical Maximum Broken Ice	- 3.0 ft
Isolated Maximum Level Ice	- 1.5 ft
Isolated Maximum Broken Ice	- 6.0 ft

THE GREAT LAKES — ST. LAWRENCE SEAWAY SYSTEM



ICE CONDITIONS, FEBRUARY

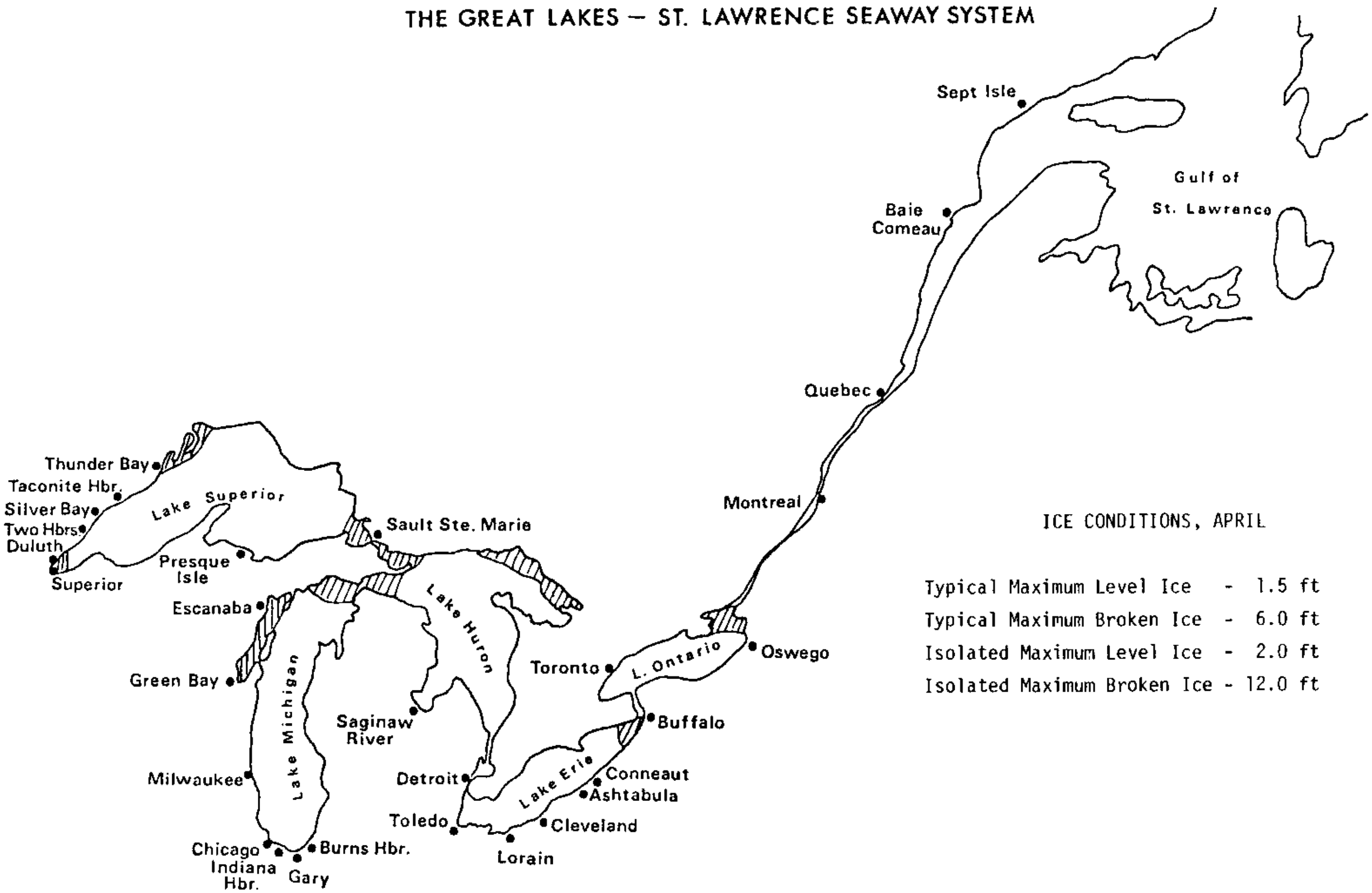
Typical Maximum Level Ice	-	2 ft
Typical Maximum Broken Ice	-	6 ft
Isolated Maximum Level Ice	-	3 ft
Isolated Maximum Broken Ice	-	15 ft



ICE CONDITIONS, MARCH

Typical Maximum Level Ice - 2 ft
Typical Maximum Broken Ice - 6 ft
Isolated Maximum Level Ice - 3 ft
Isolated Maximum Broken Ice - 15 ft

THE GREAT LAKES — ST. LAWRENCE SEAWAY SYSTEM

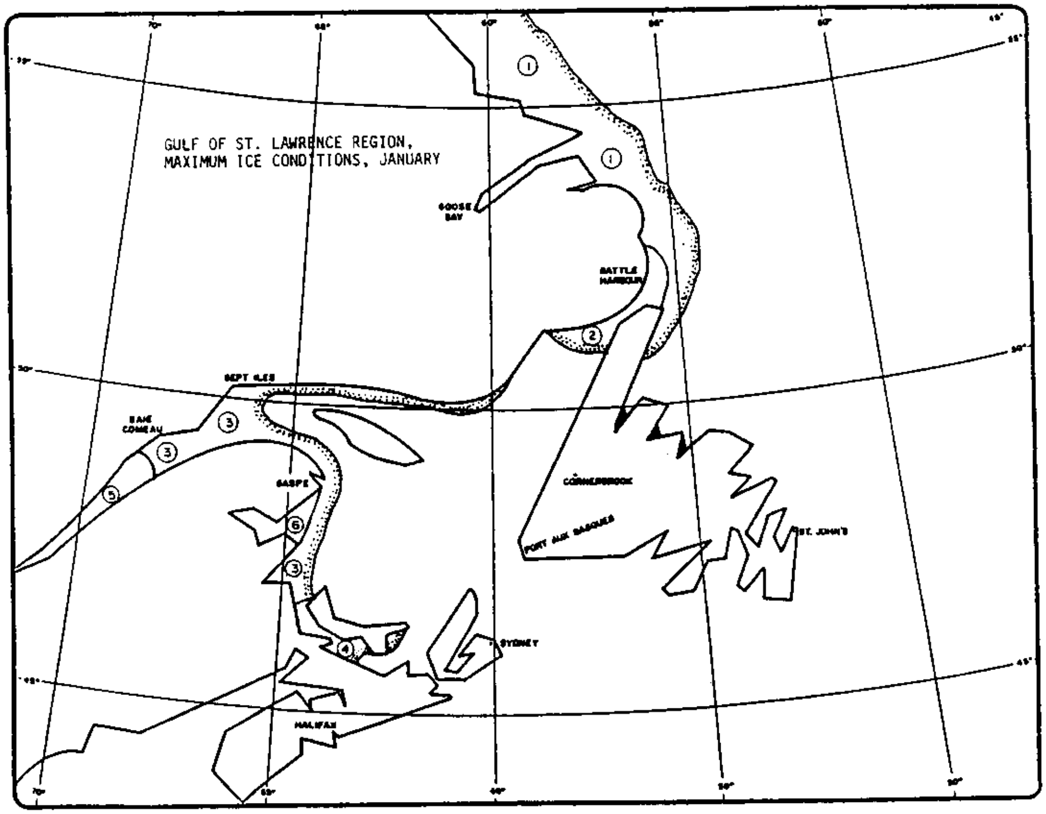


ICE CONDITIONS, APRIL

Typical Maximum Level Ice - 1.5 ft
Typical Maximum Broken Ice - 6.0 ft
Isolated Maximum Level Ice - 2.0 ft
Isolated Maximum Broken Ice - 12.0 ft

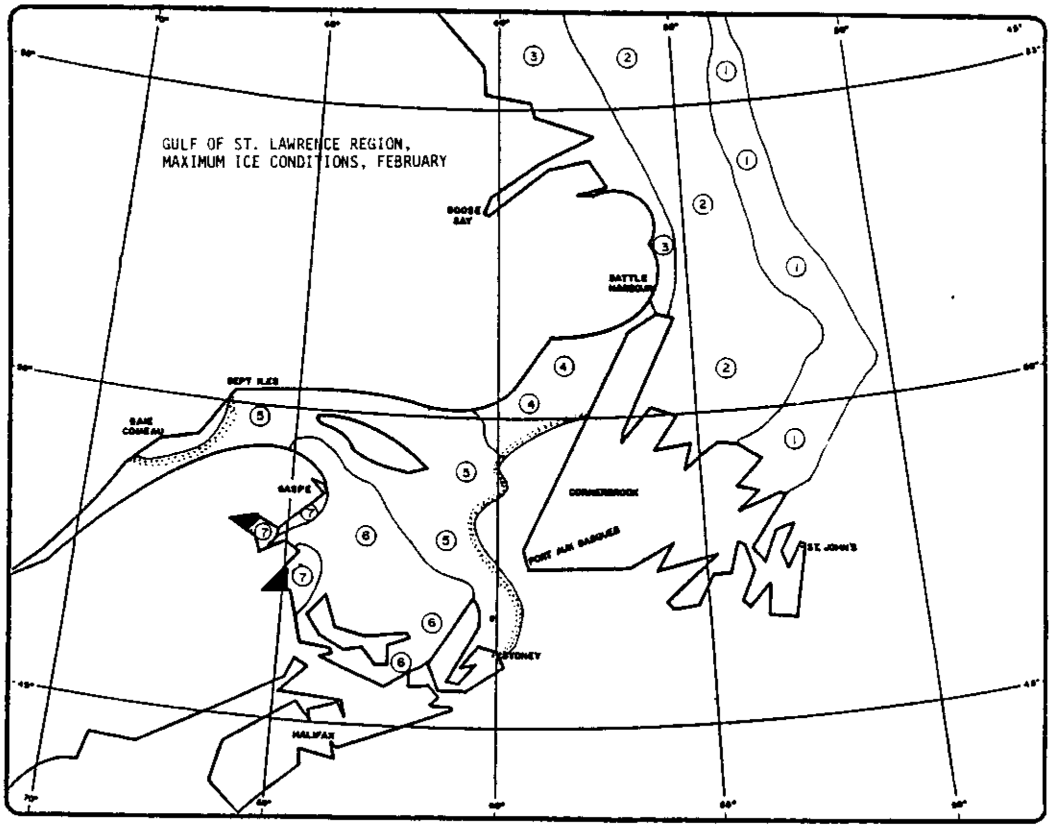
APPENDIX A.5

GULF OF ST. LAWRENCE - MAXIMUM AND AVERAGE ICE CONDITIONS BY MONTH



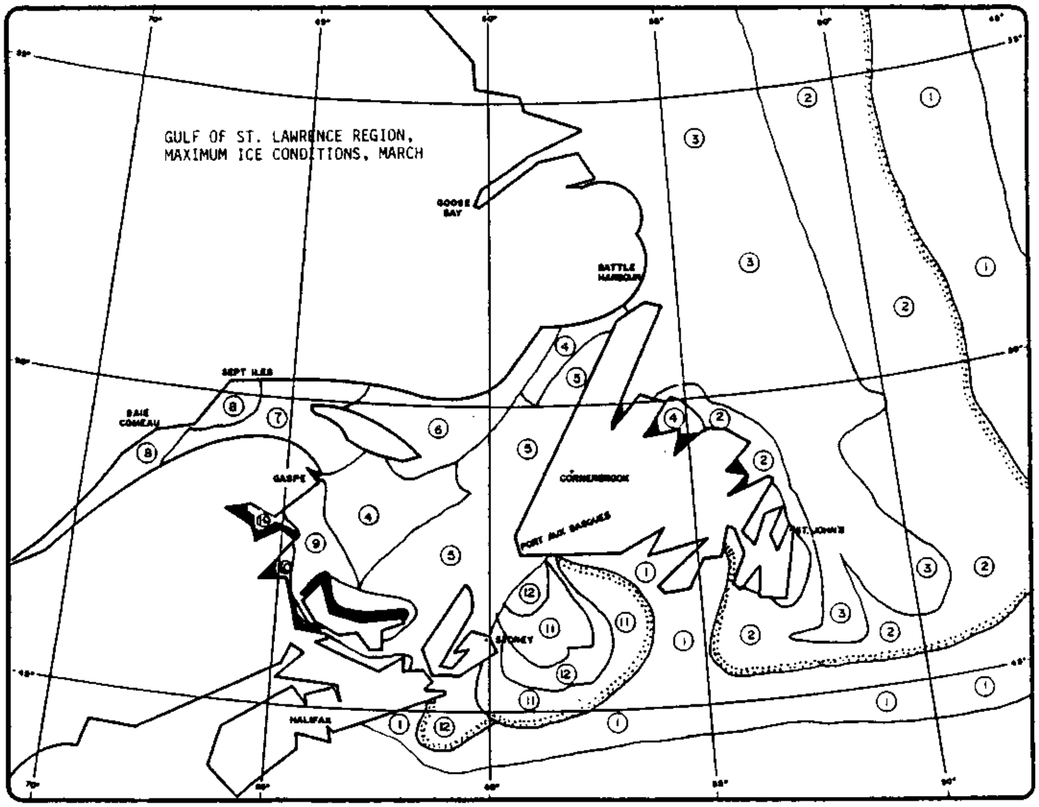
MAXIMUM ICE CONDITIONS, JANUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 1.25
2	FY 0.6
3	FY 0.4
4	FY 0.2
5	FY 1.0
6	FY 1.25



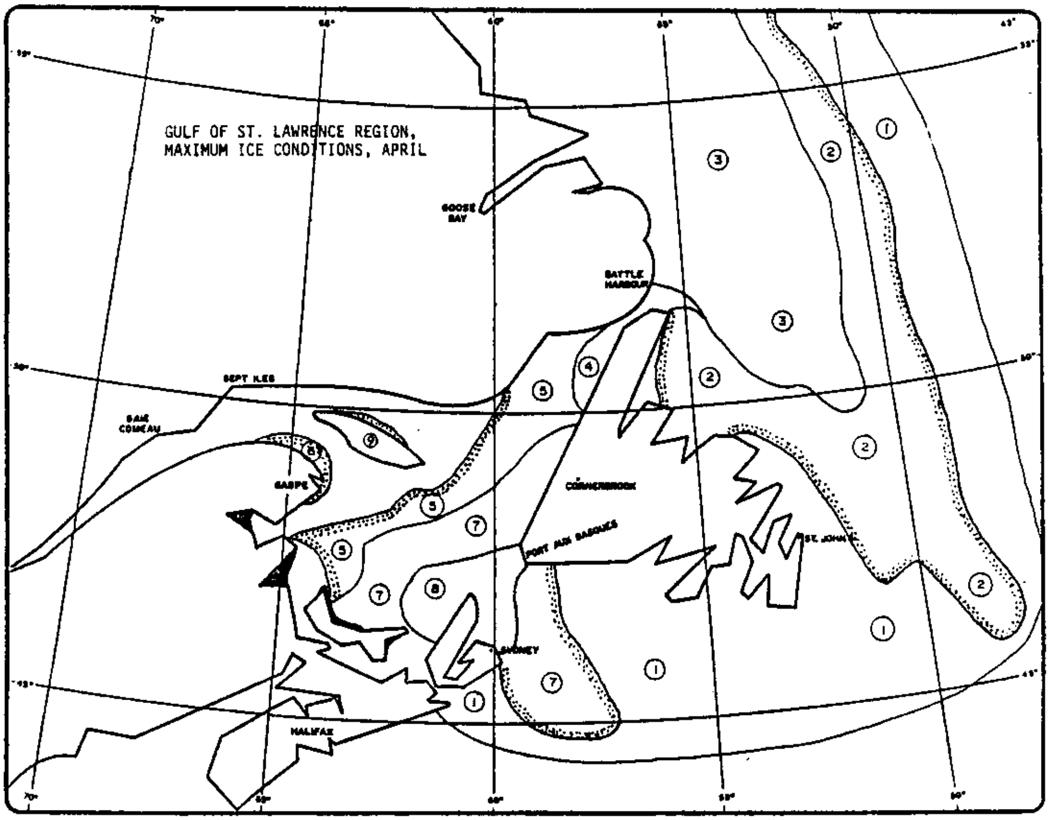
MAXIMUM ICE CONDITIONS, FEBRUARY

ICE AREA	ICE CHARACTERISTICS
1	BI 0.6-2.5
2	FY 3.2
3	FY 1.2
4	FY 0.8
5	FY 1.0
6	FY 2.0
7	FY 2.3



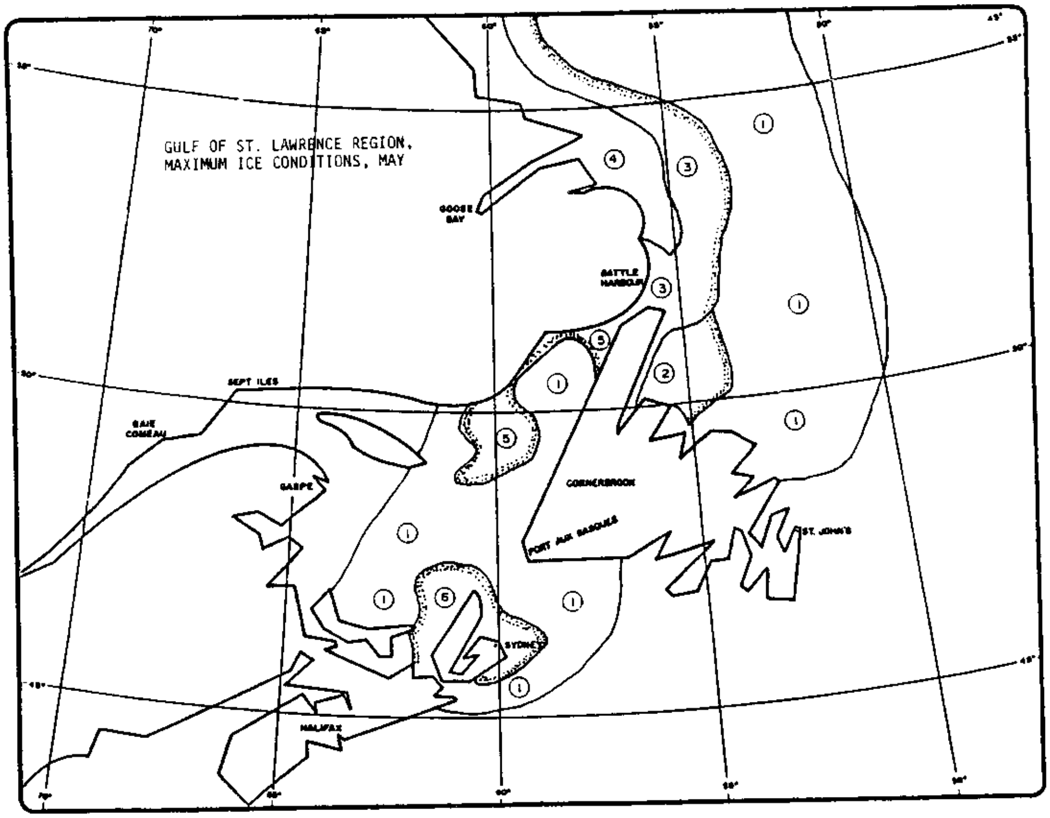
MAXIMUM ICE CONDITIONS, MARCH

ICE AREA	ICE CHARACTERISTICS
1	ICEBERGS
2	BI 0.8-3.0
3	FY 4.0
4	FY 2.5
5	FY 1.8
6	FY 2.8
7	FY 2.0
8	FY 2.2
9	FY 3.0
10	FY 3.2
11	BI 0.8-2.2
12	BI 0.4-2.2



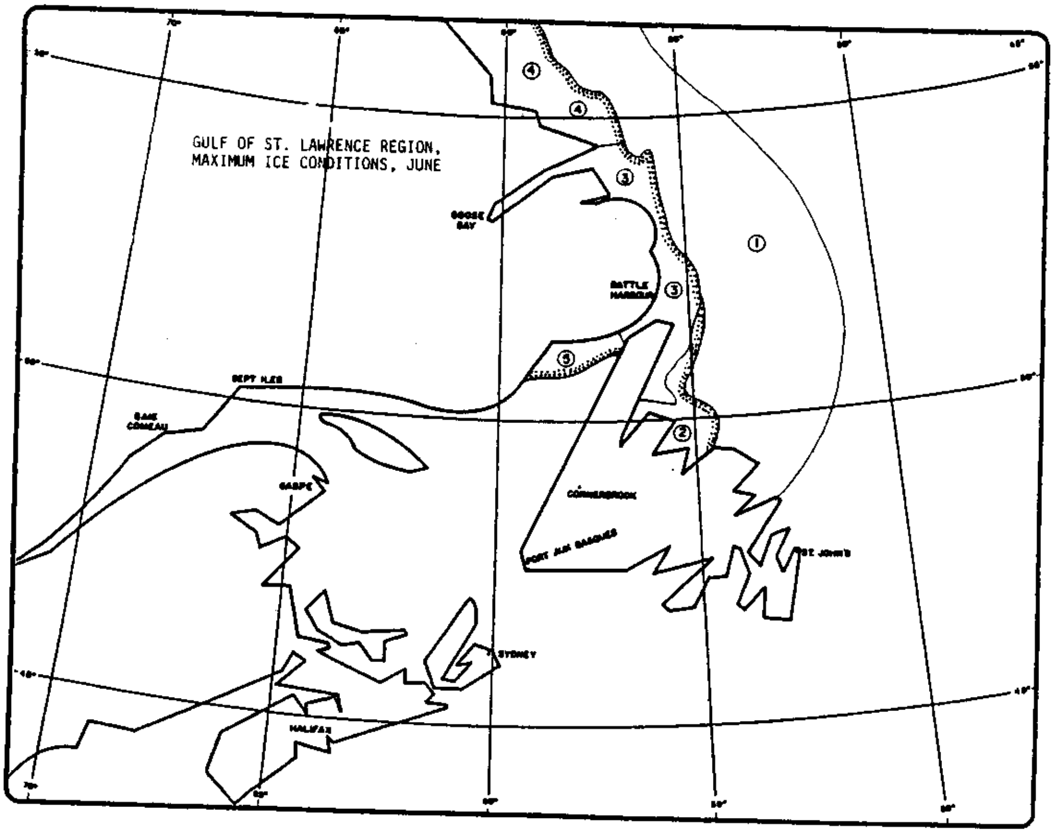
MAXIMUM ICE CONDITIONS, APRIL

ICE AREA	ICE CHARACTERISTICS
1	ICEBERGS
2	BI 0.8-3.3
3	FY 4.2
4	FY 2.8
5	BI 0.7-2.0
6	BI 0.7-1.5
7	FY 1.5
8	FY 2.0
9	BI 0.6-1.8



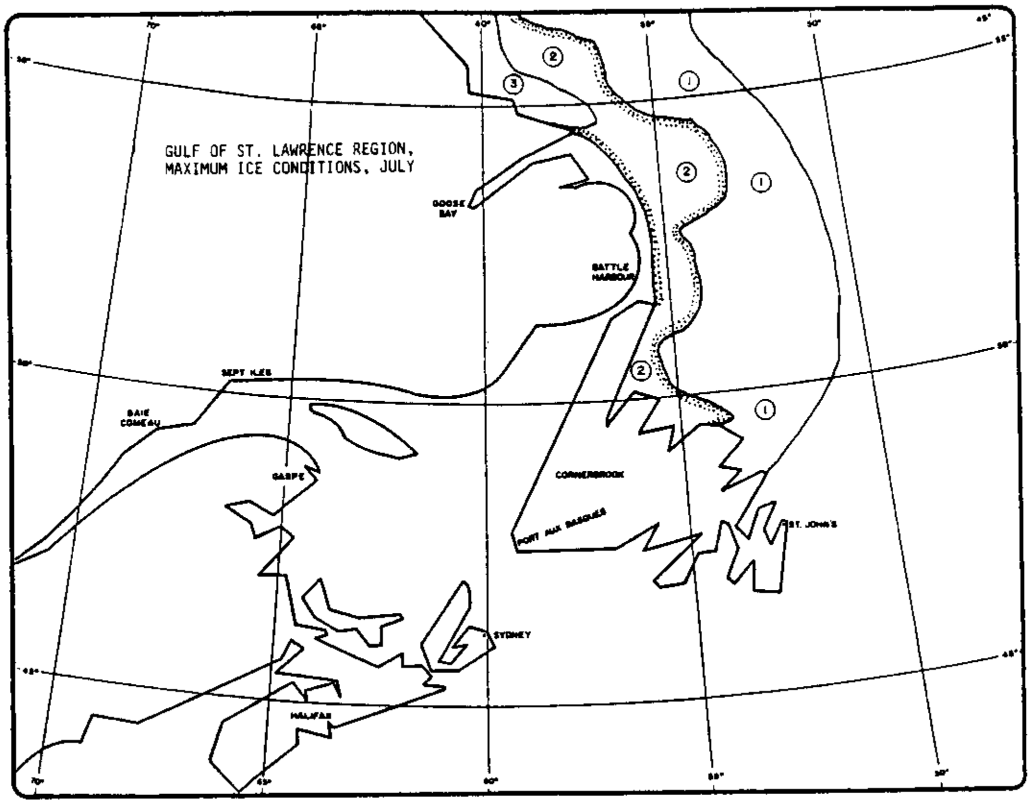
MAXIMUM ICE CONDITIONS, MAY

ICE AREA	ICE CHARACTERISTICS
1	ICEBERGS
2	BI 0.4-2.0
3	FY 2.8, MY 10.0
4	FY 3.3, MY 13.0
5	BI 0.3-1.8
6	BI 0.2-1.5



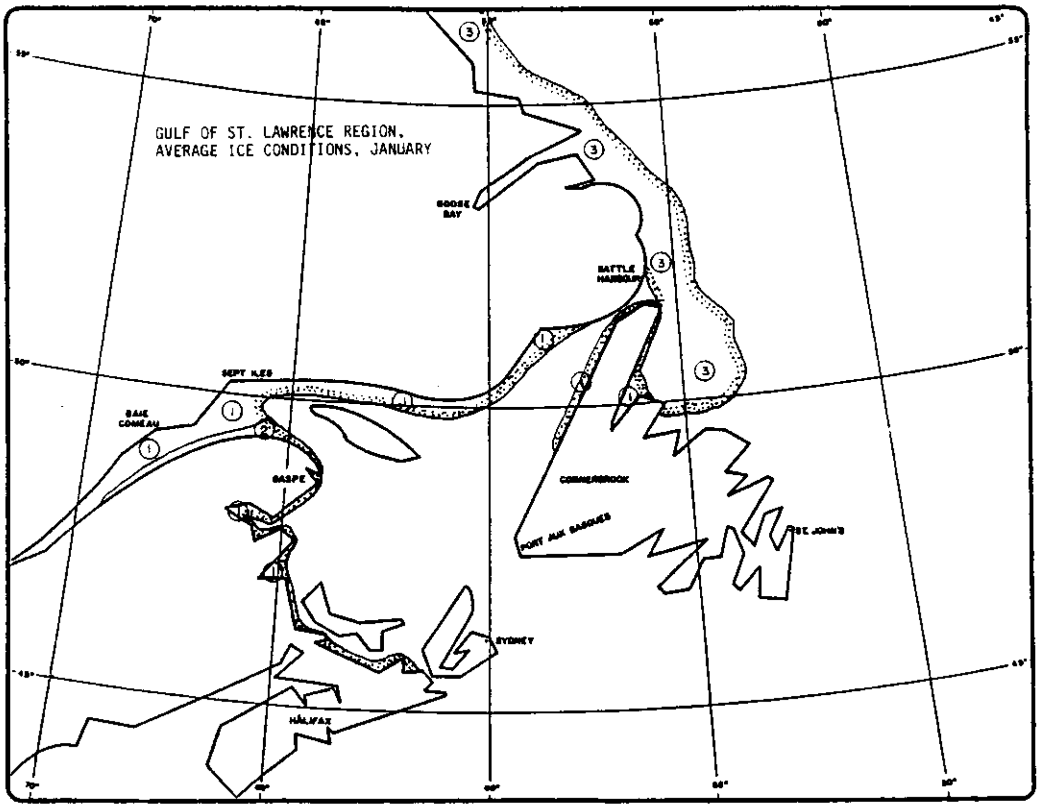
MAXIMUM ICE CONDITIONS, JUNE

ICE AREA	ICE CHARACTERISTICS
1	ICEBERGS
2	BI 0.6-1.2
3	FY 2.0, MY 10.0
4	FY 2.2, MY 12.0
5	BI 0.3-1.0



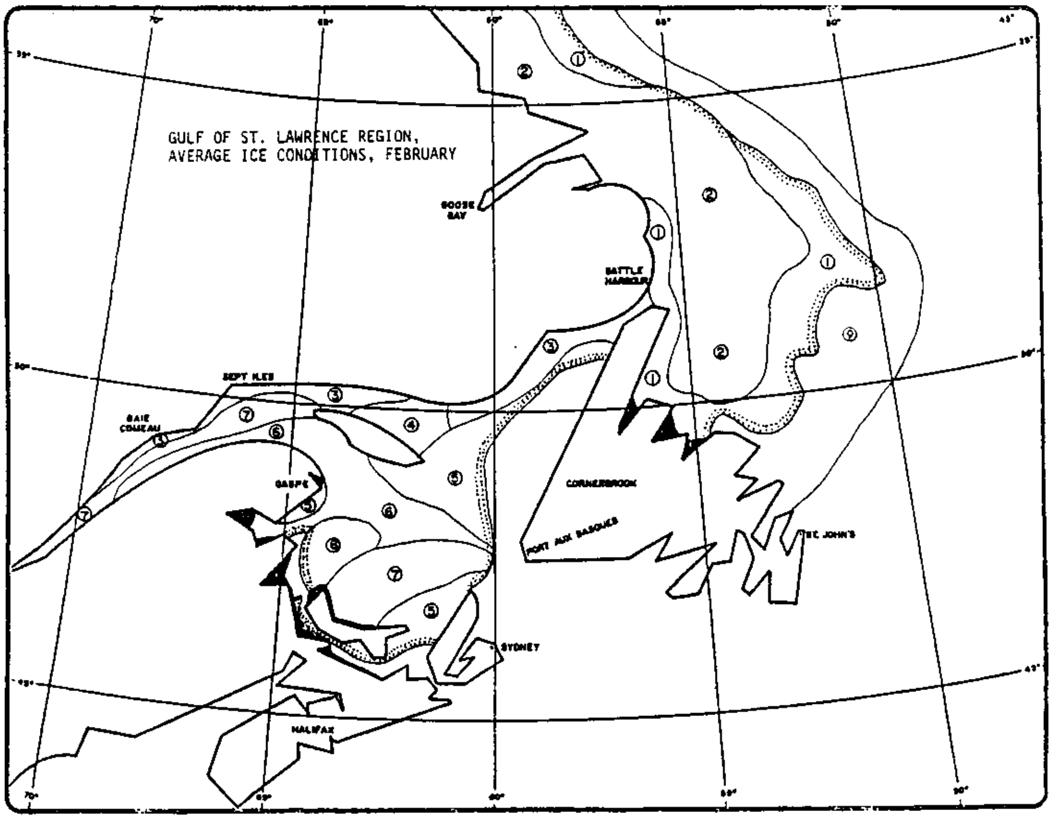
MAXIMUM ICE CONDITIONS, JULY

ICE AREA	ICE CHARACTERISTICS
1	ICEBERGS
2	BI 0.2-1.0
3	FY 1.5, MY 10.0



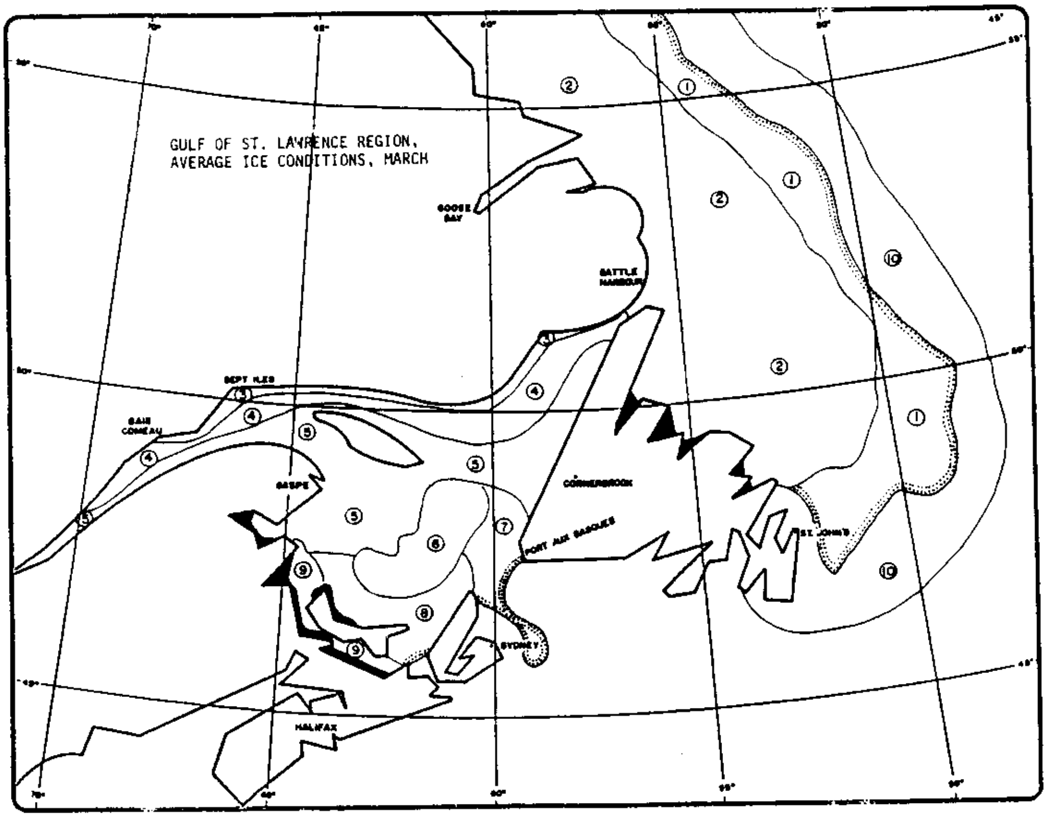
AVERAGE ICE CONDITIONS, JANUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 0.5
2	FY 1.0
3	FY 1.5



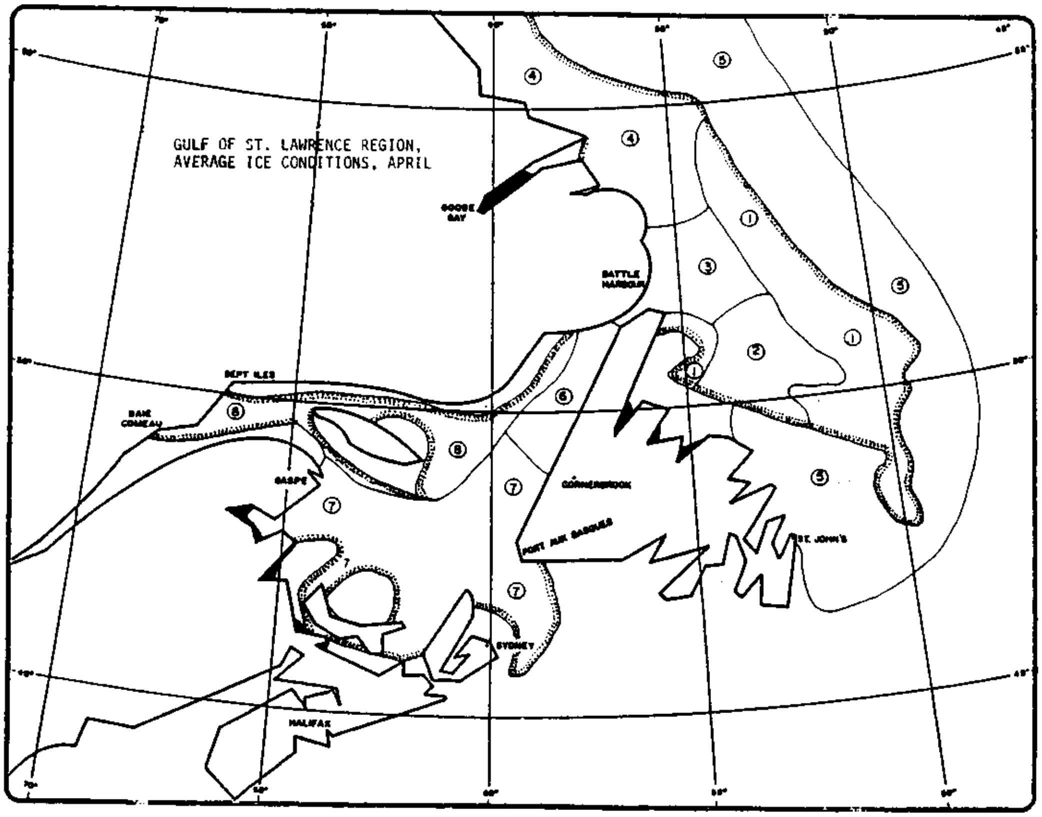
AVERAGE ICE CONDITIONS, FEBRUARY

ICE AREA	ICE CHARACTERISTICS
1	BI 0.5-0.8
2	FY 2.5
3	FY 1.5
4	FY 1.8
5	BI 0.7-0.3
6	FY 1.4
7	FY 1.2
8	FY 1.3
9	ICEBERGS



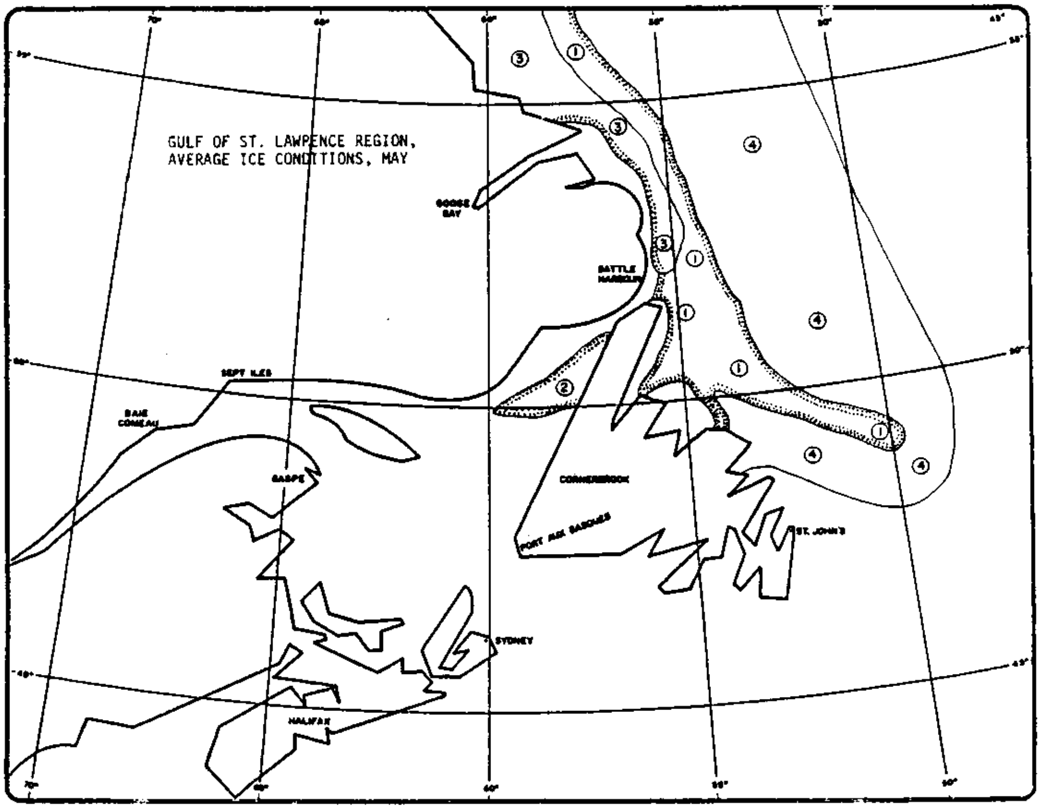
AVERAGE ICE CONDITIONS, MARCH

ICE AREA	ICE CHARACTERISTICS
1	BI 0.6-1.5
2	FY 3.0
3	FY 0.8
4	FY 1.5
5	FY 2.0-12
6	FY 2.2-10
7	FY 1.0
8	FY 1.2
9	FY 1.3
10	ICEBERGS



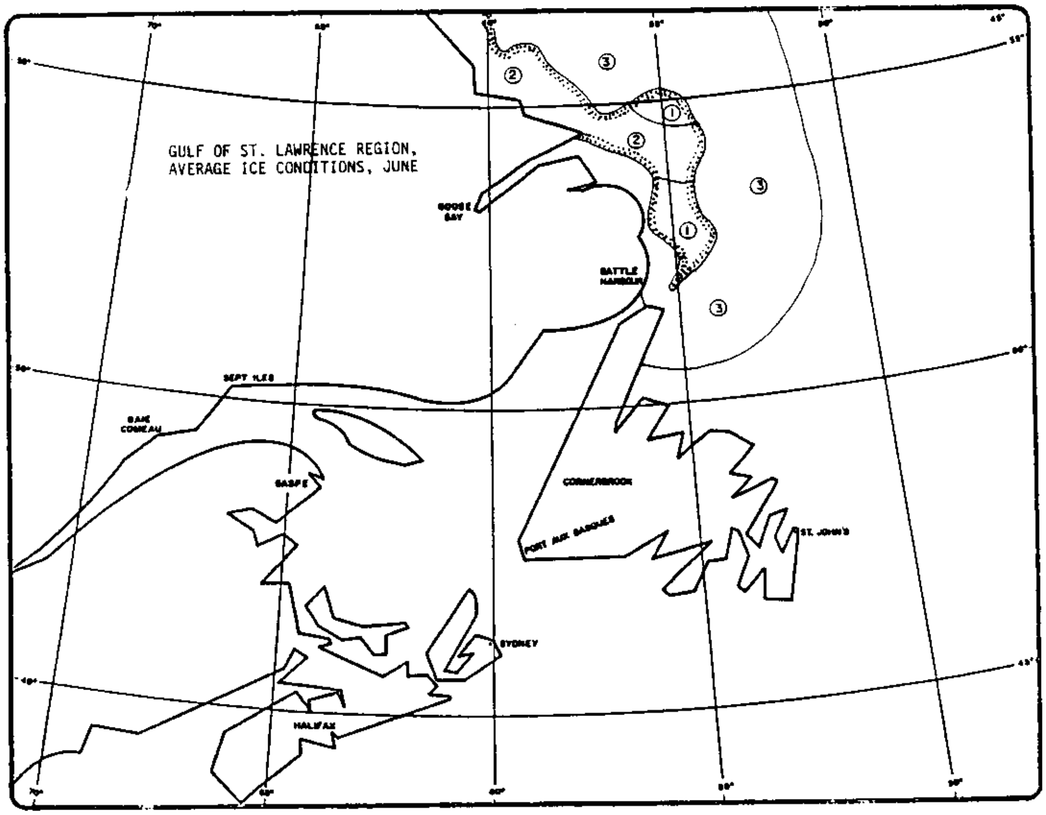
AVERAGE ICE CONDITIONS, APRIL

ICE AREA	ICE CHARACTERISTICS
1	BI 0.3-1.3
2	FY 2.5
3	FY 2.8
4	FY 3.2
5	ICEBERGS -
6	FY 1.8
7	BI 0.8-2.0
8	BI 0.6-1.5



AVERAGE ICE CONDITIONS, MAY

ICE AREA	ICE CHARACTERISTICS
1	BI 0.5-1.0
2	BI 0.3-0.7
3	FY 3.0, MY 12.0
4	ICEBERGS

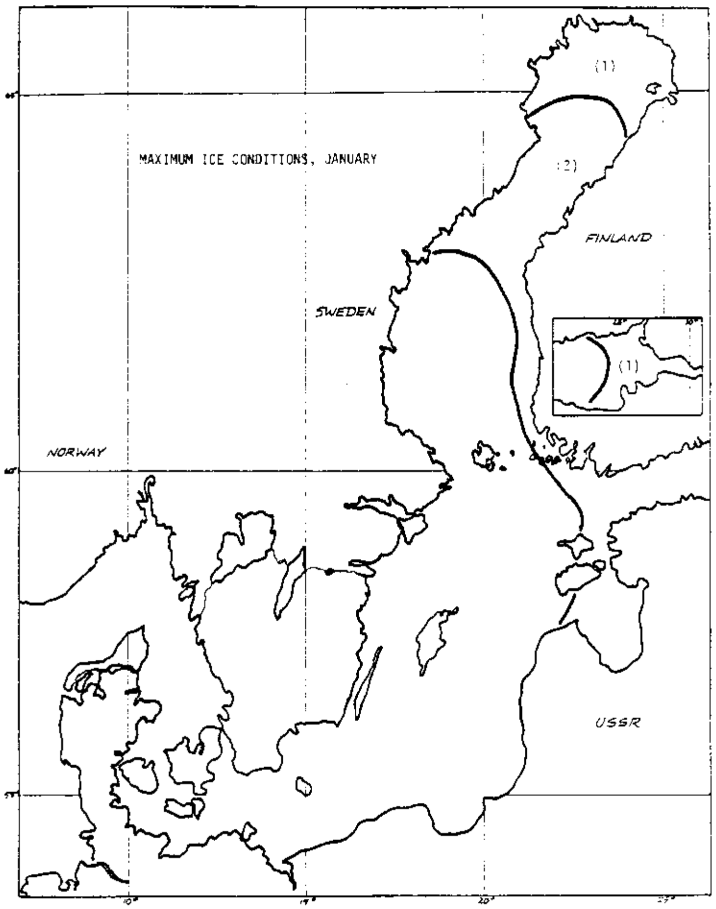


AVERAGE ICE CONDITIONS, JUNE

ICE AREA	ICE CHARACTERISTICS
1	BI 0.3-1.0
2	FY 2.0, MY 6.0
3	ICEBERGS

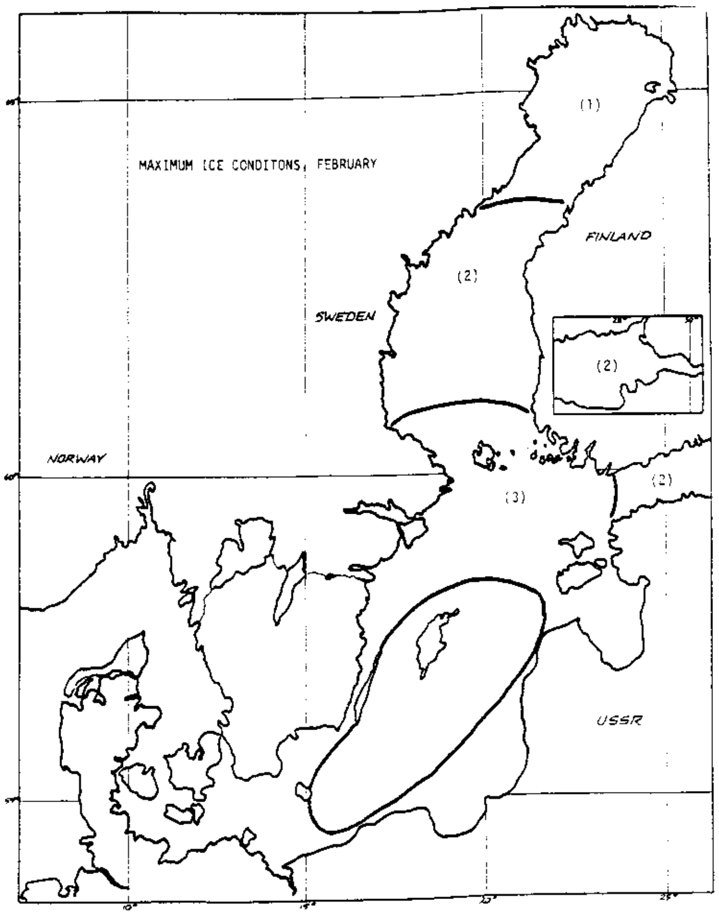
APPENDIX A.6

BALTIC SEA - MAXIMUM AND AVERAGE ICE CONDITIONS BY MONTH



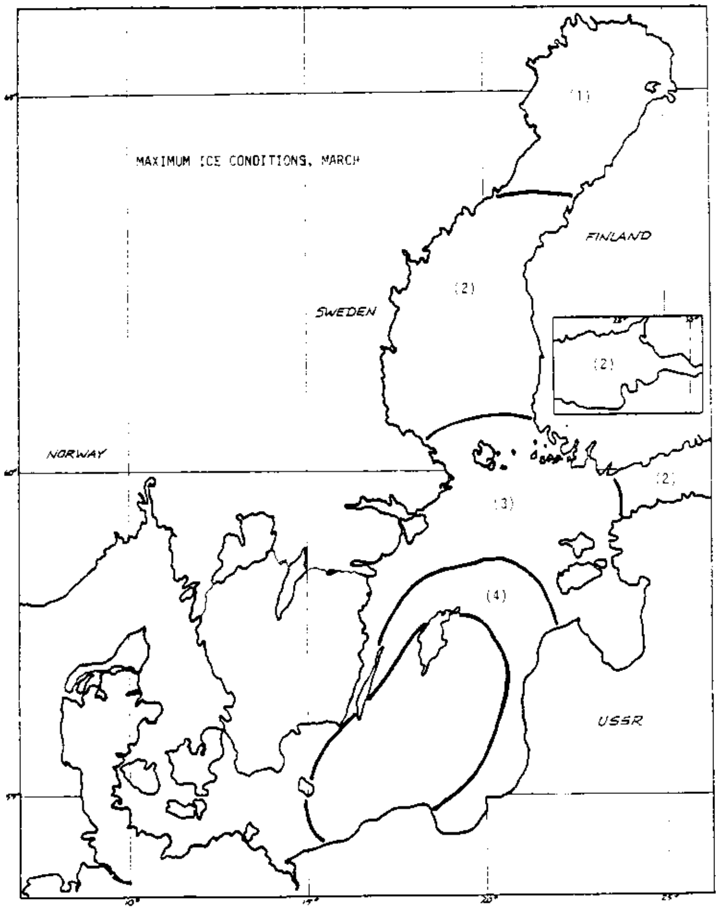
MAXIMUM ICE CONDITIONS, JANUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 2
2	FY 1



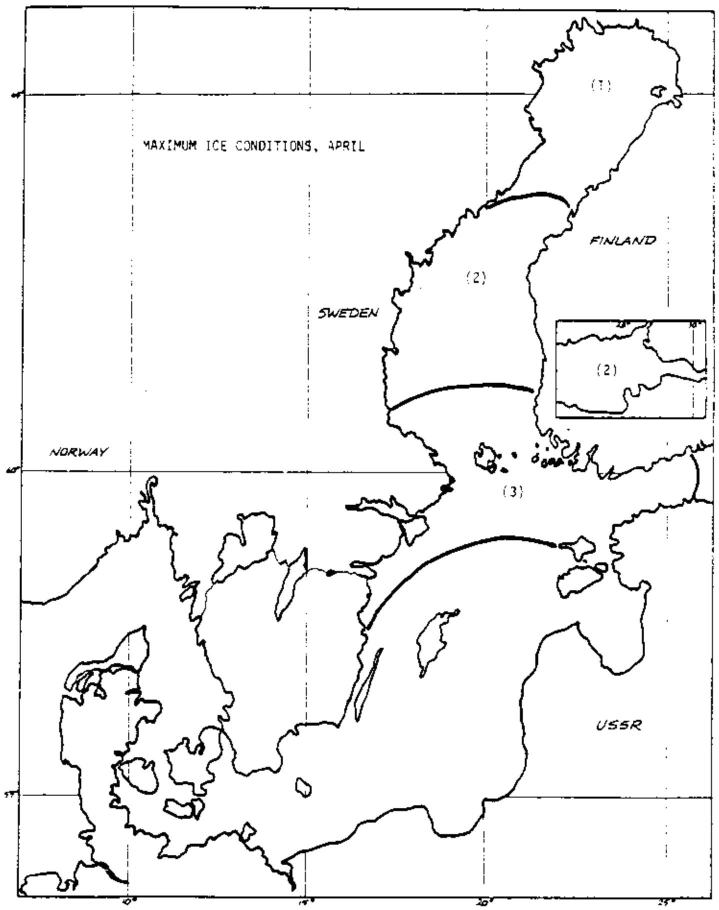
MAXIMUM ICE CONDITIONS, FEBRUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 3
2	FY 2
3	FY 1



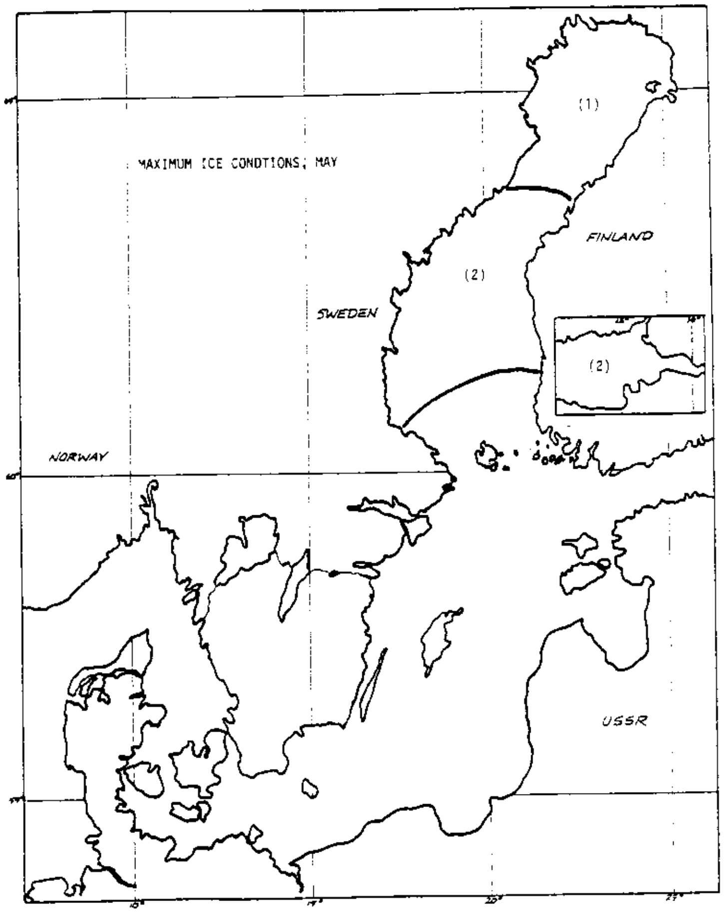
MAXIMUM ICE CONDITIONS, MARCH

ICE AREA	ICE CHARACTERISTICS
1	FY 3
2	FY 2
3	FY 1.5
4	FY 1



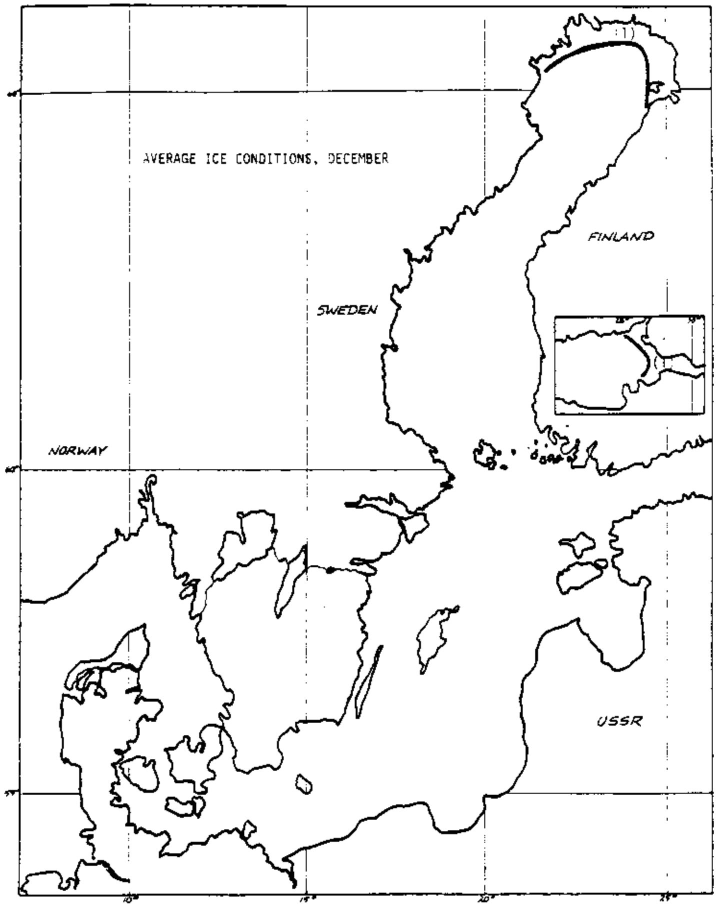
MAXIMUM ICE CONDITIONS, APRIL

ICE AREA	ICE CHARACTERISTICS
1	FY 3
2	FY 2
3	FY 1



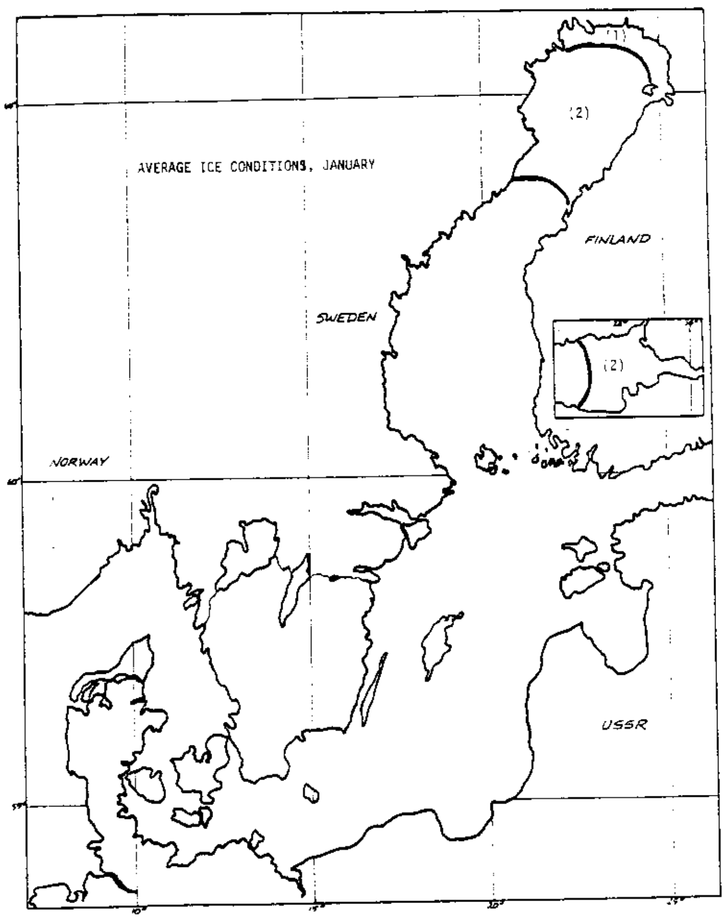
MAXIMUM ICE CONDITIONS, MAY

ICE AREA	ICE CHARACTERISTICS
1	FY 2
2	FY 1



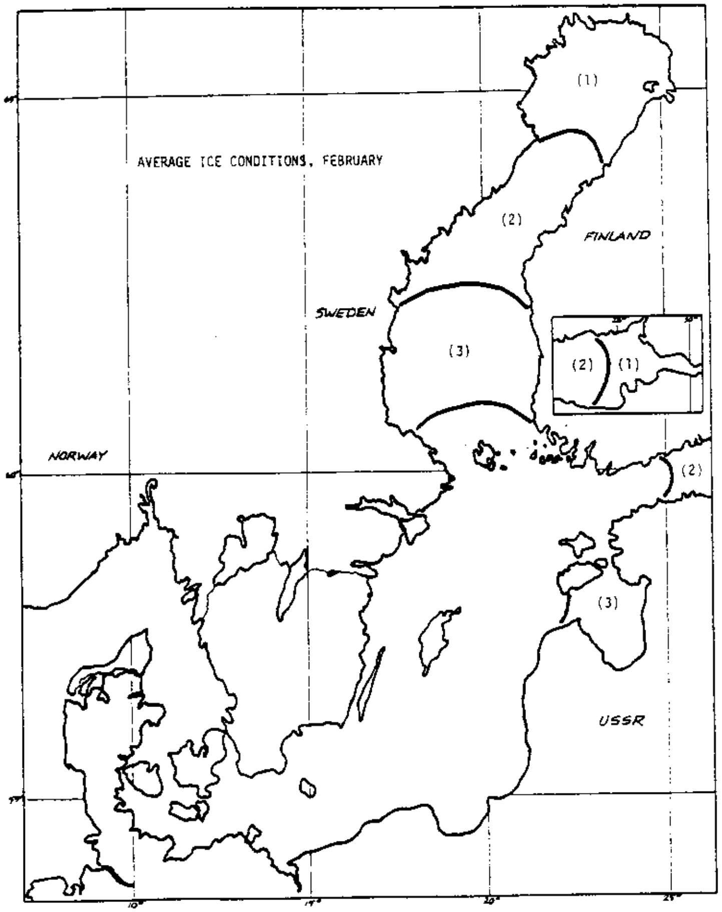
AVERAGE ICE CONDITIONS, DECEMBER

ICE AREA	ICE CHARACTERISTICS
1	FY 1



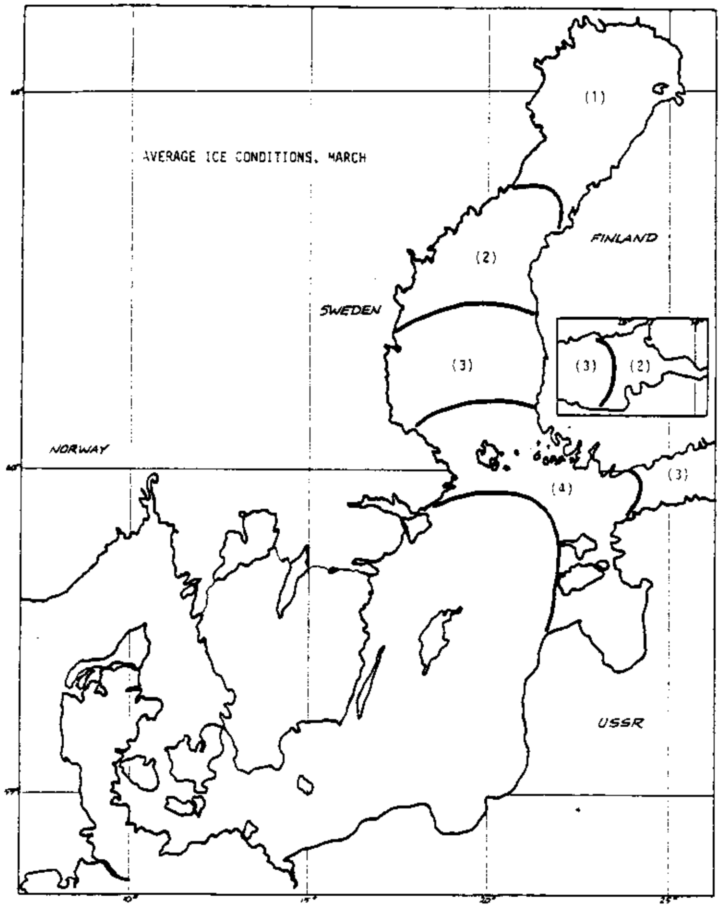
AVERAGE ICE CONDITIONS, JANUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 2
2	FY 1



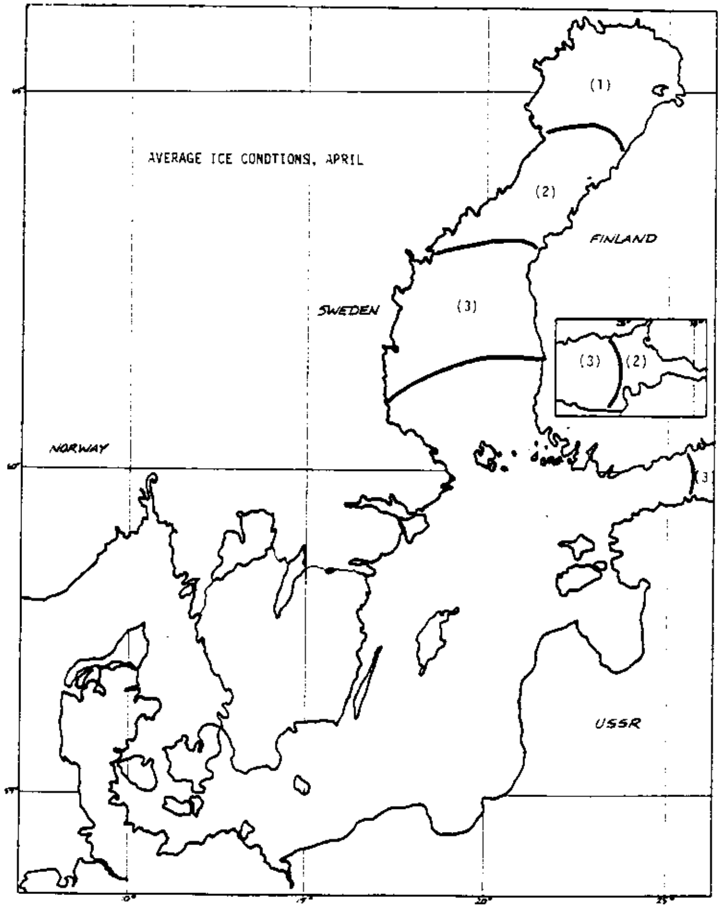
AVERAGE ICE CONDITIONS, FEBRUARY

ICE AREA	ICE CHARACTERISTICS
1	FY 3
2	FY 2
3	FY 1



AVERAGE ICE CONDITIONS, MARCH

ICE AREA	ICE CHARACTERISTICS
1	FY 3
2	FY 2
3	FY 1.5
4	FY 1



AVERAGE ICE CONDITIONS, APRIL

ICE AREA	ICE CHARACTERISTICS
1	FY 3
2	FY 2
3	FY 1

APPENDIX A.7

WORLD METEOROLOGICAL ORGANIZATION SEA ICE NOMENCLATURE

ICE TERMS ARRANGED IN ALPHABETICAL ORDER

Aged ridge: *Ridge* which has undergone considerable weathering. These ridges are best described as undulations.

Anchor ice: Submerged ice attached or anchored to the bottom, irrespective of the nature of its formation.

Bare ice: Ice without snow cover.

Belt: A large feature of *pack ice* arrangement; longer than it is wide; from 1 km to more than 100 km in width.

Bergy bit: A large piece of floating *glacier ice*, generally showing less than 5 m above sea-level but more than 1 m and normally about 100-300 sq. m in area.

Beset: Situation of a vessel surrounded by ice and unable to move.

Big floe: (see *Floe*).

Bight: An extensive crescent-shaped indentation in the *ice edge*, formed by either wind or current.

Brash ice: Accumulations of *floating ice* made up of fragments not more than 2 m across, the wreckage of other forms of ice.

Bummock: From the point of view of the submariner, a downward projection from the underside of the *ice canopy*; the counterpart of a *hummock*.

Calving: The breaking away of a mass of ice from an *ice wall, ice front*, or *iceberg*.

Close pack ice: *Pack ice* in which the *concentration* is 7/10 to 8/10 (6/8 to less than 7/8, composed of *floes* mostly in contact.

Compacted ice edge: Close, clear-cut *ice edge* compacted by wind or current; usually on the windward side of an area of *pack ice*.

Compacting: Pieces of *floating ice* are said to be compacting when they are subjected to a converging motion, which increases ice *concentration* and/or produces stresses which may result in ice deformation.

Compact pack ice: *Pack ice* in which the *concentration is* 10/10 (8/8) and no water is visible.

Concentration: The ratio in tenths of the sea surface actually covered by ice to the total area of sea surface, both ice-covered and *ice-free*, at a specific location or over a defined area.

Concentration boundary: A line approximating the transition between two areas of *pack ice* with distinctly different *concentrations*.

Consolidated pack ice: *Pack ice* in which the *concentration* is 10/10 (8/8) and the *floes* are frozen together.

Consolidated ridge. A *ridge* in which the base has frozen together.

Crack: Any *fracture* which has not parted.

Dark nilas: *Nilas* which is under 5 cm in thickness and is very dark in color.

Deformed ice: A general term for ice which has been squeezed together and in places forced upwards (and downwards). Subdivisions are *rafted ice, ridged ice*, and *hummocked ice*.

Difficult area: A general qualitative expression to indicate, in a relative manner, that the severity of ice conditions prevailing in an area is such that navigation in it is difficult.

Diffuse ice edge: Poorly defined *ice edge* limiting an area of dispersed ice; usually on the leeward side of an area of *pack ice*.

Diverging: *Ice fields* or *floes* in an area are subjected to diverging or dispersive motion, thus reducing ice *concentration* and/or relieving stress in the ice.

Dried ice: *Sea ice* from the surface of which melt-water has disappeared after the formation of *cracks* and *thaw holes*. During the period of drying, the surface whitens.

Easy area: A general qualitative expression to indicate, in a relative manner, that ice conditions prevailing in an area are such that navigation in it is not difficult.

Fast ice: *Sea ice* which forms and remains fast along the coast, where it is attached to the shore, to an *ice wall*, to an *ice front*, between shoals or grounded *icebergs*. Vertical fluctuations may be observed during changes of sea-level. Fast ice may be formed *in situ* from sea water or by freezing of *pack ice* of any age to the shore, and it may extend a few metres or several hundred kilometres from the coast. Fast ice may be more than one year old and may then be prefixed with the appropriate age category(*old*, *second-year*, or *multi-year*). If it is thicker than about 2 m above sea-level it is called an *ice shelf*.

Fast-ice boundary: The *ice boundary* at any given time between *fast ice* and *pack ice*.

Fast-ice edge: The demarcation at any given time between *fast ice* and *open water*.

Finger rafted ice: Type of *rafted ice* in which *floes* thrust "fingers" alternately over and under the other.

Finger rafting: Type of rafting whereby interlocking thrusts are formed, each floe thrusting "fingers" alternately over and under the other. Common in *nilas* and *grey ice*.

Firn: Old snow which has recrystallized into a dense material. Unlike snow, the particles are to some extent joined together; but, unlike ice, the air spaces in it still connect with each other.

First-year ice: *Sea ice* of not more than one winter's growth, developing from *young ice*; thickness 30 cm - 2 m. May be subdivided into *thin first-year ice* /white ice, *medium first-year ice*, and *thick first-year ice*.

Flaw: A narrow separation zone between *pack ice* and *fast ice*, where the pieces of ice are in chaotic state; it forms when pack ice shears under the effect of a strong wind or current along the *fast ice boundary*.

Flaw lead: A passage-way between *pack ice* and *fast ice* which is navigable by surface vessels.

Flaw polynya: A *polynya* between *pack ice* and *fast ice*.

Floating ice: Any form of ice found floating in water. The principal kinds of floating ice are *lake ice*, *river ice*, and *sea ice*, which form by the freezing of water at the surface, and *glacier ice* (*ice of land origin*) formed on land or in an *ice shelf*. The concept includes ice that is stranded or grounded.

Floe: Any relatively flat piece of *sea ice* 20 m or more across. Floes are subdivided according to horizontal extent as follows:

GIANT: Over 10 km across.
VAST: 2-10 km across.
BIG: 500-2,000 m across.
MEDIUM: 100-500 m across.
SMALL: 20-100 m across.

Floeberg: A massive piece of *sea ice* composed of a *hummock*, or a group of *hummocks*, frozen together and separated from any ice surroundings. It may float up to 5 m above sea-level.

Flooded ice: *Sea ice* which has been flooded by melt-water or river water and is heavily loaded by water and wet snow.

Fracture: Any break or rupture through *very close pack ice*, *compact pack ice*, *consolidated pack ice*, *fast ice*, or a single *floe* resulting from deformation processes. Fractures may contain *brash ice* and/or be covered with *nilas* and/or *young ice*. Length may vary from a few meters to many kilometers.

Fracture zone: An area which has a great number of fractures.

Fracturing: Pressure process whereby ice is permamently deformed, and rupture occurs. Most commonly used to describe breaking across *very close pack ice*, *compact pack ice*, and *consolidated pack ice*.

Frazil ice: Fine spicules or plates of ice, suspended in water.

Friendly ice: From the point of view of the submariner, an *ice canopy* containing may large *skylights* or other features which permit a submarine to surface. There must be more than ten such features per 30 nautical miles (56 km) along the submarine's track.

Frost smoke: Fog-like clouds due to contact of cold air with relatively warm water, which can appear over openings in the ice, or leeward of the *ice edge*, and which may persist while ice is forming.

Giant floe: (see *Floe*).

Glacier: A mass of snow and ice continuously moving from higher to lower ground or, if afloat, continuously spreading. The principal forms of glacier are: inland ice sheets, *ice shelves, ice streams*, ice caps, ice piedmonts, cirque glaciers, and various types of mountain (valley) glaciers.

Glacier berg: An irregularly shaped *iceberg*.

Glacier ice: Ice in, or originating from, *a glacier*, whether on land or floating on the sea as *icebergs, bergy bits,* or *growlers*.

Glacier tongue: Projecting seaward extenstion of a *glacier*, usually afloat. In the Antarctic glacier tongues may extend over many tens of kilometers.

Grease ice: A later stage of freezing than *frazil ice* when the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the sea a matt appearance.

Grey ice: *Young ice* 10-15 cm thick. Less elastic than *nilas* and breaks on swell. Usually rafts under pressure.

Grey-white ice: *Young ice* 15-30 cm thick. Under pressure more likely to ridge than to raft.

Grounded hummock: Hummocked *grounded ice* formation. There are single grounded *hummocks* and lines (or chains) of grounded *hummocks*.

Grounded ice: *Floating ice* which is aground in shoal water.

Growler: Smaller piece of ice than *a bergy bit* or *floeberg*, often transparent but appearing green or almost black in color, extending less than 1 m above the sea surface and normally occupying an area of about 20 sq. m.

Hostile ice: From the point of view of the submariner, an *ice canopy* containing no large *skylights*.

Hummock: A hillock of broken ice which has been forced upwards by pressure. May be fresh or weathered. The submerged volume of broken ice under the hummock, forced downwards by pressure, is termed a *hummock*.

Hummocked ice: *Sea ice* piled haphazardly one piece over another to form an uneven surface. When weathered, has the appearance of smooth hillocks.

Hummocking: The pressure process by which *sea ice* is forced into *hummocks*. When the floes rotate in the process it is termed screwing.

Iceberg: A massive piece of ice of greatly varying shape, more than 5 m above sea-level, which has broken away from a *glacier*, and which may be afloat or aground. Icebergs may be described as *tabular*, dome-shaped, sloping, pinnacled, weathered, or *glacier bergs*.

Iceberg tongue: A major accumulation of *icebergs* projecting from the coast, held in place by grounding and joined together by *fast ice*.

Ice blink: A whitish glare on low clouds above an accumulation of distant ice.

Ice-bound: A harbor, inlet, etc., is said to be ice-bound when navigation by ships is prevented on account of ice, except possibly with the assistance of an icebreaker.

Ice boundary: The demarcation at any given time between *fast ice* and *pack ice* or between areas of *pack ice* of different *concentrations*.

Ice breccia: Ice pieces of different age frozen together.

Ice cake: Any relatively flat piece of *sea ice* less than 20 m across.

Ice canopy: *Pack ice* from the point of view of the submariner.

Ice cover: The ratio of an area of ice of any concentration to the total area of sea surface within some large geographic local; this local may be global, hemispheric, or prescribed by a specific oceanographic entity such as Baffin Bay or the Barents Sea.

Ice edge: The demarcation at any given time between the open sea and *sea ice* of any kind, whether fast or drifting. It may be termed *compacted* or *diffuse*.

Ice field: Area of *pack ice* consisting of any size of *floes*, which is greater than 10 km across.

Icefoot: A narrow fringe of ice attached to the coast, unmoved by tides and remaining after the *fast ice* has moved away.

Ice-free: No *sea ice* present. There may be some *ice of land origin*.

Ice front: The vertical cliff forming the seaward face of an *ice shelf* or other floating *glacier* varying in height from 2-50 m or more above sea-level.

Ice island: A large piece of floating ice about 5 m above sea-level, which has broken away from an Arctic ice shelf, having a thickness of 30-50 m and an area of from a few thousand square meters to 500 sq. km or more, and usually characterized by a regularly undulating surface which gives it a ribbed appearance from the air.

Ice jam: An accumulation of broken *river ice* or *sea ice* caught in a narrow channel.

Ice keel: From the point of view of the submariner, a downward-projecting ridge on the underside of the *ice canopy*; the counterpart of a ridge. Ice keels may extend as much as 50 m below sea-level.

Ice limit: Climatological term referring to the extreme minimum or extreme maximum extent of the *ice edge* in any given month or period based on observations over a number of years. Term should be preceded by minimum or maximum.

Ice massif: A concentration of *sea ice* covering hundreds of square kilometers, which is found in the same region every summer.

Ice of land origin: Ice formed on land or in an *ice shelf*, found floating in water. The concept includes,ice that is stranded or grounded.

Ice patch: An area of *pack ice* less than 10 km across.

Ice port: An embayment in an *ice front*, often of a temporary nature, where ships can moor alongside and unload directly onto the ice shelf.

Ice rind: A brittle shiny crust of ice formed on a quiet surface by direct freezing or from *grease ice*, usually in water of low salinity. Thickness to about 5 cm. Easily broken by wind or swell, commonly breaking in rectangular pieces.

Ice shelf: A floating ice sheet of considerable thickness showing 2-50 m or more above sea-level, attached to the coast. Usually of great horizontal extent and with a level or gently undulating surface. Nourished by annual snow accumulation and often also by the seaward extension of land *glaciers*. Limited areas may be aground. The seaward edge is termed an *ice front*.

Ice stream: Part of an inland ice sheet in which the ice flows more rapidly and not necessarily in the same direction as the surrounding ice. The margins are sometimes clearly marked by a change in direction of the surface slope but may be indistinct.

Ice under pressure: Ice in which deformation processes are actively occurring and hence a potential inpediment or danger to shipping.

Ice wall: An ice cliff forming the seaward margin of a *glacier* which is not afloat. An ice wall is aground, the rock basement being at or below sea-level.

Lake ice: Ice formed on a lake, regardless of observed location.

Large fracture: More than 500 m wide.

Large ice field: An *ice field* over 20 km across.

Lead: Any *fracture* or passage-way through *sea ice* which is navigable by surface vessels.

Level ice: *Sea ice* which is unaffected by deformation.

Light nilas: *Nilas* which is more than 5 cm in thickness and rather lighter in color than *dark nilas*.

Mean ice edge: Average position of the *ice edge* in any given month or period based on observations over a number of years. Other terms which may be used are mean maximum ice edge and mean minimum ice edge.

Medium first-year ice: *First-year ice* 70-120 cm thick.

Medium floe: (see *Floe*).

Medium fracture: 200 to 500 m wide.

Medium ice field: An *ice field* 15-20 km across.

Multi-year ice: *Old ice* up to 3 m or more thick which has survived at least two summers' melt. *Hummocks* even smoother than in *second-year ice*, and the ice is almost salt-free. Color, where bare, is usually blue. Melt pattern consists of large interconnecting irregular *puddles* and a well-developed drainage system.

New ice: A general term for recently formed ice which includes *frazil ice, grease ice, slush,* and *shuga*. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat.

New ridge: *Ridge* newly formed with sharp peaks and slope of sides usually 40°. Fragments are visible from the air at low altitude.

Nilas: A thin elastic crust of ice, easily bending on waves and swell and under pressure, thrusting in a pattern of interlocking "fingers" (*finger rafting*). Has a matt surface and is up to 10 cm in thickness. May be subdivided into *dark nilas* and *light nilas*.

Nip: Ice is said to nip when it forcibly presses against a ship. A vessel so caught, though undamaged, is said to have been nipped.

Old ice: *Sea ice* which has survived at least one summer's melt. Most topographic features are smoother than on *first-year ice*. May be subdivided into *second-year ice* and *multi-year ice*.

Open pack ice: *Pack ice* in which the ice *concentration* is 4/10 to 6/10 (3/8 to less than 6/8) with many *leads* and *polynyas*, and the *floes* are generally not in contact with one another.

Open water: A large area of freely navigable water in which *sea ice* is present in *concentrations* less than 1/10 (1/8). When there is no sea ice present, the area should be termed *ice-free*, even though icebergs are present.

Pack ice: Term used in a wide sense to include any area of *sea ice*, other than *fast ice*, no matter what from it takes or how it is disposed.

Pancake ice: Predominantly circular pieces of ice from 30 cm - 3 m in diameter, and up to about 10 cm in thickness, with raised rims due to the pieces striking against one another. It may be formed on a slight swell from *grease ice*, *shuga* or *slush* or as a result of the breaking of *ice rind*, *nilas* or, under severe conditions of swell or waves, of *grey ice*. It also sometimes forms at some depth, at an interface between water bodies of different physical characteristics, from where it floats to the surface; its appearance may rapidly cover wide areas of water.

Polynya: Any non-linear shaped opening enclosed in ice. Polynyas may contain *brash ice* and/or be covered with *new ice*, *nilas* or *young ice*; submariners refer to these as *skylights*. Sometines the polynya is limited on one side by the coast and is called a *shore polynya* or by *fast ice* and is called a *flaw polynya*. If it recurs in the same position every year, it is called a *recurring polynya*.

Puddle: An accumulation on ice of melt-water, mainly due to melting snow, but in the more advanced stages also to the melting of ice. Initial stage consists of patches of melted snow.

Rafted ice: Type of *deformed ice* formed by one piece of ice overriding another.

Rafting: Pressure processes whereby one piece of ice overrides another. Most common in *new* and *young ice*.

Ram: An underwater ice projection from an *ice wall*, *ice front*, *iceberg*, or *floe*. Its formation is usually due to a more intensive melting and erosion of the unsubmerged part.

Recurring polynya: A *polynya* which recurs in the same position every year.

Ridge: A line or wall of broken ice forced up by pressure. May be fresh or weathered. The submerged volume of broken ice under a ridge, forced downwards by pressure, is termed an *ice keel*.

Ridged ice: Ice piled hapharzardly one piece over another in the form of ridges or walls. Usually found in first-year ice.

Ridged-ice zone: An area in which much *ridged ice* with similar characteristics has formed.

Ridging: The pressure process by which *sea ice* is forced into *ridges*.

River ice: Ice formed on a river, regardless of observed location.

Rotten ice: *Sea ice* which has become honeycombed and which is in an advanced state of disintegration.

Sastrugi: Sharp, irregular ridges formed on a snow surface by wind erosion and deposition. On mobile *floating ice* the ridges are parallel to the direction of the prevailing wind at the time they were formed.

Sea ice: Any form of ice found at sea which has originated from the freezing of sea water.

Second-year ice: *Old ice* which has survived only one summer's melt. Because it is thicker and less dense than *first-year ice*, it stands higher out of the water. In contrast to *multi-year ice*, summer melting produces a regular pattern of numerous small *puddles*. Bare patches and puddles are usually greenish-blue.

Shearing: An area of *pack ice* is subject to shear when the ice motion varies significantly in the direction normal to the motion, subjecting the ice to rotational forces. These forces may result in phenomena similar to a *flaw*.

Shore lead: A *lead* between *pack ice* and the shore or between *pack ice* and an *ice front*.

Shore polynya: A *polynya* between *pack ice* and the coast or between *pack ice* and an *ice front*.

Shuga: An accumulation of spongy white ice lumps, a few centimeters across; they are formed from *grease ice* or *slush* and sometimes from *anchor ice* rising to the surface.

Skylight: From the point of view of the submariner, thin places in the *ice canopy*, usually less than 1 m thick and appearing from below as relatively light, translucent patches in dark surroundings. The under-surface of a skylight is normally flat. Skylights are called large if big enough for a submarine to attempt to surface through them (120 m), or small if not.

Slush: Snow which is saturated and mixed with water on land or ice surfaces, or as a viscous floating mass in water after a heavy snowfall.

Small floe: (see *Floe*).

Small fracture: 50 to 200 m wide.

Small ice cake: An ice cake less than 2 m across.

Small ice field: An *ice field* 10-15 km across.

Snow-covered ice: Ice covered with snow.

Snowdrift: An accumulation of wind-blown snow deposited in the lee of obstructions or heaped by wind eddies. A crescent-shaped snowdrift, with ends pointing down-wind, is known as a snow barchan.

Standing floe: A separate *floe* standing vertically or inclined and enclosed by rather smooth ice.

Stranded ice: Ice which has been floating and has been deposited on the shore by retreating high water.

Strip: Long narrow area of *pack ice*, about 1 km or less in width, usually composed of small fragments detached from the main mass of ice, and run together under the influence of wind, swell, or current.

Tabular berg: A flat-topped *iceberg*. Most tabular bergs form by *calving* from an *ice shelf* and show horizontal banding.

Thaw holes: Vertical holes in *sea ice* formed when surface *puddles melt through to the underlying water*.

Thick first-year ice: *First-year ice* 30-70 cm thick.

Tide crack: Crack at the line of junction between an immovable *ice foot* or *ice wall* and *fast ice*, the latter subject to rise and fall of the tide.

Tongue: A projection of the ice edge up to several kilometers in length, caused by wind or current.

Vast floe: (see *Floe*).

Very close pack ice: *Pack ice* in which the *concentration* is 9/10 to less than 10/10 (7/8 to less than 8/8).

Very open pack ice: *Pack ice* in which the *concentration* is 1/10 to 3/10 (1/8 to less than 3/8) and water preponderates over ice.

Very small fracture: 0 to 50 m wide.

Very weathered ridge: *Ridge* with tops very rounded, slope of sides usually 20° - 30°.

Water sky: Dark streaks on the underside of low clouds, indicating the presence of water features in the vicinity of *sea ice*.

Weathered ridge: *Ridge* with peaks slightly rounded and slope of sides usually 30° to 40°. Individual fragments are not discernible.

Weathering: Processes of ablation and accumulation which gradually eliminate irregularities in an ice surface.

White ice: See *Thin first-year ice*.

Young coastal ice: The initial stage of *fast ice* formation consisting of *nilas* or *young ice*, its width varying from a few meters up to 100-200 m from the shoreline.

Young ice: Ice in the transition stage between *nilas* and *first-year ice*, 10-30 cm in thickness. May be subdivided into *grey ice* and *grey-white ice*.

APPENDIX B

CALCULATED ICE STRENGTHENED SCANTLINGS FOR THREE REPRESENTATIVE SHIPS

Abbreviations used in this Appendix are as follows:

MS = Mild steel
HTS = Higher strength steel
ASTM = American Society for Testing and Materials
USCG = United States Coast Guard
ABS = American Bureau of Shipping
LR = Lloyd's Register of Shipping (British)
DNV = Det Norske Veritas (Norwegian)
BV = Bureau Veritas (French)
NKK = Nippon Kaiji Kyokoi (Japanese)
GL = Germanisscher Lloyd (German)

TABLE B-1.1

ABS STRENGTHENING FOR

NAVIGATION IN ICE

POLAR STAR

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
A	NA	12.9	5.8	0.60	NA	12.9	5.8	0.50	NA	12.9	5.8	0.50
B	NA	12.9	5.8	0.60	NA	25.8	5.8	0.60-0.46	NA	25.8	5.8	0.46
C	NA	12.9	5.8 w/ 4.4 inter	0.50	NA	25.8	5.8	0.40	NA	25.8	5.8	0.40*
IAA	234.5	25.8	51.4	1.26	122.5	25.8	26.9	0.96	89.5	25.8	19.6	0.83
IA	213.5	25.8	46.8	1.24	98.0	25.8	21.5	0.86	65.5	25.8	14.4	0.72
IB	192.0	25.8	42.1	1.18	65.5	25.8	14.4	0.72	41.0	25.8	9.0	0.59
IC	171.0	25.8	37.5	1.11	34.1	25.8	7.5	0.54	17.1	25.8	3.8	0.41*

Y = 50,000 psi

* Minimum should probably be equal to rule value of 0.42.

Note: Classes IAA, IA, IB, & IC are identical to the Finnish-Swedish Regulations for Navigation in Ice.

TABLE B-1.1 (Continued)

LLOYD'S STRENGTHENING FOR

NAVIGATION IN ICE

POLAR STAR

	FORWARD				MIDSHIP				AFT			
Ice Class	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
1*	NA	12.9	5.8	1.25	NA	12.9	5.8	0.55	NA	12.9	5.8	0.55
1	NA	12.9	5.8	0.52	NA	12.9	5.8	0.50	NA	12.9	5.8	0.50
2	NA	12.9	5.8	0.52	NA	25.8	5.8	0.56	NA	25.8	5.8	0.56
3	NA	12.9	5.8 w/ 2.9-4.6 inter	0.50	NA	25.8	5.8	0.40	NA	25.8	5.8	0.42
IA Super	← Same as ABS IAA →											
IA	← Same as ABS IA →											
IB	← Same as ABS IB →											
IC	← Same as ABS IC →											

TABLE B-1.1 (Continued)

CANADIAN ASPPR STRENGTHENING

FOR NAVIGATION IN ICE

POLAR STAR[1]

Ice Class	FORWARD P (psi)	FORWARD Frame Spacing (in)	FORWARD Frame S.M. (in^3)	FORWARD Plating Thick. (in)	MIDSHIP P (psi)	MIDSHIP Frame Spacing (in)	MIDSHIP Frame S.M. (in^3)	MIDSHIP Plating Thick. (in)	AFT P (psi)	AFT Frame Spacing (in)	AFT Frame S.M. (in^3)	AFT Plating Thick. (in)
1	250	25.8 (16.0)[2]	54.8 (34.0)[2]	1.22 (0.75)[2]	100	25.8 (16.0)	21.9 (13.6)	0.77 (0.48)	100	25.8 (16.0)	21.9 (13.6)	0.77 (0.48)
1A	400		87.7 (54.4)	1.54 (0.95)	260		57.0 (35.3)	1.24 (0.77)	325		71.2 (44.2)	1.39 (0.86)
2	600		131.5 (81.6)	1.88 (1.17)	400		87.7 (54.4)	1.54 (0.95)	500		109.6 (68.0)	1.72 (1.07)
3	800		175.4 (108.8)	2.18 (1.35)	530		116.2 (72.0)	1.77 (1.10)	660		144.7 (89.7)	1.98 (1.23)
4	1000		219.2 (135.9)	2.43 (1.51)	660		144.7 (89.7)	1.98 (1.23)	820		179.7 (111.5)	2.20 (1.37)
6	1200		263.0 (163.1)	2.66 (1.65)	750		164.4 (102.0)	2.11 (1.31)	940		206.0 (127.8)	2.36 (1.46)
7	1400		306.9 (190.3)	2.88 (1.78)	850		186.3 (115.5)	2.24 (1.39)	1050		230.2 (142.7)	2.49 (1.55)
8	1500		328.8 (203.9)	2.98 (1.85)	950		208.2 (129.1)	2.37 (1.47)	1200		263.0 (163.1)	2.66 (1.65)
10	1500		328.8 (203.9)	2.98 (1.85)	950		208.2 (129.1)	2.37 (1.47)	1200		263.0 (163.1)	2.66 (1.65)

1. Assuming no waste stowed in contact with shell.
2. Scantlings for alternate frame spacing.

NOTE: Yield stress assumed to be 50,000 psi.

TABLE B-1.1 (Continued)

DET NORSKE VERITAS STRENGTHENING FOR

NAVIGATION IN ICE

POLAR STAR

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
ICEC*	N/A	12.0	13.5- 1.3	0.69	N/A	25.8	5.8	0.40	N/A	25.8	5.8	0.42
IA*	Same as ABS IAA											
IA	Same as ABS IA											
IB	Same as ABS IB											
IC	Same as ABS IC											
Icebreaker	N/A	16.3	27.5	1.38	N/A	16.3	27.5	1.11	N/A	16.3	27.5	1.38
Arctic Icebreaker		16.3	34.4	1.79	N/A	16.3	34.4	1.44	N/A	16.3	34.4	1.79

* Scantlings should not exceed ABS IC.

TABLE B-1.1 (Continued)

BUREAU VERITAS STRENGTHENING FOR
NAVIGATION IN ICE
POLAR STAR*

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
Glace 1-Super	N/A	12.9	11.6-5.8	1.26	N/A	12.9	5.8	1.26	N/A	12.9	11.6-5.8	1.26
Glace I	N/A	12.9	11.6-5.8	0.60	N/A	12.9	5.8	0.48	N/A	12.9	11.6-5.8	0.48
Glace II	N/A	12.9	11.6-5.8	0.60	N/A	25.8	5.8	0.46	N/A	25.8	5.8	0.46
III	N/A	12.9	5.8-4.35	0.50	N/A	25.8	5.8	0.40	N/A	25.8	5.8	0.42
IA Super	Same as ABS IAA											
IA	Same as ABS IA											
IB	Same as ABS IB											
IC	Same as ABS IC											

* Rule scantlings are from ABS.

TABLE B-1.1 (Continued)

NIPPON KAIJI KYOKAI

STRENGTHENING FOR NAVIGATION IN ICE

POLAR STAR

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
AA	N/A	16.0	57.1	1.31-1.09	N/A	16.0	27.5	0.88	N/A	16.0	57.1	0.95-0.79
A	N/A	16.0	38.1	1.10-0.92	N/A	16.0	18.7	0.79	N/A	16.0	38.1	0.95-0.79
B	N/A	16.0	26.0	1.10-0.92	N/A	25.8	5.8	0.69	N/A	16.0	26.0	0.69-0.57
C	N/A	16.0	12.1	0.95-0.79	N/A	25.8	5.8	0.67	N/A	16.0	12.1	0.42
IA-Super	Same as ABS IAA											
IA	Same as ABS IA											
IB	Same as ABS IB											
IC	Same as ABS IC											

V = 18 knots

TABLE B-1.1 (Continued)

USSR REGISTER OF SHIPPING

STRENGTHENING FOR NAVIGATION IN ICE

<u>POLAR STAR</u>

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in)	Plating Thick. (in)
YΛA	← Each Vessel Considered Separately →											
YΛ	273	12.9	15.6	0.71	129	12.9	10.1	0.54	129	12.9	10.1	0.54
Λ1	162	12.9	7.2	0.60	99	12.9	6.3	0.50	99	12.9	6.3	0.50
Λ2	N/A	12.9	7.0-5.8	0.60	N/A	25.8	5.8	0.46	N/A	25.8	7.0-5.8	0.46
Λ3	N/A	12.9	5.8-4.4	0.50	N/A	25.8	5.8	0.40	N/A	25.8	5.8	0.42
Λ4	N/A	15.5	5.8	0.50	N/A	25.8	5.8	0.40	N/A	25.8	5.8	0.42

σ_y = 50,000 psi

Note: Rule scantlings are from ABS.

TABLE B-1.1 (Continued)

REGISTER OF THE PEOPLES REPUBLIC

OF CHINA

POLAR STAR*

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
BI*	NA	12.9	11.6	0.72	NA	12.9	5.8	0.56	NA	12.9	11.6	0.50
BI	NA	12.9	11.6	0.60	NA	12.9	5.8	0.50	NA	12.9	11.6	0.48
BII	NA	12.9	11.6	0.56	NA	25.8	5.8	0.46	NA	25.8	5.8	0.44
BIII	NA	12.9	5.8	0.50	NA	25.8	5.8	0.40	NA	25.8	5.8	0.42
B (River Vessels)	NA	12.9	5.8-1.7	0.55	NA	25.8	5.8	0.40	NA	25.8	5.8	0.42

*Rule scantlings are from ABS.

TABLE B-1.2

ABS STRENGTHENING FOR

NAVIGATION IN ICE

M.V. ARCTIC

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
A	NA	16.5	116.9	1.00	NA	16.5	116.9	0.84	NA	16.5	116.9	0.84
B	NA	16.5	116.9	1.00	NA	32.9	116.9	1.00-0.77	NA	32.9	116.9	0.77
C	NA	16.5	116.9 w/ 87.7 inter.	0.84	NA	32.9	116.9	0.67	NA	32.9	116.9	0.67
IAA	234.5	32.9	234.2	1.57	122.5	32.9	122.3	1.16	89.5	32.9	89.4	1.00
IA	213.5	32.9	213.2	1.50	98.0	32.9	97.9*	1.04	65.5	32.9	65.4*	0.87
IB	192.0	32.9	141.8	1.43	65.5	32.9	65.9*	0.87	41.0	32.9	41.0*	0.70
IC	171.0	32.9	170.8	1.35	34.1	32.9	32.9*	0.65***	17.1	32.9	17.1*	0.48**

Y = 50,000 psi

*** Minimum should probably be equal to rule value of 0.67.
** Minimum should probably be equal to rule value of 0.60
* Minimum S.M. should probably be equal to rule value of 116.9.

TABLE B-1.2 (Continued)

LLOYD'S STRENGTHENING FOR

NAVIGATION IN ICE

M.V. ARCTIC

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
1*	NA	16.5	116.9	1.25	NA	16.5	116.9	0.75	NA	16.5	116.9	0.67
1	NA	16.5	116.9	0.80	NA	16.5	116.9	0.67	NA	16.5	116.9	0.67
2	NA	16.5	116.9	0.80	NA	32.9	116.9	0.87	NA	32.9	116.9	0.87
3	NA	16.5	116.9 w/ 58.5-93.5 inter	0.67	NA	32.9	116.9	0.67	NA	32.9	116.9	0.60
IA Super	← Same as ABS IAA →											
IA	← Same as ABS IA →											
IB	← Same as ABS IB →											
IC	← Same as ABS IC →											

TABLE B-1.2 (Continued)

CANADIAN ASPPR STRENGTHENING

FOR NAVIGATION IN ICE

MV ARCTIC[1]

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
1	250	32.9 (16.5)[3]	249.7 (125.2)[3]	1.55 (0.78)[3]	100	32.9 (16.5)	99.9[2] (50.1)	0.98 (0.49)	100	32.9 (16.5)	99.9[2] (50.1)	0.98 (0.49)
1A	400	↓	399.5 (200.4)	1.96 (0.98)	100	↓	99.9[2] (50.1)	0.98 (0.49)	325	↓	324.6 (162.8)	1.77 (0.88)
2	600	↓	599.2 (300.5)	2.40 (1.20)	260	↓	259.7 (130.2)	1.58 (0.79)	500	↓	499.4 (250.4)	2.19 (1.10)
3	800	↓	799.0 (400.7)	2.77 (1.39)	400	↓	399.5 (200.4)	1.96 (0.98)	660	↓	659.2 (330.2)	2.52 (1.26)
4	1000	↓	998.7 (500.9)	3.10 (1.55)	530	↓	529.3 (265.5)	2.26 (1.13)	820	↓	819.0 (410.7)	2.81 (1.40)
6	1200	↓	1198.5 (601.1)	3.40 (1.70)	660	↓	659.2 (330.2)	2.52 (1.26)	940	↓	938.8 (470.8)	3.01 (1.50)
7	1400	↓	1398.2 (701.2)	3.67 (1.84)	750	↓	749.1 (375.7)	2.69 (1.34)	1050	↓	1048.7 (525.9)	3.18 (1.59)
8	1500	↓	1498.1 (751.3)	3.80 (1.90)	850	↓	848.9 (425.8)	2.86 (1.43)	1200	↓	1198.5 (601.1)	3.40 (1.70)
10	1500	↓	1498.1 (751.3)	3.80 (1.90)	950	↓	948.8 (475.8)	3.02 (1.51)	1200	↓	1198.5 (601.1)	3.40 (1.70)

1. With side tanks.
2. Should be equal to rule value of 116.9.
3. Scantlings for alternate frame spacing.

NOTE: Yield stress assumed to be 50,000 psi.

TABLE B-1.2 (Continued)

DET NORSKE VERITAS STRENGTHENING
FOR NAVIGATION IN ICE

M.V. ARCTIC

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)
ICEC*	N/A	12.0	325-242	1.00	N/A	32.9	116.9	0.67	N/A	32.9	116.9	0.60
IA★	Same as ABS IAA											
IA	Same as ABS IA											
IB	Same as ABS IB											
IC	Same as ABS IC											
Icebreaker	N/A	20.5	1161	0.85	N/A	20.5	1161	0.68	N/A	20.5	1161	0.85
Arctic Icebreaker	N/A	20.5	1451	1.11	N/A	20.5	1451	0.98	N/A	20.5	1451	1.11

* Scantlings should not exceed ABS IC.

TABLE B-1.2 (Continued)

BUREAU VERITAS STRENGTHENING FOR

NAVIGATION IN ICE

M.V. ARCTIC*

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
Glace I-Super	N/A	16.5	233.8-116.9	1.26	N/A	16.5	116.9	1.20	N/A	16.5	233.8-116.9	1.10
Glace I	N/A	16.5	233.8-116.9	1.01	N/A	16.5	116.9	0.80	N/A	16.5	233.8-116.9	0.80
Glace II	N/A	16.5	233.8-116.9	1.01	N/A	32.9	116.9	0.77	N/A	32.9	116.9	0.77
Glace III	N/A	16.5	116.9 87.7	0.84	N/A	32.9	116.9	0.67	N/A	32.9	116.9	0.60
IA Super	Same as ABS IAA											
IA	Same as ABS IA											
IB	Same as ABS IB											
IC	Same as ABS IC											

*Rule values are from ABS.

TABLE B-1.2 (Continued)

NIPPON KAIJI KYOKAI

STRENGTHENING FOR NAVIGATION IN ICE

M.V. ARCTIC

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)
AA	N/A	16.5	10.91	1.57-1.31	N/A	16.5	134.6	1.04	N/A	16.5	10.91	1.12-0.94
A	N/A	16.5	7.27	1.31-1.09	N/A	16.5	90.2	0.94	N/A	16.5	7.27	1.12-0.94
B	N/A	16.5	4.96	1.31-1.09	N/A	32.9	116.9	0.89	N/A	16.5	4.96	0.80-0.67
C	N/A	16.5	2.31	1.12-0.94	N/A	32.9	116.9	0.67	N/A	16.5	2.31	0.60
IA-Super	Same as ABS IAA											
IA	Same as ABS IA											
IB	Same as ABS IB											
IC	Same as ABS IC											

V = 17 knots

TABLE B-1.2 (Continued)

USSR REGISTER OF SHIPPING

STRENGTHENING FOR NAVIGATION IN ICE

M.V. ARCTIC

	FORWARD				MIDSHIP				AFT			
Ice Class	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
YΛA	← Each Vessel Considered Separately →											
YΛ	409	16.5	98.6	1.06	255	16.5	120.6	0.84	255	16.5	120.6	0.84
Λ1	245	16.5	45.1	1.00	224	16.5	79.5	0.83	224	16.5	79.5	0.83
Λ2	NA	16.5	140.3-116.9	1.00	NA	32.9	116.9	0.77	NA	32.9	116.9	0.77
Λ3	NA	16.5	116.9-87.7	0.84	NA	32.9	116.9	0.67	NA	32.9	116.9	0.60
Λ4	NA	19.7	116.9	0.84	NA	32.9	116.9	0.67	NA	32.9	116.9	0.60

NOTE: Rule scantlings are from ABS.

TABLE B-1.2 (Continued)

REGISTER OF THE PEOPLES REPUBLIC

OF CHINA

M.V. ARCTIC*

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
BI*	NA	16.5	234	1.21	NA	16.5	116.9	0.94	NA	16.5	234	0.84
BI	NA	16.5	234	1.00	NA	16.5	116.9	0.80	NA	16.5	234	0.80
BII	NA	16.5	323	0.94	NA	32.9	116.9	0.74	NA	32.9	116.9	0.74
BIII	NA	16.5	116.9	0.84	NA	32.9	116.9	0.67	NA	32.9	116.9	0.60
B (River Vessels)	NA	16.5	116.9-35.1	0.76	NA	32.9	116.9	0.67	NA	32.9	116.9	0.60

*Rule scantlings are from ABS.

TABLE B-1.3

ABS STRENGTHENING FOR NAVIGATION IN ICE

ARCTIC TANKER

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)
A	NA	19.8	38.4	1.00	NA	19.8	38.4	1.00*	NA	19.8	38.4	1.00
B	NA	19.8	38.4	1.00	NA	39.5	38.4	1.00*	NA	39.5	38.4	1.00
C	NA	19.8	38.4 w/ 28.8 inter	1.00	NA	39.5	38.4	1.00*	NA	39.5	38.4	0.78
IAA	234.5	39.5	67.8	1.81	122.5	39.5	35.4**	1.33	89.5	39.5	25.9**	1.15
IA	213.5	39.5	61.7	1.73	98.0	39.5	28.3**	1.20	65.5	39.5	18.9**	0.99
IB	192.0	39.5	55.5	1.64	65.5	39.5	18.9**	0.99*	41.0	39.5	11.9**	0.80
IC	171.0	39.5	49.4	1.55	34.1	39.5	9.85**	0.74	17.1	39.5	4.9**	0.55***

Y = 50,000 psi

***Should probably be equal to rule value of 0.78.
**Should probably be equal to rule value of 38.4.
*Should probably be equal to rule value of 1.05.

TABLE B-1.3 (Continued)

LLOYD'S STRENGTHENING FOR

NAVIGATION IN ICE

ARCTIC TANKER

	FORWARD				MIDSHIP				AFT			
Ice Class	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
1*	NA	19.8	38.4	1.25	NA	19.8	38.4	1.25	NA	19.8	38.4	1.15
1	NA	19.8	38.4	1.00	NA	19.8	38.4	1.00*	NA	19.8	38.4	1.00
2	NA	19.8	38.4	1.00	NA	39.5	38.4	1.00*	NA	39.5	38.4	1.00
3	NA	19.8	38.4 w/ 19.2-30.7 inter	1.00	NA	39.5	38.4	1.05	NA	39.5	38.4	0.78
IA Super	← Same as ABS IAA →											
IA	← Same as ABS IA →											
IB	← Same as ABS IB →											
IC	← Same as ABS IC →											

* Should probably be equal to rule value of 1.05.

TABLE B-1.3 (Continued)

CANADIAN ASPPR STRENGTHENING

FOR NAVIGATION IN ICE

ARCTIC TANKER[1]

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)
1	400	39.5 (19.8)[3]	106.2 (53.3)[3]	2.36 (1.18)[3]	100	39.5 (19.8)	26.6[2] (13.3)	1.18 (0.59)	100	39.5 (19.8)	26.6** (13.3)	1.18 (0.59)
1A	600	↓	159.4 (79.9)	2.88 (1.45)	260	↓	69.1 (34.6)	1.90 (0.95)	325	↓	86.3 (43.3)	2.12 (1.06)
2	800	↓	212.5 (106.5)	3.33 (1.67)	400	↓	106.2 (53.3)	2.36 (1.18)	500	↓	132.8 (66.6)	2.63 (1.32)
3	1000	↓	265.6 (133.1)	3.72 (1.87)	530	↓	140.8 (70.6)	2.71 (1.36)	660	↓	175.3 (87.9)	3.03 (1.52)
4	1200	↓	318.7 (159.8)	4.08 (2.04)	660	↓	175.3 (87.9)	3.03 (1.52)	820	↓	217.8 (109.2)	3.37 (1.69)
6	1400	↓	371.8 (186.4)	4.41 (2.21)	750	↓	199.2 (99.8)	3.23 (1.62)	940	↓	249.7 (125.1)	3.61 (1.81)
7	1500	↓	398.4 (199.7)	4.56 (2.92)	850	↓	225.7 (113.2)	3.43 (1.72)	1050	↓	278.9 (139.8)	3.82 (1.91)
8	1500	↓	398.4 (199.7)	4.56 (2.29)	950	↓	252.3 (126.5)	3.63 (1.82)	1200	↓	318.7 (159.8)	4.08 (2.04)
10	1500	↓	398.4 (199.7)	4.56 (2.29)	950	↓	252.3 (126.5)	3.63 (1.82)	1200	↓	318.7 (159.8)	4.08 (2.04)

1. No side tanks; waste stowed next to shell.
2. Should be equal to rule value of 38.5.
3. Scantlings for alternate frame spacing.

TABLE B-1.3 (Continued)

DET NORSKE VERITAS STRENGTHENING FOR

NAVIGATION IN ICE

ARCTIC TANKER

	FORWARD				MIDSHIP				AFT			
Ice Class	*P* (psi)	Frame Spacing (in)	Frame S.M. (in)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in)	Plating Thick. (in)
ICE C*	N/A	12.0	131-760	1.00	N/A	39.5	38.4	1.05	N/A	39.5	30.4	0.78
IA★		Same as ABS IAA										
IA		Same as ABS IA										
IB		Same as ABS IB										
IC		Same as ABS IC										
Icebreaker	N/A	27.4	61.2	3.17	N/A	27.4	61.2	2.53	N/A	27.9	61.2	3.17
Arctic Icebreaker	N/A	27.4	76.5	4.12	N/A	27.9	76.5	3.29	N/A	27.9	76.5	4.12

* Scantlings should not exceed ABS IC.

TABLE B-1.3 (Continued)

BUREAU VERITAS STRENGTHENING

FOR NAVIGATION IN ICE

ARCTIC TANKER*

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
Glace I-Super	N/A	19.8	76.8-38.4	1.26	N/A	19.8	38.4	1.26	N/A	19.8	7.68-38.4	1.26
Glace I	N/A	19.8	76.8-38.4	1.00	N/A	19.8	38.4	1.00**	N/A	19.8	7.68-38.4	1.00
Glace II	N/A	19.8	76.8-38.4	1.00	N/A	39.5	38.4	1.00**	N/A	39.5	38.4	1.00
III	N/A	19.8	38.4-28.8	1.00	N/A	39.5	38.4	1.00**	N/A	39.5	38.4	1.00
IA Super	Same as ABS IAA											
IA	Same as ABS IA											
IB	Same as ABS IB											
IC	Same as ABS IC											

** Should be equal to rule value of 1.05.

* Rule values are from ABS.

TABLE B-1.3 (Continued)

NIPPON KAIJI KYOKAI

STRENGTHENING FOR NAVIGATION IN ICE

ARCTIC TANKER

	FORWARD				MIDSHIP				AFT			
Ice Class	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
AA	N/A	19.8	185.7	1.99-1.66	N/A	19.8	98.7	1.31	N/A	19.8	185.7	1.41-1.18
A	N/A	19.8	123.8	1.66-1.38	N/A	19.8	66.2	1.18	N/A	19.8	123.8	1.41-1.18
B	N/A	19.8	84.4	1.66-1.38	N/A	39.5	38.4	1.12	N/A	19.8	84.4	1.00-0.83
C	N/A	19.8	39.4	1.41 1.18	N/A	39.5	38.4	1.05	N/A	19.8	39.4	0.78
IA-super	Same as ABS IAA											
IA	Same as ABS IA											
IB	Same as ABS IB											
IC	Same as ABS IC											

V = 24 knots

TABLE B-1.3 (Continued)

USSR REGISTER OF SHIPPING

STRENGTHENING FOR NAVIGATION IN ICE

ARCTIC TANKER

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in^3)	Plating Thick. (in)
Y A	← Each Vessel Considered Separately →											
Y	1030	19.8	70.5	2.02	487	19.8	51.8	1.39	487	19.8	51.8	1.39
1	619	19.8	32.3	1.58	458	19.8	34.2	1.35	458	19.8	34.2	1.35
2	NA	19.8	46.1-38.4	1.00	NA	39.5	38.4	1.05	NA	39.5	38.4	1.00
3	NA	19.8	38.4-28.8	1.00	NA	39.5	38.4	1.05	NA	39.5	38.4	0.78
4	NA	23.7	38.4	1.00	NA	39.5	38.4	1.05	NA	39.5	38.4	0.78

NOTE: Rule scantlings are from ABS.

TABLE B-1.3 (Continued)

REGISTER OF THE PEOPLES REPUBLIC

OF CHINA

ARCTIC TANKER*

Ice Class	FORWARD				MIDSHIP				AFT			
	P (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)	*P* (psi)	Frame Spacing (in)	Frame S.M. (in³)	Plating Thick. (in)
BI*	NA	19.8	76.8	1.26	NA	19.8	38.4	1.26	NA	19.8	76.8	1.26
BI	NA	19.8	76.8	1.00	NA	19.8	38.4	1.00***	NA	19.8	76.8	1.00
BII	NA	19.8	76.8	1.00	NA	39.5	38.4	1.00***	NA	39.5	38.4	1.00
BIII	NA	19.8	38.4	1.00	NA	39.5	38.4	1.05	NA	39.5	38.4	0.78
B (River Vessels)	NA	19.8	38.4-11.5	0.55**	NA	39.5	38.4	1.05	NA	39.5	38.4	0.78

*** Should be equal to rule value of 1.05.
** Should be equal to rule value of 0.78.
* Rule Scantlings are from ABS.

APPENDIX B-2

CALCULATED LOAD-CARRYING CAPABILITIES OF RESULTING SCANTLINGS FOR THREE REPRESENTATIVE SHIPS

METHOD USED TO CALCULATE THE LOAD CARRYING CAPABILITY OF SHELL PLATING AND TRANSVERSE FRAMES

The load carrying capability of each of the ice strengthened structures was calculated by the method used by Johansson [B-16] in the analysis of ice damage data. This method assumes that the plating and framing can no longer carry a load when 3 plastic hinges are formed.

Plating is assumed to be a fixed-fixed beam with a uniformly distributed load. Then the pressure to form 3 plastic hinges is

$$P \text{ [psi]} = \frac{4\sigma_y t^2}{s^2 f_d} \qquad \text{(B-1)}$$

where

σ_y = yield stress of the material [psi]

t = plating thickness [in]

s = frame spacing [in]

f_d = a factor which gives a reduction in plating stress due to limited vertical extension of the ice pressure

Transverse frames are assumed to be fixed-fixed beams with a uniformly distributed load 800 mm long acting at mid-span. Then the pressure which the frames will support prior to development of three plastic hinges is:

$$P = \frac{16\sigma_y \text{ [SM]}}{cs\ (2l-c)} \qquad \text{(B-2)}$$

where

σ_y and s are defined above

l = frame span [ft]

c = extent of the load [in]

SM = section modulus of the frame and associated plating [in^3]

Substituting 800 mm [31.5 in] for c and applying unit conversion constants, equation (B-2) becomes:

$$P \text{ [psi]} = \frac{0.254\ \sigma_y \text{ [S.M.]}}{s\ (12l-15.75)} \qquad \text{(B-3)}$$

Then the normal load carrying capability is the load the plating or framing will carry (P) over the pressure specified in the rules (P_{rule}).

TABLE B-2.1
COMPARISON OF ICE STRENGTHENED SCANTLINGS
IN TERMS OF NORMALIZED LOAD CARRYING CAPABILITY

POLAR STAR

RULE	CLASS	AREA	FRAME SPAC. [in]	FRAME S.M. [in³]	PLATE THICK. [in]	P/P_{Rule}	P_{Plate} [psi]	P_{Frame} [psi]	P/P_{Rule}
ABS	+A1	Mid	25.8	5.8	0.40	NA	55	33	NA
		Bow & Stern	25.8	5.8	0.42	NA	60	33	NA
	A	B	12.9	5.8	0.60	7.35	441	66	2.00
		M	12.9	5.8	0.50	5.58	307	66	2.00
		S	12.9	5.8	0.50	5.12	307	66	2.00
	B	B	12.9	5.8	0.60	7.35	441	66	2.00
		M	25.8	5.8	0.53	1.75	96	33	1.00
		S	25.8	5.8	0.46	1.20	72	33	1.00
	C	B	12.9	5.1	0.50	5.12	307	58	1.76
		M	25.8	5.8	0.40	1.00	55	33	1.00
		S	25.8	5.8	0.42	1.00	60	33	1.00
	IAA	B	25.8	51.4	1.26	9.03	542	293	8.88
		M	25.8	26.9	0.96	5.73	315	153	4.64
		S	25.8	19.6	0.83	3.92	235	112	3.39
	IA	B	25.8	46.8	1.24	8.75	525	267	8.09
		M	25.8	21.5	0.86	4.60	253	123	3.73
		S	25.8	14.4	0.72	2.95	177	82	2.48
	IB	B	25.8	42.1	1.18	7.92	475	240	7.27
		M	25.8	14.4	0.72	3.22	177	82	2.48
		S	25.8	9.0	0.59	1.98	119	51	1.55
	IC	B	25.8	37.5	1.11	7.02	421	214	6.48
		M	25.8	7.5	0.54	1.82	100	43	1.30
		S	25.8	5.8	0.42	1.00	60	33	1.00
LLOYD'S	1*	B	12.9	5.8	1.25	31.93	1916	66	2.00
		M	12.9	5.8	0.55	6.75	371	66	2.00
		S	12.9	5.8	0.55	6.18	371	66	2.00
	1	B	12.9	5.8	0.52	5.53		66	2.00
		M	12.9	5.8	0.50	5.58	307	66	2.00
		S	12.9	5.8	0.50	5.12	307	66	2.00
	2	B	12.9	5.8	0.52	5.53	332	66	2.00
		M	25.8	5.8	0.56	1.95	107	33	1.00
		S	25.8	5.8	0.56	1.78	107	33	1.00
	3	B	12.9	4.8	0.50	5.12	307	55	1.67
		M	25.8	5.8	0.40	1.00	55	33	1.00
		S	25.8	5.8	0.42	1.00	60	33	1.00
	IA Super, IA, IB, IC	← Same as ABS →							
ASPPR	1	B	25.8	54.8	1.22	8.47	508	313	9.48
		M		21.9	0.77	3.67	202	125	3.79
		S		21.9	0.77	3.37	202	125	3.79
	1A	B		87.7	1.54	13.50	810	501	15.18
		M		57.0	1.24	9.55	525	325	9.85
		S		71.2	1.39	11.00	660	406	12.30
	2	B		131.5	1.88	20.12	1207	750	22.73
		M		87.7	1.54	14.70	809	501	15.18
		S		109.6	1.72	16.83	1010	626	18.97
	3	B		175.4	2.18	27.05	1623	1001	30.33
		M		116.2	1.77	19.45	1070	663	20.09
		S		144.7	1.98	22.31	1339	826	25.03
	4	B		219.2	2.43	33.60	2016	1251	37.91
		M		144.7	1.98	24.34	1339	826	25.03
		S		179.7	2.20	27.53	1652	1026	31.09
	6	B		263.0	2.66	40.27	2416	1501	45.48
		M		164.4	2.11	27.63	1520	938	28.42
		S		206.0	2.36	31.70	1902	1176	35.64
	7	B		306.9	2.88	47.18	2831	1752	53.09
		M		186.3	2.24	31.14	1713	1063	32.21
		S		230.2	2.49	35.28	2117	1314	39.82
	8	B		328.8	2.98	50.53	3032	1877	56.88
		M		208.2	2.37	34.87	1918	1188	36.00
		S		263.0	2.66	40.27	2416	1501	45.48
	10	B		328.8	2.98	50.53	3032	1877	56.88
		M		208.2	2.37	34.87	1918	1188	36.00
		S		263.0	2.66	40.27	2416	1501	45.48

TABLE B-2.1 (Continued)
COMPARISON OF ICE STRENGTHENED SCANTLINGS
IN TERMS OF NORMALIZED LOAD CARRYING CAPABILITY

POLAR STAR

RULE	CLASS	AREA	FRAME SPAC. [in]	FRAME S.M. [in³]	PLATE THICK. [in]	P/P_{Rule}	P_{Plate} [psi]	P_{Frame} [psi]	P/P_{Rule}
DNV	ICE C	B	12.0	7.4	0.69	11.02	661	91	2.77
		M	25.8	5.8	0.40	1.00	55	33	1.00
		S	25.8	5.8	0.42	1.00	60	33	1.00
	ICEBREAKER	B	16.3	27.5	1.38	9.77	586	248	7.52
		M	16.3	27.5	1.11	6.89	379	248	7.52
		S	16.3	27.5	1.38	9.77	586	248	7.52
	ARCTIC ICEBREAKER	B	16.3	34.4	1.79	16.42	985	311	9.42
		M	16.3	34.4	1.44	11.60	638	311	9.42
		S	16.3	34.4	1.79	16.42	985	311	9.42
	IA*, IA, IB, IC	← Same as ABS →							
BUREAU VERITAS	Glace 1-Super	B	12.9	8.7	1.26	32.43	1946	99	3.00
		M	12.9	5.8	1.26	35.38	1946	66	2.00
		S	12.9	8.7	1.26	32.43	1946	99	3.00
	Glace 1	B	12.9	8.7	0.60	7.35	441	99	3.00
		M	12.9	5.8	0.48	5.15	283	66	2.00
		S	12.9	8.7	0.48	4.72	283	99	3.00
	Glace 2	B	12.9	8.7	0.60	7.35	441	99	3.00
		M	25.8	5.8	0.46	1.31	72	33	1.00
		S	25.8	5.8	0.46	1.20	72	33	1.00
	Glace 3	B	12.9	5.1	0.50	5.12	307	58	1.76
		M	25.8	5.8	0.40	1.00	55	33	1.00
		S	25.8	5.8	0.42	1.00	60	33	1.00
	IA Super, IA, IB, IC	← Same as ABS →							
RUSSIAN	YA	B	12.9	15.6	0.71	10.30	618	178	5.39
		M	12.9	10.1	0.54	6.51	358	115	3.48
		S	12.9	10.1	0.54	5.97	358	115	3.48
	A1	B	12.9	7.2	0.60	7.35	441	82	2.48
		M	12.9	6.3	0.50	5.58	307	72	2.18
		S	12.9	6.3	0.50	5.12	307	72	2.18
	A2	B	12.9	6.4	0.60	7.35	441	73	2.21
		M	25.8	5.8	0.46	1.31	72	33	1.00
		S	25.8	6.4	0.46	1.20	72	37	1.12
	A3	B	12.9	5.1	0.50	5.12	307	58	1.76
		M	25.8	5.8	0.40	1.00	55	33	1.00
		S	25.8	5.8	0.42	1.00	60	33	1.00
	A4	B	15.5	5.8	0.50	3.58	215	55	1.67
		M	25.8	5.8	0.40	1.00	55	33	1.00
		S	25.8	5.8	0.42	1.00	60	33	1.00
NKK	AA	B	16.0	57.1	1.20	19.33	1160	525	15.91
		M	16.0	27.5	0.88	11.35	624	253	7.67
		S	16.0	57.1	0.87	10.17	610	525	15.91
	A	B	16.0	38.1	1.01	13.70	822	351	10.64
		M	16.0	18.7	0.79	9.15	503	172	5.21
		S	16.0	38.1	0.87	10.17	610	351	10.64
	B	B	16.0	26.0	1.01	13.70	822	239	7.24
		M	25.8	5.8	0.69	2.96	163	33	1.00
		S	16.0	26.0	0.63	5.33	320	239	7.24
	C	B	16.0	12.1	0.87	10.17	610	111	3.36
		M	25.8	5.8	0.67	2.78	153	33	1.00
		S	16.0	12.1	0.42	2.77	142	111	3.36
	IA Super, IA, IB, IC	← Same as ABS →							
PEOPLES REPUBLIC OF CHINA	BI*	B	12.9	11.6	0.72	10.60	636	132	4.00
		M	12.9	5.8	0.56	7.00	385	66	2.00
		S	12.9	11.6	0.50	5.12	307	132	4.00
	BI	B	12.9	11.6	0.60	7.35	441	132	4.00
		M	12.9	5.8	0.50	5.58	307	66	2.00
		S	12.9	11.6	0.48	4.72	283	132	4.00
	BII	B	12.9	11.6	0.56	6.42	385	132	4.00
		M	25.8	5.8	0.46	1.31	72	33	1.00
		S	25.8	5.8	0.44	1.10	66	33	1.00
	BIII	B	12.9	5.8	0.50	5.12	307	66	2.00
		M	25.8	5.8	0.40	1.00	55	33	1.00
		S	25.8	5.8	0.42	1.00	60	33	1.00
	B (River Vessels)	B	12.9	3.8	0.55	6.18	371	43	1.30
		M	25.8	5.8	0.40	1.00	55	33	1.00
		S	25.8	5.8	0.42	1.00	60	33	1.00

TABLE B-2.2
COMPARISON OF ICE STRENGTHENED SCANTLINGS
IN TERMS OF NORMALIZED LOAD CARRYING CAPABILITY

M.V. ARCTIC

RULE	CLASS	AREA	FRAME SPAC. [in]	FRAME S.M. [in³]	PLATE THICK. [in]	P/P_{Rule}	P_{Plate} [psi]	P_{Frame} [psi]	P/P_{Rule}
ABS	+A1	M	32.9	116.9	0.67	NA	104	146	NA
		B&S	32.9	116.9	0.60	NA	83	146	NA
	A	B	16.5	116.9	1.00	9.12	757	292	2.00
		M	16.5	116.9	0.84	5.13	534	292	2.00
		S	16.5	116.9	0.84	6.43	534	292	2.00
	B	B	16.5	116.9	1.00	9.12	757	292	2.00
		M	32.9	116.9	0.89	1.76	183	146	1.00
		S	32.9	116.9	0.77	1.65	137	146	1.00
	C	B	16.5	102.3	0.84	6.43	534	255	1.75
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	32.9	116.9	0.67	1.25	104	146	1.00
	IAA	B	32.9	234.2	1.57	6.85	569	293	2.01
		M	32.9	122.3	1.16	2.99	311	153	1.05
		S	32.9	116.9	1.00	2.78	231	146	1.00
	IA	B	32.9	213.2	1.50	6.27	520	267	1.83
		M	32.9	116.9	1.04	2.40	250	146	1.00
		S	32.9	116.9	0.87	2.11	175	146	1.00
	IB	B	32.9	191.8	1.43	5.69	472	240	1.64
		M	32.9	116.9	0.87	1.68	175	146	1.00
		S	32.9	116.9	0.70	1.36	113	146	1.00
	IC	B	32.9	170.8	1.35	5.07	421	214	1.47
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	32.9	116.9	0.60	1.00	83	146	1.00
LLOYD'S	1*	B	16.5	116.9	1.25	14.25	1183	292	2.00
		M	16.5	116.9	0.75	4.10	426	292	2.00
		S	16.5	116.9	0.67	4.10	340	292	2.00
	1	B	16.5	116.9	0.80	5.84	485	292	2.00
		M	16.5	116.9	0.67	3.27	340	292	2.00
		S	16.5	116.9	0.67	4.09	340	292	2.00
	2	B	16.5	116.9	0.80	5.84	485	292	2.00
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	32.9	116.9	0.87	2.11	175	146	1.00
	3	B	16.5	96.5	0.67	4.09	340	240	1.64
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	32.9	116.9	0.60	1.00	83	146	1.00
	IA Super, IA, IB, IC	Same as ABS							
ASPPR	1	B	32.9	249.7	1.55	6.69	555	313	2.14
		M		116.9	0.98	2.13	222	146	1.00
		S		116.9	0.98	2.67	222	146	1.00
	1A	B		399.5	1.96	10.68	887	500	3.42
		M		116.9	0.98	2.13	222	146	1.00
		S		324.6	1.77	8.72	724	406	2.78
	2	B		599.2	2.40	10.02	1330	750	5.14
		M		259.7	1.58	5.54	576	325	2.23
		S		499.4	2.19	13.34	1108	625	4.28
	3	B		799.0	2.77	21.35	1772	1000	6.85
		M		399.5	1.96	8.53	887	500	3.42
		S		659.2	2.52	17.46	1467	826	5.66
	4	B		998.7	3.10	26.73	2219	1251	8.57
		M		529.3	2.26	11.35	1180	663	4.54
		S		819.0	2.81	21.98	1824	1026	7.03
	6	B		1198.5	3.40	32.17	2670	1501	10.28
		M		659.2	2.52	14.11	1467	826	5.66
		S		938.8	3.01	25.22	2093	1176	8.05
	7	B		1398.2	3.67	37.48	3111	1751	11.99
		M		749.1	2.69	16.07	1671	938	6.42
		S		1048.7	3.18	28.14	2336	1313	8.99
	8	B		1498.1	3.80	40.18	3335	1876	12.85
		M		848.9	2.86	18.16	1889	1063	7.28
		S		1198.5	3.40	32.17	2670	1501	10.28
	10	B		1498.1	3.80	40.15	3335	1876	12.85
		M		948.8	3.02	20.26	2107	1188	8.14
		S		1198.5	3.40	32.17	2670	1501	10.28
DNV	ICE C	B	12.0	284.0	1.00	--	1402	975	6.67
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	32.9	116.9	0.60	1.00	83	146	1.00
	ICEBREAKER	B	20.5	1161.0	0.85	4.46	370	2333	15.98
		M	20.5	1161.0	0.68	2.28	237	2333	15.98
		S	20.5	1161.0	0.85	4.46	370	2333	15.98
	ARCTIC ICEBREAKER	B	20.5	1451.0	1.11	7.60	631	2916	19.97
		M	20.5	1451.0	0.98	4.72	491	2916	19.97
		S	20.5	1451.0	1.11	7.60	631	2916	19.97
	IA*, IA, IB, IC	Same as ABS							

TABLE B-2.2 (Continued)
COMPARISON OF ICE STRENGTHENED SCANTLINGS
IN TERMS OF NORMALIZED LOAD CARRYING CAPABILITY

M.V. ARCTIC

RULE	CLASS	AREA	FRAME SPAC. [in]	FRAME S.M. [in³]	PLATE THICK. [in]	P/P_{Rule}	P_{Plate} [psi]	P_{Frame} [psi]	P/P_{Rule}
BUREAU VERITAS	Glace I Super	B	16.5	175.4	1.26	14.48	1202	438	3.00
		M	16.5	116.9	1.20	10.49	1091	292	2.00
		S	16.5	175.4	1.10	11.04	916	438	3.00
	Glace I	B	16.5	175.4	1.01	9.31	773	438	3.00
		M	16.5	116.9	0.80	4.66	485	292	2.00
		S	16.5	175.4	0.80	5.84	485	438	3.00
	Glace II	B	16.5	175.4	1.01	9.31	773	438	3.00
		M	32.9	116.9	0.77	1.32	137	146	1.00
		S	32.9	116.9	0.77	1.65	137	146	1.00
	Glace III	B	16.5	102.3	0.84	6.43	534	255	1.75
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	32.9	116.9	0.60	1.00	83	146	1.00
	IA Super, IA, IB, IC	← Same as ABS →							
RUSSIAN	YA	B	16.5	120.6	1.06	10.25	851	301	2.06
		M	16.5	120.6	0.84	5.13	534	301	2.06
		S	16.5	120.6	0.84	6.43	534	301	2.06
	A1	B	16.5	128.6	1.00	9.12	757	321	2.20
		M	16.5	116.9	0.83	5.02	522	292	2.00
		S	16.5	116.9	0.83	6.29	522	292	2.00
	A2	B	16.5	128.6	1.00	9.12	757	321	2.20
		M	32.9	116.9	0.77	1.32	137	146	1.00
		S	32.9	116.9	0.77	1.65	137	146	1.00
	A3	B	16.5	102.3	0.84	6.43	534	255	1.75
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	32.9	116.9	0.60	1.00	83	146	1.00
	A4	B	16.5	116.9	0.84	6.43	534	292	2.00
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	32.9	116.9	0.60	1.00	83	146	1.00
NKK	AA	B	16.5	1091.0	1.44	18.92	1570	2724	18.66
		M	16.5	134.6	1.04	7.88	819	336	2.30
		S	16.5	1091.0	1.03	9.67	803	2724	18.66
	A	B	16.5	727.0	1.20	13.13	1090	1815	12.43
		M	16.5	90.2	0.94	6.43	669	225	1.54
		S	16.5	727.0	1.03	9.67	803	1815	12.43
	B	B	16.5	496.0	1.20	13.13	1090	1238	8.48
		M	32.9	116.9	0.89	1.76	183	146	1.00
		S	16.5	496.0	0.74	5.00	415	1238	8.48
	C	B	16.5	231.0	1.03	9.67	803	577	3.95
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	16.5	231.0	0.60	3.29	273	577	3.95
	IA Super, IA, IB, IC	← Same as ABS →							
PEOPLES REPUBLIC OF CHINA	BI*	B	16.5	234.0	1.21	13.36	1109	584	4.00
		M	16.5	116.9	0.94	6.43	669	292	2.00
		S	16.5	234.0	0.84	6.43	534	584	4.00
	BI	B	16.5	234.0	1.00	9.12	757	584	4.00
		M	16.5	116.9	0.80	4.66	485	292	2.00
		S	16.5	234.0	0.80	5.84	485	584	4.00
	BII	B	16.5	234.0	0.94	8.06	669	584	4.00
		M	32.9	116.9	0.74	1.21	126	146	1.00
		S	32.9	116.9	0.74	8.06	126	146	1.00
	BIII	B	16.5	116.9	0.84	6.43	534	292	2.00
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	32.9	116.9	0.60	1.00	87	146	1.00
	B (River Vessels)	B	16.5	76.0	0.76	5.26	437	190	1.30
		M	32.9	116.9	0.67	1.00	104	146	1.00
		S	32.9	116.9	0.60	1.00	83	146	1.00

TABLE B-2.3
COMPARISON OF ICE STRENGTHENED SCANTLINGS
IN TERMS OF NORMALIZED LOAD CARRYING CAPABILITY

ARCTIC TANKER

RULE	CLASS	AREA	FRAME SPAC. [in]	FRAME S.M. [in³]	PLATE THICK. [in]	P/P_{Rule}	P_{Plate} [psi]	P_{Frame} [psi]	P/P_{Rule}
ABS	+A1	M	39.5	38.4	1.05	NA	196	166	NA
		B&S	39.5	38.4	0.78	NA	108	166	NA
	A	B	19.8	38.4	1.00	5.03	543	332	2.00
		M	19.8	38.4	1.05	3.05	598	332	2.00
		S	19.8	38.4	1.00	5.03	543	332	2.00
	B	B	19.8	38.4	1.00	5.03	543	332	2.00
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	1.00	1.05	178	166	1.00
	C	B	19.8	33.6	1.00	5.03	543	290	1.75
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S		38.4	0.78	1.00	108	166	1.00
	IAA	B		67.8	1.81	5.40	583	294	1.77
		M		38.4	1.33	1.61	315	166	1.00
		S		38.4	1.15	2.18	235	166	1.00
	IA	B		61.7	1.73	4.94	533	267	1.61
		M		38.4	1.20	1.31	256	166	1.00
		S		38.4	0.99	1.61	174	166	1.00
	IB	B		55.7	1.64	4.44	479	241	1.45
		M		38.4	1.05	1.00	196	166	1.00
		S		38.4	0.80	1.06	114	166	1.00
	IC	B		49.4	1.55	3.96	428	214	1.29
		M		38.4	1.05	1.00	196	166	1.00
		S		38.4	0.78	1.00	108	166	1.00
LLOYD'S	1*	B	19.8	38.4	1.25	7.85	848	332	2.00
		M	19.8	38.4	1.25	4.33	848	332	2.00
		S	19.8	38.4	1.15	6.65	718	332	2.00
	1	B	19.8	38.4	1.00	5.03	543	332	2.00
		M	19.8	38.4	1.05	3.05	598	332	2.00
		S	19.8	38.4	1.00	5.03	543	332	2.00
	2	B	19.8	38.4	1.00	5.03	543	332	2.00
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	1.00	1.65	178	166	1.00
	3	B	19.8	31.7	1.00	5.03	543	274	1.65
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	0.78	1.00	108	166	1.00
	IA Super, IA, IB, IC	Same as ABS							
ASPPR	1	B	39.5	106.2	2.36	9.19	992	460	2.77
		M		38.4	1.18	1.29	248	166	1.00
		S		38.4	1.18	2.30	248	166	1.00
	1A	B		159.4	2.88	13.67	1477	690	4.16
		M		69.1	1.90	3.28	643	299	1.80
		S		86.3	2.12	7.41	800	374	2.25
	2	B		212.5	3.33	18.28	1974	920	5.54
		M		106.2	2.36	5.06	992	460	2.77
		S		132.8	2.63	11.40	1231	575	3.46
	3	B		265.6	3.72	22.81	2463	1150	6.93
		M		140.8	2.71	6.67	1308	610	3.67
		S		175.3	3.03	15.14	1635	759	4.57
	4	B		318.7	4.08	27.44	2964	1380	8.31
		M		175.3	3.03	8.34	1635	759	4.57
		S		217.8	3.37	18.72	2022	943	5.68
	6	B		371.8	4.41	32.06	3462	1610	9.70
		M		199.2	3.23	9.47	1857	863	5.20
		S		249.7	3.61	21.48	2320	1081	6.51
	7	B		398.4	4.56	34.28	3702	1725	10.39
		M		225.7	3.43	10.69	2095	977	5.89
		S		278.9	3.82	24.06	2598	1208	7.28
	8	B		398.4	4.56	34.28	3702	1725	10.39
		M		252.3	3.63	11.97	2346	1093	6.58
		S		318.7	4.08	27.44	2964	1380	8.31
	10	B		398.4	4.56	34.28	3702	1725	10.39
		M		252.3	3.63	11.97	2346	1093	6.58
		S		318.7	4.08	27.44	2964	1380	8.31

TABLE B-2.3 (Continued)
COMPARISON OF ICE STRENGTHENED SCANTLINGS
IN TERMS OF NORMALIZED LOAD CARRYING CAPABILITY

ARCTIC TANKER

RULE	CLASS	AREA	FRAME SPAC. [in]	FRAME S.M. [in³]	PLATE THICK. [in]	P/P_{Rule}	P_{Plate} [psi]	P_{Frame} [psi]	P/P_{Rule}
DNV	ICE C	B	12.0	103.5	1.00	12.86	1389	1475	8.89
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	0.78	1.00	108	166	1.00
	ICEBREAKER	B	27.9	61.2	3.17	28.13	3038	375	2.26
		M		61.2	2.53	9.87	1935	375	2.26
		S		61.2	3.17	28.13	3038	375	2.26
	ARCTIC ICEBREAKER	B		76.5	4.12	47.51	5131	469	2.83
		M		76.5	3.29	16.69	3272	469	2.83
		S		76.5	4.12	47.51	5131	469	2.83
	IA* / IA / IB / IC		Same as ABS						
BUREAU VERITAS	Glace I-Super	B	19.8	57.6	1.26	7.98	862	498	3.00
		M	19.8	38.4	1.26	4.40	862	332	2.00
		S	19.8	57.6	1.26	7.96	862	498	3.00
BUREAU VERITAS	Glace I	B	19.8	57.6	1.00	5.03	543	498	3.00
		M	19.8	38.4	1.05	3.05	598	332	2.00
		S	19.8	57.6	1.00	5.03	543	498	3.00
	Glace II	B	19.8	57.6	1.00	5.03	543	498	3.00
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	1.00	1.65	178	166	1.00
	Glace III	B	19.8	33.6	1.00	5.03	543	290	1.75
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	1.00	1.65	178	166	1.00
	IA Super / IA / IB / IC		Same as ABS						
USSR	YA	B	19.8	70.5	2.02	20.50	2214	609	3.67
		M	19.8	51.8	1.39	5.35	1049	447	2.69
		S	19.8	51.8	1.39	9.71	1049	447	2.69
	A1	B	19.8	42.3	1.58	12.55	1355	365	2.20
		M	19.8	38.4	1.35	5.05	989	332	2.00
		S	19.8	38.4	1.35	9.16	989	332	2.00
	A2	B	19.8	42.3	1.00	5.03	543	365	2.20
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	1.00	1.65	178	166	1.00
	A3	B	19.8	33.6	1.00	5.03	543	290	1.75
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	0.78	1.00	108	166	1.00
	A4	B	23.7	38.4	1.00	3.67	396	277	1.67
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	0.78	1.00	108	166	1.00
NKK	AA	B	19.8	185.7	1.83	16.82	1817	1604	9.66
		M		98.7	1.31	4.75	931	853	5.14
		S		185.7	1.30	8.49	917	1604	9.66
	A	B		123.8	1.52	11.61	1254	1069	6.44
		M		66.2	1.18	3.87	756	570	3.43
		S		123.8	1.30	8.49	917	1069	6.44
	B	B		84.4	1.52	11.61	1254	729	4.39
		M	39.5	38.4	1.12	1.14	223	166	1.00
		S	19.8	84.4	0.92	4.25	459	729	4.39
	C	B	19.8	39.4	1.30	8.49	917	340	2.05
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	19.8	39.4	0.78	3.06	330	340	2.05
	IA Super / IA / IB / IC		Same as ABS						
PEOPLES REPUBLIC OF CHINA	BI*	B	19.8	76.8	1.26	7.98	862	663	3.99
		M	19.8	38.4	1.26	4.40	862	332	2.00
		S	19.8	76.8	1.26	7.98	862	663	3.99
	BI	B	19.8	76.8	1.00	5.03	543	663	3.99
		M	19.8	38.4	1.05	3.05	598	332	2.00
		S	19.8	76.8	1.00	5.03	543	663	3.99
	BII	B	19.8	76.8	1.00	5.03	543	663	3.99
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	1.00	1.65	178	166	1.00
	BIII	B	39.5	38.4	1.00	1.65	178	166	1.00
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	0.78	1.00	108	166	1.00
PEOPLES REPUBLIC OF CHINA	B (River Vessels)	B	19.8	25.0	0.55	1.52	164	216	1.30
		M	39.5	38.4	1.05	1.00	196	166	1.00
		S	39.5	38.4	0.78	1.00	108	166	1.00

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APPENDIX B-3

TABULAR LISTING OF LOW-TEMPERATURE STEELS AND THEIR PROPERTIES

TABLE B-3.1

STEEL TYPES USED FOR SHIPS NAVIGATING IN ICE

MATERIAL SPECIFICATION SOURCE:	REGION OF APPLICATION:				
	ICE BELT, ICE FRAMES, SHELL, WEATHER DECKS	ICE STRINGERS & OTHER ICE MEMBERS	STRUCTURE ADJ. TO SHELL & WEATHER DECKS	SUPERSTRUCT., INTERIOR STRUCTURE	SPECIAL APPLICATIONS
American Bureau of Shipping (1980)	ABS MS Grades A,B,D,E,DS,CS ABS HTS Grades AH32, DH32, EH32, AH36, DH36, EH36	Ditto	Ditto	Ditto	
Lloyd's Register of Shipping (1979) - British Classification Rules for Ships	LR MS Grades A,B,D,E, LR HTS Grades AH27S, DH27S, EH27S, AH32, DH32, EH32, AH34S, DH34S, EH34S, AH36, DH36, EH36	Ditto	Ditto	Ditto	
Det Norske Veritas (1977)- Norwegian Classification Rules for Ships	DNV MS Grades NVA, NVB, NVD, NVE DNV HTS Grades NVA27S, NVD27S, NVE27S, NVA32, NVD32, NVE32, NVA36, NVD36, NVE36, NVA40S, NVD40S, NVE40S	Ditto	Ditto	Ditto	
Bureau Veritas (1977) - French Classification Rules for Ships	BV MS Grades A, B, D, E BV HTS Grades AH32, DH32, EH32, AH36, DH36, EH36	Ditto	Ditto	Ditto	
Nippon Kaiji Koykai (1979) - Japanese Classification Rules for Ships	NKK MS Grades KA, KB, KD, KE NKK HTS Grades KA32, KD32, KE32, KA36, KD36, KE36	Ditto	Ditto	Ditto	
Germanischer Lloyd (1980) German Classification Rules for Ships	GL MS Grades A, B, D, E GL HTS Grades A32, D32, E32, A36, D36, E36	Ditto	Ditto	Ditto	
Specifications for USCG 400-Foot Polar Class Icebreaker	CG-A537M for plates and shapes	CG-A537M for fabricated shapes; CG-A537M, ASTM-A537 Class 1, ASTM - A537 Class 2 for rolled shapes	CG-A537M for plates, ASTM - A537 Class 1 & ASTM-A537 Class 2 for rolled shapes	ABS Steel Grades	HY-80 for flight deck and around large deck openings
Specifications for USCG 140-Foot Harbor Tug	ASTM-A537 Class 1 or 2, and ABS Grade E	ASTM-A537 Class 1 or 2, and ABS Grade E	ABS Steel Grades B, C or CS	ABS steel Grades B, C or CS	
Specifications for Nuclear Icebreaking Tanker	CG-A537M (except for shell)	CG-A537M	ABS Steel Grades (including shell)	ABS Steel Grades	

TABLE B-3.2

STEEL TYPES PROPOSED FOR SHIPS NAVIGATING IN ICE

MATERIAL SPECIFICATION SOURCE:	REGION OF APPLICATION:				
	ICE BELT, ICE FRAMES, SHELL, WEATHER DECKS	ICE STRINGERS & OTHER ICE MEMBERS	STRUCTURE ADJ. TO SHELL & WEATHER DECKS	SUPERSTRUCT., INTERIOR STRUCTURE	SPECIAL APPLICATIONS
Additional materials proposed for ice-strengthened ships as recommended by steel manufacturers	ASTM-A 710 Gr.A, Class 3	Ditto	Ditto		
	ASTM-A 633 Gr. A & B	"	"		
	ASTM-A 633 Gr. C	"	"		
	ASTM-A 633 Gr. D	"	"		
	ASTM-A 633 Gr. E	"	"		
	ASTM-A 737 Gr. B	"	"		
	ASTM-A 678 Gr. A	"	"		
	ASTM-A 678 Gr. B	"	"		
	ASTM-A 678 Gr. C	"	"		
	ABS Gr. V-039	"	"		
	ABS Gr. V-051	"	"		

TABLE B-3.3

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ABS MS Gr. A	Lloyd's Register MS Gr. A	Norske Veritas MS Gr. NVA
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, vacuum-arc remelt, or electro-slag remelt process	Open-hearth, electric-furnace, or basic-oxygen process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Any method, except rimmed steel*	Any method, except rimmed steel*	Any method, except rimmed steel*
HEAT TREATMENT	Not required	Not required	Not required
CHEMICAL COMPOSITION (Ladle Analysis - %)	Except for Gr. A shapes & bars, the carbon content + 1/6 of the manganese content is not to exceed 0.40%. If this condition is satisfied, manganese may be up to 1.65%.	The sum of carbon content plus 1/6 of the manganese content shall not exceed 0.40%.	Carbon plus 1/6 of the manganese content is not to exceed 0.40%.
Carbon (max.)	0.23	0.23	0.23**
Manganese	2.5 x carbon **	2.5 x carbon **	2.5 x carbon
Phosphorus (max.)	0.04	0.05	0.04
Sulphur (max.)	0.04	0.05	0.04
Silicon		0.50 max.	0.35 max.
Chromium			
Nickel			
Molybdenum			
Copper			
Titanium			
Vanadium			
Aluminum			
Others			
Notes:	*Rimmed steel is accepted for plates up to 12.5 MM (1/2 IN). **Min. for 12.5 MM (1/2 IN).	*Rimmed steel is accepted for plates up to 12.5 MM (1/2 IN). **Min. for 12.5 MM (1/2 IN).	*For thickn. 12.5 MM (1/2 IN) rimmed steel may be accepted. **For thickn. 12.5 MM (1/2 IN) a higher carbon content may be accepted upon special approval.
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	41 - 50 (58 - 71)	41 - 50 (58 - 71)	41 - 50 (58 - 71)
Yield (min.) KG/MM^2 (KSI)	24 (34) incl. 25 MM (1 IN) 23 (32) above 25 MM (1 IN)	24 (34)	24 (34) incl. 25 MM (1 IN) 23 (32) above 25 MM (1 IN)
Elongation (min.) % in $5.65\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	21 in 200 MM (8 IN) or 24 in 50 MM (2 IN)	22	22
CHARPY V-NOTCH IMPACT TEST Temperature °C Energy, KG-M (FT-LB)	None required	None required	None required
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 140	110 - 140	110 - 140
REQUIRED WELDING AND FABRICATION TECHNIQUES	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.0	1.0	1.0

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Bureau Veritas MS Gr. A	NKK MS Gr. KA	German Lloyd MS Gr. A
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society	Open-hearth, basic-oxygen, or electric-furnace process, or other approved by the society	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society
DEOXIDATION	Not reqd., but rimmed steel not above 12.5 MM (1/2 IN)	Semi-killed or killed*	Any method, except rimmed steel above 12.5 MM (1/2 IN)
HEAT TREATMENT	Not required	Not required	Not required
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	*	0.23	0.23
Manganese	*	2.5 x C min.	2.5 x C min.*
Phosphorus (max.)	0.05	0.04	0.04
Sulphur (max.)	0.05	0.04	0.04
Silicon		0.35 max.	0.35 max.
Chromium			
Nickel			
Molybdenum			
Copper			
Titanium			
Vanadium			
Aluminum			
Others			
Notes:	*Manganese content not to be less than 2-1/2 times the carbon content for more than 12.5 MM (1/2 IN).	*Rimmed steel is accepted for plates up to 12.5 MM (1/2 IN) inclusive.	*Manganese content may be less below 12.5 MM (1/2 IN).
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	41 - 50 (58 - 71)	41 - 50 (58 - 71)	41 - 50 (58 - 71)
Yield (min.) KG/MM^2 (KSI)	24 (34)	24 (34)	24 (34)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22	22	22
CHARPY V-NOTCH IMPACT TEST Temperature °C Energy, KG-M (FT-LB)	None required	None required	None required
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 140	110 - 140	110 - 140
REQUIRED WELDING AND FABRICATION TECHNIQUES	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.0	1.0	1.0

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ABS MS Gr. B	Lloyd's Register MS Gr. B	Norske Veritas MS Gr. NVB
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, vacuum-arc remelt, or electro-slag remelt process	Open-hearth, electric-furnace, or basic-oxygen process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Any method, except rimmed steel	Any method, except rimmed steel	Any method, except rimmed steel
HEAT TREATMENT	Not required	Not required	Not required
CHEMICAL COMPOSITION (Ladle Analysis - %)	The carbon content + 1/6 of the manganese content is not to exceed 0.40%. If this condition is satisfied, manganese may be up to 1.65%.	The sum of carbon content plus 1/6 of the manganese content shall not exceed 0.40%.	Carbon plus 1/6 of the manganese content is not to exceed 0.40%.
Carbon (max.)	0.21	0.21	0.21
Manganese	0.80 - 1.10*	0.80 min.*	0.80*
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.35 max.	0.50 max.	0.35 max.
Chromium			
Nickel			
Molybdenum			
Copper			
Titanium			
Vanadium			
Aluminum			
Others			
Notes:	*0.60 min. for fully killed or cold flanging quality.	*If silicon content is 0.10 or more, min. manganese may be 0.60.	*If silicon content is 0.10, min. manganese may be reduced to 0.60%.
TENSILE REQUIREMENTS Ultimate KG/MM^2 (KSI) Yield (min.)KG/MM^2 (KSI) Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	41 - 50 (58 - 71) 24 (34) 21 in 200 MM (8 IN) or 24 in 50 MM (2 IN)	41 - 50 (58 - 71) 24 (34) 22	41 - 50 (58 - 71) 24 (34) 22
CHARPY V-NOTCH IMPACT TEST Temperature °C Energy, KG-M (FT-LB)	Required for thicknesses above 25 MM (1 IN) only 0 2.8 (20) Longitudinal 2.0 (14) Transverse	Required for thicknesses above 25 MM (1 IN) only 0 2.8 (20) Longitudinal	0 2.8 (20) Longitudinal 2.0 (14) Transverse
NDT TEMPERATURE °C	+10 to + 16		
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN	46 (333)		
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 140	110 - 140	110 - 140
REQUIRED WELDING AND FABRICATION TECHNIQUES	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.015	1.015	1.015

TABLE 8-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Bureau Veritas MS Gr. B	NKK MS Gr. KB	German. Lloyd MS Gr. B
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society	Open-hearth, basic-oxygen, or electric-furnace process, or other approved by the society	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society
DEOXIDATION	Rimmed steel not to be used	Semi-killed or killed	Any method, except rimmed steel
HEAT TREATMENT	Not required	Not required	Not required
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.21	0.21	0.21
Manganese	0.80 - 1.40	0.80 min.	0.80 min.
Phosphorus (max.)	0.05	0.04	0.04
Sulphur (max.)	0.05	0.04	0.04
Silicon	0.35 max.	0.35 max.	0.35 max.
Chromium			
Nickel			
Molybdenum			
Copper			
Titanium			
Vanadium			
Aluminum			
Others			
Notes:			
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	41 - 50 (58 - 71)	41 - 50 (58 - 71)	41 - 50 (58 - 71)
Yield (min.) KG/MM^2 (KSI)	24 (34)	24 (34)	24 (34)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22	22	22
CHARPY V-NOTCH IMPACT TEST	None required		
Temperature °C		0	0
Energy, KG-M (FT-LB)		2.8 (20) Longitudinal 2.1 (15) Transverse	2.8 (20) Longitudinal
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 140	110 - 140	110 - 140
REQUIRED WELDING AND FABRICATION TECHNIQUES	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.015	1.015	1.015

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ABS MS Gr. DS	ABS HTS Gr. AH32	Lloyd's Register HTS Gr. AH27S
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, vacuum-arc remelt, or electro-slag remelt process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, electric-furnace, or basic-oxygen process
DEOXIDATION	Fully killed, fine grain practice	Semi-killed or killed	Semi-killed or silicon-killed
HEAT TREATMENT	Normalized	Normd.above 35 MM(1.38 IN)* Normd.above 12.5MM(1/2IN)**	Normd.above 35 MM(1.38 IN)*
CHEMICAL COMPOSITION (Ladle Analysis - %)	The carbon content + 1/6 of the manganese content is not to exceed 0.40%. If this condition is satisfied, manganese may be up to 1.65%.		
Carbon (max.)	0.16	0.18	0.18
Manganese	1.0 - 1.35	0.90 - 1.60***	0.70 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.35	0.10 - 0.50	0.05 max.
Chromium		0.25 max.	0.20 max.
Nickel		0.40 max.	0.40 max.
Molybdenum		0.08 max.	0.08 max.
Copper		0.35 max.	0.35 max.
Titanium			
Vanadium		0.10 max.	0.03 - 0.10
Aluminum			0.015 min.
Others		0.05 max. Cb	0.015 - 0.05 Nb
Notes:		*If aluminum-treated. **If columbium or vanadium practice used. ***12.5 MM (1/2 IN) and under may have min. manganese of 0.70%.	*Above 12.5 MM (1/2 IN), if niobium or aluminum + niobium practice is used.
TENSILE REQUIREMENTS Ultimate KG/MM^2 (KSI) Yield (min.)KG/MM^2 (KSI) Elongation (min.) % in $5.65\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	41 - 50 (58 - 71) 24 (34) 21 in 200 MM (8 IN) or 24 in 50 MM (2 IN)	48 - 60 (68 - 85) 32 (45.5) 19 in 200 MM (8 IN) or 22 in 50 MM (2 IN)	41 - 52 (58 - 74) 27 (38.5) 22
CHARPY V-NOTCH IMPACT TEST Temperature °C Energy, KG-M (FT-LB)	None required	None required	Required for thicknesses above 12.5 MM (1/2 IN) only 0 2.8 (20) Longitudinal
NDT TEMPERATURE °C		-12 to -7	
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN		14 (101)	
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 140	135 - 170	110 - 147
REQUIRED WELDING AND FABRICATION TECHNIQUES	Conventional welding methods. No preheating. Normal forming and cutting practice.	Moderate preheat for welding. Low hydrogen practice. Normal forming and cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.09	1.11	1.11

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Lloyd's Register HTS Gr. AH32	Norske Veritas HTS Gr. NVA 27S	Norske Veritas HTS Gr. NVA32
PROCESS OF MANUFACTURE	Open-hearth, electric-furnace, or basic-oxygen process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Semi-killed or silicon-killed	Semi-killed or fully killed	Fully killed
HEAT TREATMENT	Normd. above 35 MM(1.38 IN)*	Not required	Normalized
CHEMICAL COMPOSITION (Ladle Analysis ~ %)			
Carbon (max.)	0.18	0.20	0.18
Manganese	0.70 - 16.0	0.70 min.	0.9 - 1.6*
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.05 max.		0.10 - 0.50
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.03 - 0.10	0.10 max.	0.10 max.
Aluminum	0.015 min.	0.08 max.	0.08 max.
Others	0.015 - 0.05 Nb	0.05 max. Nb	0.05 max. Nb
Notes:	*Above 12.5 MM (1/2 IN), if niobium or aluminum + niobium practice is used.		*0.70 min. may be used for 12.5 MM (1/2 IN) and less.
TENSILE REQUIREMENTS Ultimate KG/MM^2 (KSI)	45 - 60 (64 - 85)	41 - 52 (58 - 74)	45 - 60 (64 - 85)
Yield (min.) KG/MM^2 (KSI)	32 (45.5)	27 (38.5)	32 (45.5)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22	22	22
CHARPY V-NOTCH IMPACT TEST	Required for thicknesses above 12.5 MM (1/2 IN) only	None required	
Temperature °C	0		0
Energy, KG-M (FT-LB)	3.16 (23) Longitudinal		3.16 (23) Longitudinal 2.24 (16) Transverse
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	125 - 170	110 - 147	125 - 170
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.11	1.11	1.11

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Bureau Veritas HTS Gr. AH32	NKK HTS Gr. KA32	German. Lloyd HTS Gr. A32
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace or any equivalent approved by the society	Open-hearth, basic-oxygen, or electric-furnace process, or other approved by the society	Open-hearth, basic-oxygen, electric-furnace or any equivalent approved by the society
DEOXIDATION	Unrimmed steel, killed above 12.5 MM (1/2 IN)	Killed	Killed
HEAT TREATMENT	Not required*	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.10	0.18
Manganese	0.70 - 1.60 **	0.90 - 1.60	0.90 - 1.60*
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.05 max. ***	0.10 - 0.50	0.10 - 0.50
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.10 max.		
Aluminum	0.06 max.	0.015 min.	0.07 max.
Others	0.05 max. Nb		
Notes:	*Not required, if aluminum or vanadium treated. **0.90-1.60 above 12.5 MM (1/2 IN). ***0.10-0.50 above 12.5 MM (1/2 IN).		*Minimum is 0.70 below 12.5 MM (1/2 IN).
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	45 - 60 (64 - 85)	48 - 60 (68 - 85)	48 - 60 (68 - 85)
Yield (min.) KG/MM^2 (KSI)	32 (45.5)	32 (45.5)	32 (45.5)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	20	22	22
CHARPY V-NOTCH IMPACT TEST	None required		
Temperature °C		0	0
Energy, KG-M (FT-LB)		3.2 (23) Longitudinal 2.3 (17) Transverse	3.2 (23) Longitudinal 2.2 (16) Transverse
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	125 - 170	135 - 170	125 - 170
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.11	1.11	1.11

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ABS HTS Gr. AH36	Lloyd's Register HTS Gr. AH34S	Lloyd's Register HTS Gr. AH36
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, electric-furnace, or basic-oxygen process	Open-hearth, electric-furnace, or basic-oxygen process
DEOXIDATION	Semi-killed or killed	Semi-killed or silicon-killed	Semi-killed or silicon-killed
HEAT TREATMENT	Normd.above 35 MM(1.38 IN)* Normd.above 12.5MM(1/2IN)**	Normd.above 35 MM(1.38 IN)*	Normd.above 35 MM(1.38 IN)*
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.90 - 1.60***	070 - 1.60	070 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.50	0.05 max.	0.05 max.
Chromium	0.25 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.10 max.	0.03 - 0.10	0.03 - 0.10
Aluminum		0.015 min.	0.015 min.
Others	0.05 max. Cb	0.015 - 0.05 Nb	0.015 - 0.05 Nb
Notes:	*If aluminum treated. **If columbium or vanadium practice used. ***12.5 MM (1/2 IN) and under may have min. manganese of 0.70%.	*Above 12.5 MM (1/2 IN), if niobium or aluminum + niobium practice is used.	*Above 12.5 MM (1/2 IN), if niobium or aluminum + niobium practice is used.
TENSILE REQUIREMENTS Ultimate KG/MM^2 (KSI) Yield (min.)KG/MM^2 (KSI) Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	50 - 63 (71 - 90) 36 (51) 19 in 200 MM (8 IN) or 22 in 50 MM (2 IN)	62 (88) 34 (48) 22	50 - 63 (71 - 90) 36 (51) 21
CHARPY V-NOTCH IMPACT TEST Temperature °C Energy, KG-M (FT-LB)	None required	Required for thicknesses above 12.5 MM (1/2 IN) only 0 3.47 (25) Longitudinal	Required for thicknesses above 12.5 MM (1/2 IN) only 0 3.47 (25) Longitudinal
NDT TEMPERATURE °C	-12 to -7		
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	140 - 181	177	140 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.17	1.17	1.17

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Norske Veritas HTS Gr. NVA 36	Norske Veritas HTS Gr. NVA40S	Bureau Veritas HTS Gr. AH36
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society
DEOXIDATION	Fully killed	Fully killed	Unrimmed steel, killed above 12.5 MM (1/2 IN)
HEAT TREATMENT	Not required	Normd.above 12.5 MM(1/2 IN)	Not required*
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.9 - 1.6*	0.9 - 1.6*	0.70 - 1.60**
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.50	0.10 - 0.50	0.50 max.***
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.10 max.	0.10 max.	0.10 max.
Aluminum	0.08 max.	0.08 max.	0.06 max.
Others	0.05 max. Nb	0.05 max. Nb	0.05 max. Nb
Notes:	*0.70 min. may be used for 12.5 MM (1/2 IN) and less.	*0.70 min. may be used for 12.5 MM (1/2 IN) and less.	*Not required if aluminum or vanadium treated. **0.90-1.60 above 12.5 MM (1/2 IN). ***0.10-0.50 above 12.5 MM (1/2 IN).
TENSILE REQUIREMENTS Ultimate KG/MM^2 (KSI)	50 - 63 (71 - 90)	54 - 66 (77 - 94)	50 - 63 (71 - 90)
Yield (min.)KG/MM^2 (KSI)	36 (51)	40 (57)	36 (51)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	21	20	20
CHARPY V-NOTCH IMPACT TEST			None required
Temperature °C	0	0	
Energy, KG-M (FT-LB)	3.47 (25) Longitudinal 2.45 (18) Transverse	4.0 (29) Longitudinal 2.65 (19) Transverse	
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	140 - 181	153 - 190	140 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.17	1.17	1.17

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	NKK HTS Gr. KA36	German. Lloyd HTS Gr. A36	ABS MS Gr. D
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace process, or other approved by the society	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society	Open-hearth, basic-oxygen, electric-furnace, vacuum-arc remelt, or electro-slag remelt process
DEOXIDATION	Killed	Killed	Fully killed, fine grain practice
HEAT TREATMENT	Normalized	Normalized	Normd.above 35 MM (1.38 IN)
CHEMICAL COMPOSITION (Ladle Analysis - %)			The carbon content + 1/6 of the manganese content is not to exceed 0.40%. If this condition is satisfied, manganese may be up to 1.65%.
Carbon (max.)	0.18	0.18	0.21
Manganese	0.90 - 1.60	0.90 - 1.60*	0.70 - 1.35*
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.50	0.10 - 0.50	0.10 - 0.35
Chromium	0.20 max.	0.20 max.	
Nickel	0.40 max.	0.40 max.	
Molybdenum	0.08 max.	0.08 max.	
Copper	0.35 max.	0.35 max.	
Titanium			
Vanadium	0.10 max.	0.10 max.	
Aluminum	0.015 min.	0.07 max.	
Others	0.05 max. Nb	0.05 max. Nb	
Notes:		*Minimum is 0.70 below 12.50 MM (1/2 IN).	*0.60 min. for 25 MM (1 IN) thickness and under.
TENSILE REQUIREMENTS Ultimate KG/MM² (KSI) Yield (min.)KG/MM² (KSI) Elongation (min.) % in 5.65 √A MM (IN) or as noted (A=area of spe.)	50 - 63 (71 - 90) 36 (51) 21	50 - 63 (71 - 90) 36 (51) 21	41 - 50 (58 - 71) 24 (34) 21 in 200 MM (8 IN) or 24 in 50 MM (2 IN)
CHARPY V-NOTCH IMPACT TEST Temperature °C Energy, KG-M (FT-LB)	0 3.5 (25) Longitudinal 2.5 (18) Transverse	0 3.5 (25) Longitudinal 2.4 (17) Transverse	-10 2.8 (20) Longitudinal 2.0 (14) Transverse
NDT TEMPERATURE °C			-35 aver.
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	140 - 181	140 - 181	110 - 140
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.17	1.17	1.31

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ABS MS Gr. CS	Lloyd's Register MS Gr. D	Norske Veritas MS Gr. NVD
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, vacuum-arc remelt, or electro-slag remelt process	Open-hearth, electric-furnace, or basic-oxygen process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Fully killed, fine grain practice	Fully killed, fine grain practice	Any method except rimmed steel
HEAT TREATMENT	Normalized	Normalized	Normd.above 25 MM (1 IN)*
CHEMICAL COMPOSITION (Ladle Analysis - %)	The carbon content + 1/6 of the manganese content is not to exceed 0.40%. If this condition is satisfied, manganese may be up to 1.65%.	The sum of carbon content plus 1/6 of the manganese content shall not exceed 0.40%.	Carbon plus 1/6 of the manganese content is not to exceed 0.40%
Carbon (max.)	0.16	0.21	0.21
Manganese	1.0 - 1.35	0.70 - 1.40*	0.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.35	0.10 - 0.50 max.	0.35 max.
Chromium			
Nickel			
Molybdenum			
Copper			
Titanium			
Vanadium			
Aluminum		0.015 min.	
Others			
Notes:		*For 25.5 MM (1 IN) or less, min. manganese may be 0.60.	*With fine grain practice, normalizing is only required for thicknesses above 35 MM (1.38 IN).
TENSILE REQUIREMENTS			
Ultimate KG/MM² (KSI)	41 - 50 (58 - 71)	41 - 50 (58 - 71)	41 - 50 (58 - 71)
Yield (min.)KG/MM² (KSI)	24 (34)	24 (34)	24 (34)
Elongation (min.) % in 5.65 √A MM (IN) or as noted (A=area of spe.)	21 in 200 MM (8 IN) or 24 in 50 MM (2 IN)	22	22
CHARPY V-NOTCH IMPACT TEST	None required		
Temperature °C		0	-10
Energy, KG-M (FT-LB)		4.8 (35) Longitudinal	2.75 (20) Longitudinal 2.0 (14) Transverse
NDT TEMPERATURE °C	-57 to -51		
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN	98 (709)		
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 140	110 - 140	110 - 140
REQUIRED WELDING AND FABRICATION TECHNIQUES	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.31	1.31	1.31

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Bureau Veritas MS Gr. D	NKK MS Gr. KD	German. Lloyd MS Gr. D
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society	Open-hearth, basic-oxygen, electric-furnace process, or other approved by the society	Open-hearth, basic-oxygen, electric-furnace process, or other approved by the society
DEOXIDATION	Rimmed steel not be used	Semi-killed or killed*	Any method, except rimmed steel*
HEAT TREATMENT	Not required	Normd above 25 MM (1 IN)	Normd above 25.5 MM (1 IN)
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.21	0.21	0.21
Manganese	0.60 - 1.40	0.60 min.	0.70 - 1.40
Phosphorus (max.)	0.05	0.04	0.04
Sulphur (max.)	0.05	0.04	0.04
Silicon	0.35 max.	0.35 max.	0.10 - 0.35
Chromium			
Nickel			
Molybdenum			
Copper			
Titanium			
Vanadium			
Aluminum			0.02 min.
Others			
Notes:		*Semi-killed is accepted for thickness up to 25 MM (1 IN) inclusive.	*Aluminum treated and fine grain practice above 25.5 MM (1 IN).
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	41 - 50 (58 - 71)	41 - 50 (58 - 71)	41 - 50 (58 - 71)
Yield (min.) KG/MM^2 (KSI)	24 (34)	24 (34)	24 (34)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22	22	22
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	0	-10	- 20
Energy, KG-M (FT-LB)	4.8 (35) Longitudinal	2.8 (20) Longitudinal 2.1 (15) Transverse	2.8 (20) Longitudinal
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 140	110 - 140	110 - 140
REQUIRED WELDING AND FABRICATION TECHNIQUES	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.31	1.31	1.31

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ABS MS Gr. E	Lloyd's Register MS Gr. E	Norske Veritas MS Gr. NVE
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, vacuum-arc remelt, or electro-slag remelt process	Open-hearth, electric-furnace, or basic-oxygen process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Fully killed, fine grain practice	Fully killed, fine grain practice	Fully killed, fine grain practice
HEAT TREATMENT	Normalized	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)	The carbon content + 1/6 of the manganese content is not to exceed 0.40%. If this condition is satisfied, manganese may be up to 1.65%.	The sum of carbon content plus 1/6 of the manganese content shall not exceed 0.40%.	Carbon plus 1/6 of the manganese content is not to exceed 0.40%.
Carbon (max.)	0.18	0.18	0.18
Manganese	0.70 - 1.35	0.70 - 1.50	0.70
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.35	0.10 - 0.50	0.10 - 0.35
Chromium			
Nickel			
Molybdenum			
Copper			
Titanium			
Vanadium			
Aluminum		0.015 min.	0.015 min.
Others			
Notes:			
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	41 - 50 (58 - 71)	41 - 50 (58 - 71)	41 - 50 (58 - 71)
Yield (min.)KG/MM^2 (KSI)	24 (34)	24 (34)	24 (34)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	21 in 200 MM (8 IN) or 24 in 50 MM (2 IN)	22	22
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-40	-40	-40
Energy, KG-M (FT-LB)	2.8 (20) Longitudinal 2.0 (14) Transverse	2.75 (20) Longitudinal	2.75 (20) Longitudinal 2.0 (14) Transverse
NDT TEMPERATURE °C	-48 to -46		
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 140	110 - 140	110 - 140
REQUIRED WELDING AND FABRICATION TECHNIQUES	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.36	1.36	1.36

TABLE 8-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Bureau Veritas MS Gr. E	NKK MS Gr. KE	German. Lloyd MS Gr. E
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society	Open-hearth, basic-oxygen, electric-furnace process, or other approved by the society	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society
DEOXIDATION	Fully killed, fine grain	Killed*	Aluminum treated, fine grain practice
HEAT TREATMENT	Normalized	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.70 - 1.50	0.70 min.	0.70 - 1.50
Phosphorus (max.)	0.05	0.04	0.04
Sulphur (max.)	0.05	0.04	0.04
Silicon	0.10 - 0.35	0.10 - 0.35	0.10 - 0.35
Chromium			
Nickel			
Molybdenum			
Copper			
Titanium			
Vanadium			
Aluminum	0.015 - 0.06	0.015 min.	0.02 min.
Others			
Notes:		*Aluminum treatment is to be used as a fine grain practice.	
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	41 - 50 (58 - 71)	41 - 50 (58 - 71)	41 - 50 (58 - 71)
Yield (min.)KG/MM^2 (KSI)	24 (34)	24 (34)	24 (34)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22	22	22
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-40	-40	-40
Energy, KG-M (FT-LB)	2.8 (20) Longitudinal	2.8 (20) Longitudinal 2.1 (15) Transverse	2.8 (20) Longitudinal
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 140	110 - 140	110 - 140
REQUIRED WELDING AND FABRICATION TECHNIQUES	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.	Conventional welding methods. No preheating. Normal forming and cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.36	1.36	1.36

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ABS HTS Gr. DH32	ABS HTS Gr. DH36	Lloyd's Register HTS Gr. DH27S
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, electric-furnace, or basic-oxygen process
DEOXIDATION	Killed, fine grain practice	Killed, fine grain practice	Semi-killed or silicon-killed
HEAT TREATMENT	Normd.above 25.5 MM(1 IN)* Normd.above 12.5MM(1/2IN)**	Normd.above 25.5 MM(1 IN)* Normd.above 12.5MM(1/2IN)**	Normd.above 25.5 MM (1 IN)*
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.90 - 1.60	0.90 - 1.60	0.70 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.50	0.10 - 0.50	0.05 max.
Chromium	0.25 max.	0.25 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.10 max.	0.10 max.	0.03 - 0.10
Aluminum			0.015 min.
Others	0.05 max. Cb	0.05 max. Cb	0.015 - 0.05 Nb
Notes:	*If aluminum treated. **If columbium or vanadium practice is used.	*If aluminum treated. **If columbium or vanadium practice is used.	*Above 12.5 MM (1/2 IN), if niobium or aluminum + niobium practice is used.
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	48 - 60 (68 - 85)	50 - 63 (71 - 90)	41 - 52 (58 - 74)
Yield (min.) KG/MM^2 (KSI)	32 (45.5)	36 (51)	27 (38.5)
Elongation (min.) % in $5.65\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	19 in 200 MM (8 IN) or 22 in 50 MM (2 IN)	19 in 200 MM (8 IN) or 22 in 50 MM (2 IN)	22
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-20	-20	-20
Energy, KG-M (FT-LB)	3.5 (25) Longitudinal 2.4 (17) Transverse	3.5 (25) Longitudinal 2.4 (17) Transverse	2.75 (20) Longitudinal
NDT TEMPERATURE °C	-62 to -40	-62 to -40	
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	135 - 170	140 - 181	110 - 147
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.38	1.38	1.38

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Lloyd's Register HTS Gr. DH32	Lloyd's Register HTS Gr. DH34S	Lloyd's Register HTS Gr. DH36
PROCESS OF MANUFACTURE	Open-hearth, electric-furnace, or basic-oxygen process	Open-hearth, electric-furnace, or basic-oxygen process	Open-hearth, electric-furnace, or basic-oxygen process
DEOXIDATION	Semi-killed or silicon-killed	Semi-killed or silicon-killed	Semi-killed or silicon-killed
HEAT TREATMENT	Normd.above 25.5 MM (1 IN)*	Normd.above 25.5 MM (1 IN)*	Normd.above 25.5 MM (1 IN)*
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.90 - 1.60	0.90 - 1.60	0.90 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.05 max.	0.05 max.	0.05 max.
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.03 - 0.10	0.03 - 0.10	0.03 - 0.10
Aluminum	0.015 min.	0.015 min.	0.015 min.
Others	0.015 - 0.05 Nb	0.015 - 0.05 Nb	0.015 - 0.05 Nb
Notes:	*Above 12.5 MM (1/2 IN), if niobium or aluminum + niobium practice is used.	*Above 12.5 MM (1/2 IN), if niobium or aluminum + niobium practice is used.	*Above 12.5 MM (1/2 IN), if niobium or aluminum + niobium practice is used.
TENSILE REQUIREMENTS Ultimate KG/MM^2 (KSI)	45 - 60 (64 - 85)	62 (88)	50 - 63 (71 - 90)
Yield (min.) KG/MM^2 (KSI)	32 (45.5)	34 (48)	36 (51)
Elongation (min.) % in $5.65 \sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22	22	21
CHARPY V-NOTCH IMPACT TEST Temperature °C	-20	-20	-20
Energy, KG-M (FT-LB)	3.16 (23) Longitudinal	3.47 (25) Longitudinal	3.47 (25) Longitudinal
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	125 - 170	177	140 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.38	1.38	1.38

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Norske Veritas HTS Gr. NVD27S	Norske Veritas HTS Gr. NVD32	Norske Veritas HTS Gr. NVD36
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Semi-killed or fully killed*	Fully killed	Fully killed
HEAT TREATMENT	Normd.above 25.5 MM(1 IN)**	Normd.above 19 MM(3/4 IN)*	Normd.above 19 MM(3/4 IN)*
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.70 min.	0.9 - 1.6	0.9 - 1.6
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon		0.10 - 0.50	0.10 - 0.50
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.10 max.	0.10 max.	0.10 max.
Aluminum	0.08 max.	0.08 max.	0.08 max.
Others	0.05 max. Nb	0.05 max. Nb	0.05 max. Nb
Notes:	*For 25.5 MM (1 IN) and above to be killed and fine grain treated. **Above 12.5 MM (1/2 IN), if niobium practice is used.	*Above 12.5 MM (1/2 IN), if niobium practice is used.	*Above 12.5 MM (1/2 IN), if niobium practice is used.
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	41 - 52 (58 - 74)	45 - 60 (64 - 85)	50 - 63 (71 - 90)
Yield (min.)KG/MM^2 (KSI)	27 (38.5)	32 (45.5)	36 (51)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22	22	21
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-20	-20	-20
Energy, KG-M (FT-LB)	2.75 (20) Longitudinal 2.0 (14) Transverse	3.16 (23) Longitudinal 2.24 (16) Transverse	3.47 (25) Longitudinal 2.45 (18) Transverse
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 147	125 - 170	140 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.38	1.38	1.38

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Norske Veritas HTS Gr. NVD40S	Bureau Veritas HTS Gr. DH32	Bureau Veritas HTS Gr. DH36
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society
DEOXIDATION	Fully killed	Killed, fine grain	Killed, fine grain
HEAT TREATMENT	Normalized	Normalized*	Normalized*
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.9 - 1.6	0.90 - 1.60	0.90 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.50	0.10 - 0.50	0.10 - 0.50
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.10 max.	0.10 max.	0.05 - 0.10
Aluminum	0.08 max.	0.015 - 0.06	0.015 - 0.06
Others	0.05 max. Nb	0.05 max. Nb	0.02 - 0.05 Nb
Notes:		*Not required, if properties can be met as specified.	*Not required, if properties can be met as specified.
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	54 - 66 (77 - 94)	45 - 60 (64 - 85)	50 - 63 (71 - 90)
Yield (min.) KG/MM^2 (KSI)	40 (57)	32 (45.5)	36 (51)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	20	20	20
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-20	-20	-20
Energy, KG-M (FT-LB)	4.0 (29) Longitudinal 2.65 (19) Transverse	3.16 (23) Longitudinal	3.5 (25) Longitudinal
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	153 - 190	125 - 170	140 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.38	1.38	1.18

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	NKK HTS Gr. KD32	NKK HTS Gr. KD36	German. Lloyd HTS Gr. D32
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace process, or other approved by the society	Open-hearth, basic-oxygen, electric-furnace process, or other approved by the society	Open-hearth, basic-oxygen, electric-furnace process, or other approved by the society
DEOXIDATION	Killed	Killed	Killed
HEAT TREATMENT	Normalized	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.90 - 1.60	0.90 - 1.60	0.90 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.50	0.10 - 0.50	0.10 - 0.50
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium		0.05 - 0.10	0.02 - 0.07
Aluminum	0.015 min.	0.015 min.	
Others		0.02 - 0.05 Nb	
Notes:			
TENSILE REQUIREMENTS Ultimate KG/MM² (KSI) Yield (min.)KG/MM² (KSI) Elongation (min.) % in 5.65 √A MM (IN) or as noted (A=area of spe.)	48 - 60 (68 - 85) 32 (45.5) 22	50 - 63 (71 - 90) 36 (51) 21	48 - 60 (68 - 85) 32 (45.5) 22
CHARPY V-NOTCH IMPACT TEST Temperature °C Energy, KG-M (FT-LB)	-20 3.2 (23) Longitudinal 2.3 (17) Transverse	-20 3.5 (25) Longitudinal 2.5 (18) Transverse	-20 3.2 (23) Longitudinal 2.2 (16) Transverse
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	135 - 170	140 - 181	135 - 170
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.38	1.38	1.38

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	German. Lloyd HTS GR. D36	ASTM-A537 Class 1	ASTM-A633 Gr. D
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Killed	Fine grain practice	Fine grain practice
HEAT TREATMENT	Normalized	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.24	0.20
Manganese	0.90 - 1.60	0.70 - 1.35	0.70 - 1.35
Phosphorus (max.)	0.04	0.035	0.04
Sulphur (max.)	0.04	0.040	0.05
Silicon	0.10 - 0.50	0.15 - 0.50	0.15 - 0.50
Chromium	0.20 max.	0.25 max.	0.25 max.
Nickel	0.40 max.	0.25 max.	0.25 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.05 - 0.10		
Aluminum	0.02 - 0.07		
Others	0.02 - 0.05 Nb		
Notes:			
TENSILE REQUIREMENTS			
Ultimate KG/MM² (KSI)	50 - 63 (71 - 90)	49 - 63 (70 - 90)	49 - 63 (70 - 90)
Yield (min.) KG/MM² (KSI)	36 (51)	35 (50)	35 (50)
Elongation (min.) % in 5.65 √A MM (IN) or as noted (A=area of spe.)	21	22 in 51 MM (2 IN)	23 in 51 MM (2 IN)
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-20	-60	-40
Energy, KG-M (FT-LB)	3.5 (25) Longitudinal 2.4 (17) Transverse	2.1 (15) Longitudinal	3.5 (25) Longitudinal 2.8 (20) Transverse
NDT TEMPERATURE °C		-51 to -18	-51 aver.
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	140 - 181	138 - 181	138 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.	Controlled welding process. Moderate preheat. Low-hydrogen practice. Normal forming & cutting practice.	Controlled welding process. Moderate preheat. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.38	1.38	1.38

TABLE - B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ASTM-A633 Gr. A & B	ABS HTS Gr. EH32	ABS HTS Gr. EH36
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Fine grain practice	Killed, fine grain practice	Killed, fine grain practice
HEAT TREATMENT	Normalized	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	1.00 - 1.35	0.90 - 1.50	0.90 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.05	0.04	0.04
Silicon	0.15 - 0.50	0.10 - 0.50	0.10 - 0.50
Chromium		0.25 max.	0.25 max.
Nickel		0.40 max.	0.40 max.
Molybdenum		0.08 max.	0.08 max.
Copper		0.35 max.	0.35 max.
Titanium			
Vanadium	0.10 max.*	0.10 max.	0.10 max.
Aluminum			
Others	0.05 max. Cb**	0.05 max. Cb	0.05 max. Cb
Notes:	*Gr. B only. **Gr. A only.		
TENSILE REQUIREMENTS Ultimate KG/MM^2 (KSI) Yield (min.)KG/MM^2 (KSI) Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	44 - 58 (63 - 83) 30 (43) 23 in 51 MM (2 IN)	48 - 60 (68 - 85) 32 (45.5) 19 in 200 MM (8 IN) or 22 in 50 MM (2 IN)	50 - 63 (71 - 90) 36 (51) 19 in 200 MM (8 IN) or 22 in 50 MM (2 IN)
CHARPY V-NOTCH IMPACT TEST Temperature °C Energy, KG-M (FT-LB)	-46 3.5 (25) Longitudinal 2.8 (20) Transverse	-40 3.5 (25) Longitudinal 2.4 (17) Transverse	-40 3.5 (25) Longitudinal 2.4 (17) Transverse
NDT TEMPERATURE °C	-57 aver.	-51 to -40	-51 to -40
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN		91 (658)	
ABRASION RESISTANCE AS BRINELL HARDNESS	121 - 165	135 - 170	140 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Preheat required, if ambient temp. below 16°C. Low-hydrogen practice. Normal forming & cutting practice	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.40	1.43	1.43

TABLE 8-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Lloyd's Register HTS Gr. EH27S	Lloyd's Register HTS Gr. EH32	Lloyd's Register HTS Gr. EH34S
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Silicon-killed only	Silicon-killed only	Silicon-killed only
HEAT TREATMENT	Normalized	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.70 - 1.60	0.90 - 1.60	0.90 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 min.	0.10 min.	0.10 min.
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.03 - 0.10	0.03 - 0.10	0.03 - 0.10
Aluminum	0.015 min.	0.015 min.	0.015 min.
Others	0.015 - 0.05 Nb	0.015 - 0.05 Nb	0.015 - 0.05
Notes:			
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	41 - 52 (58 - 74)	45 - 60 (64 - 85)	62 (88)
Yield (min.) KG/MM^2 (KSI)	27 (38.5)	32 (45.5)	34 (48)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22	22	22
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-40	-40	-40
Energy, KG-M (FT-LB)	2.75 (20) Longitudinal	3.16 (23) Longitudinal	3.47 (25) Longitudinal
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	110 - 147	125 - 170	177
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.43	1.43	1.43

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Lloyd's Register HTS Gr. EH36	Norske Veritas HTS Gr. NVE27S	Norske Veritas HTS Gr. NVE32
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Silicon-killed only	Fully killed	Fully killed
HEAT TREATMENT	Normalized	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.90 - 1.60	0.70 min.	0.9 - 1.6
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 min.	0.10 - 0.50	0.10 - 0.50
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.03 - 0.10	0.10 max.	0.10 max.
Aluminum	0.015 min.	0.08 max.	0.08 max.
Others	0.01 - 0.05 Nb	0.05 max. Nb	0.05 max. Nb
Notes:			
TENSILE REQUIREMENTS Ultimate KG/MM^2 (KSI) Yield (min.)KG/MM^2 (KSI) Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	 50 - 63 (71 - 90) 36 (51) 21	 41 - 54 (58 - 77) 27 (38.5) 22	 45 - 60 (64 - 85) 32 (45.5) 22
CHARPY V-NOTCH IMPACT TEST Temperature °C Energy, KG-M (FT-LB)	 -40 3.47 (25) Longitudinal	 -40 2.75 (20) Longitudinal 2.0 (14) Transverse	 -40 3.16 (23) Longitudinal 2.24 (16) Transverse
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	140 - 181	110 - 153	125 - 170
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.43	1.43	1.43

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Norske Veritas HTS Gr. NVE36	Norske Veritas HTS Gr. NVE40S	Bureau Veritas HTS Gr. EH32
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society
DEOXIDATION	Fully killed	Fully killed	Killed, fine grain
HEAT TREATMENT	Normalized	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.9 - 1.6	0.09 - 1.6	0.09 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.50	0.10 - 0.50	0.10 - 0.50
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.10 max.	0.10 max.	0.10 max.
Aluminum	0.08 max.	0.08 max.	0.015 - 0.06
Others	0.05 max. Nb	0.05 max. Nb	0.05 max. Nb
Notes:			
TENSILE REQUIREMENTS Ultimate KG/MM^2 (KSI) Yield (min.)KG/MM^2 (KSI) Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	50 - 63 (71 - 90) 36 (51) 21	54 - 66 (77 - 94) 40 (57) 20	45 - 60 (64 - 85) 32 (45.5) 20
CHARPY V-NOTCH IMPACT TEST Temperature °C Energy, KG-M (FT-LB)	-40 3.47 (25) Longitudinal 2.45 (18) Transverse	-40 4.0 (29) Longitudinal 2.65 (19) Transverse	-40 3.16 (23) Longitudinal
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	140 - 181	153 - 190	125 - 170
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.43	1.43	1.43

TABLE 8-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	Bureau Veritas HTS Gr. EH36	NKK HTS Gr. KE32	NKK HTS Gr. KE36
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society	Open-hearth, basic-oxygen, electric-furnace process, or other approved by the society	Open-hearth, basic-oxygen, electric-furnace process, or other approved by the society
DEOXIDATION	Killed, fine grain	Killed	Killed
HEAT TREATMENT	Normalized	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.18
Manganese	0.90 - 1.60	0.90 - 1.60	0.90 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.04
Silicon	0.10 - 0.50	0.10 - 0.50	0.10 - 0.50
Chromium	0.20 max.	0.20 max.	0.20 max.
Nickel	0.40 max.	0.40 max.	0.40 max.
Molybdenum	0.08 max.	0.08 max.	0.08 max.
Copper	0.35 max.	0.35 max.	0.35 max.
Titanium			
Vanadium	0.05 - 0.10		0.05 - 0.10
Aluminum-	0.015 - 0.06	0.015 min.	0.015 min.
Others	0.02 - 0.05 Nb		0.02 - 0.05 Nb
Notes:			
TENSILE REQUIREMENTS			
Ultimate KG/MM² (KSI)	50 - 63 (71 - 90)	48 - 60 (68 - 85)	50 - 63 (71 - 90)
Yield (min.)KG/MM² (KSI)	36 (51)	32 (45.5)	36 (51)
Elongation (min.) % in 5.65 √A MM (IN) or as noted (A=area of spe.)	20	22	21
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-40	-40	-40
Energy, KG-M (FT-LB)	3.5 (25) Longitudinal	3.2 (23) Longitudinal 2.3 (17) Transverse	3.5 (25) Longitudinal 2.5 (18) Transverse
NDT TEMPERATURE °C			
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	140 - 181	135 - 170	140 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.43	1.43	1.43

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	German. Lloyd HTS Gr. E32	German. Lloyd HTS Gr. E36	ASTM-A633 Gr. C
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society	Open-hearth, basic-oxygen, electric-furnace, or any equivalent approved by the society	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Killed	Killed	Fine grain practice
HEAT TREATMENT	Normalized	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.18	0.18	0.20
Manganese	0.90 - 1.60	0.90 - 1.60	1.15 - 1.50
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.04	0.04	0.05
Silicon	0.10 - 0.50	0.10 - 0.50	0.15 - 0.50
Chromium	0.20 max.	0.20 max.	
Nickel	0.40 max.	0.40 max.	
Molybdenum	0.08 max.	0.08 max.	
Copper	0.35 max.	0.35 max.	
Titanium			
Vanadium			
Aluminum	0.02 - 0.07	0.05 - 0.10	
Others		0.02 - 0.07	0.01 - 0.05 Cb
		0.02 - 0.05 Nb	
Notes:			
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	48 - 60 (68 - 85)	50 - 63 (71 - 90)	49 - 63 (70 - 90)
Yield (min.)KG/MM^2 (KSI)	32 (45.5)	36 (51)	35 (50)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22	21	23 in 51 MM (2 IN)
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-40	-40	-46
Energy, KG-M (FT-LB)	3.2 (23) Longitudinal 2.4 (17) Transverse	3.5 (25) Longitudinal 2.2 (16) Transverse	3.5 (25) Longitudinal 2.8 (20) Transverse
NDT TEMPERATURE °C			-57 aver.
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	135 - 170	140 - 181	137 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming and cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.43	1.43	1.43

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ASTM-A678 Gr. A	ABS Low - Temp. Gr. V-039	ABS Low - Temp. Gr. V-051
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Fine grain practice	Fine grain practice	Fine grain practice
HEAT TREATMENT	Quenched & tempered	Normalized	Normalized
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.16	0.20	0.16
Manganese	0.90 - 1.50	0.90 - 1.35	1.15 - 1.50
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.05	0.04	0.04
Silicon	0.15 - 0.50	0.10 - 0.35	0.10 - 0.35
Chromium		0.25 max.	0.25 max.
Nickel		0.80 max.	0.80 max.
Molybdenum		0.08 max.	0.08 max.
Copper	0.20 - 0.35*	0.35 max.	0.35 max.
Titanium			
Vanadium		0.10 max.	0.10 max.
Aluminum		0.065 max.	0.065 max.
Others		0.05 max. Cb	0.05 max. Cb
Notes:	*When specified		
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	49 - 63 (70 - 90)	41 - 63 (58 - 90)	41 - 63 (58 - 90)
Yield (min.)KG/MM^2 (KSI)	35 (50)	25 (36)	25 (36)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22 in 51 MM (2 IN)	22	22
CHARPY V-NOTCH IMPACT TEST	Purchaser specs.		
Temperature °C	-73	-39	-51
Energy, KG-M (FT-LB)	2.8 (20) Longitudinal 2.0 (14) Transverse	3.5 (25) Longitudinal 2.3 (17) Transverse	3.5 (25) Longitudinal 2.3 (17) Transverse
NDT TEMPERATURE °C	-62 aver.	-57 aver.	-57 aver.
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	138 - 181	110 - 181	110 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Controlled welding process. Moderate preheat. Low-hydrogen practice. Normal forming & cutting practice.	Preheat required, if ambient temp. below 0°C Low-hydrogen practice. Selected electrodes. Normal forming & cutting practice	Preheat required, if ambient temp. below 0°C Low-hydrogen practice. Selected electrodes. Normal forming & cutting practice
RELATIVE COST FACTOR (Based on ABS Grade A)	1.46	1.46	1.46

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ASTM-A678 Gr. B	ASTM-A633 Gr. E	ASTM-A678 Gr. C
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Fine grain practice	Fine grain practice	Fine grain practice
HEAT TREATMENT	Quenched & tempered	Normalized*	Quenched & tempered
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.20	0.22	0.22
Manganese	0.70 - 1.35	1.15 - 1.50	1.00 - 1.60
Phosphorus (max.)	0.04	0.04	0.04
Sulphur (max.)	0.05	0.05	0.05
Silicon	0.15 - 0.50	0.15 - 0.50	0.20 - 0.50
Chromium	0.25 max.		0.25 max.
Nickel	0.25 max.		0.25 max.
Molybdenum	0.08 max.		0.08 max.
Copper	0.20 - 0.35*		0.20 - 0.35*
Titanium			
Vanadium		0.04 - 0.11	
Aluminum			
Others		0.01 - 0.03 Nitrogen	
Notes:	*When specified	*Double normalized above 76 MM (3 IN).	*When specified
TENSILE REQUIREMENTS			For 38 MM (1.5 IN) incl.
Ultimate KG/MM² (KSI)	56 - 70 (80 - 100)	56 - 70 (80 - 100)	63 - 77 (90 - 110)
Yield (min.) KG/MM² (KSI)	42 (60)	42 (60)	49 (70)
Elongation (min.) % in 5.65 √A MM (IN) or as noted (A=area of spe.)	22 in 51 MM (2 IN)	23 in 51 MM (2 IN)	19 in 51 MM (2 IN)
CHARPY V-NOTCH IMPACT TEST	Purchaser specs.		Purchaser Specs.
Temperature °C	-73	-40	-73
Energy, KG-M (FT-LB)	2.0 (14) Longitudinal 1.4 (10) Transverse	3.5 (25) Longitudinal 2.8 (20) Transverse	2.8 (20) Longitudinal 2.0 (14) Transverse
NDT TEMPERATURE °C	-57 aver.	-46 aver.	-73 to -68
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN			
ABRASION RESISTANCE AS BRINELL HARDNESS	159 - 202	159 - 202	181 - 221
REQUIRED WELDING AND FABRICATION TECHNIQUES	Controlled welding process. Moderate preheat. Low-hydrogen practice. Normal forming & cutting practice.	Controlled welding process. Moderate preheat. Low-hydrogen practice. Normal forming and cutting practice.	Controlled welding process with preheating. Low-hydrogen practice. Selected electrodes. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.48	1.49	1.50

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ASTM-A537 Class 2	ASTM-A737 Gr. B	CG-A537 Gr. M
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Fine grain practice	Killed, fine grain practice	
HEAT TREATMENT	Quenched & tempered	Normalized	Quenched & tempered
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.24	0.22	0.16
Manganese	0.70 - 1.35	1.10 - 1.55	0.90 - 1.50
Phosphorus (max.)	0.035	0.035	0.035
Sulphur (max.)	0.040	0.035	0.040
Silicon	0.15 - 0.50	0.10 - 0.55	0.15 - 0.35
Chromium	0.25 max.		0.25 max.
Nickel	0.25 max.		0.25 max.
Molybdenum	0.08 max.		0.08 max.
Copper	0.35 max.		0.35 max.
Titanium			
Vanadium			
Aluminum			
Others		0.05 max. Cb	
Notes:			
TENSILE REQUIREMENTS			
Ultimate KG/MM^2 (KSI)	56 - 70 (80 - 100)	49 - 63 (70 - 90)	49 - 63 (70 - 90)
Yield (min.)KG/MM^2 (KSI)	42 (60)	35 (50)	35 (50)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	22 in 51 MM (2 IN)	23 in 51 MM (2 IN)	22 in 51 MM (2 IN)
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-60	-46	-51
Energy, KG-M (FT-LB)	2.1 (15) Longitudinal	3.5 (25) Longitudinal 2.8 (20) Transverse	2.8 (20) Transverse
NDT TEMPERATURE °C	-62 to -51		-62 aver.
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN	76 (550)		
ABRASION RESISTANCE AS BRINELL HARDNESS	159 - 202	137 - 181	138 - 181
REQUIRED WELDING AND FABRICATION TECHNIQUES	Controlled welding process. Moderate preheat. Low-hydrogen practice. Normal forming & cutting practice.	Moderate preheat for welding. Low-hydrogen practice. Normal forming & cutting practice.	Controlled welding process. Moderate preheat. Low-hydrogen practice. Normal forming & cutting practice.
RELATIVE COST FACTOR (Based on ABS Grade A)	1.51	1.51	1.52

TABLE B-3.3 (Continued)

PROPERTIES OF STEELS USED FOR ICE-STRENGTHENED SHIPS

STEEL TYPE & GRADE	ASTM-A710 Gr. A Class 3	HY-80 MIL-S-16216H	HY-100 MIL-S-16216H
PROCESS OF MANUFACTURE	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process	Open-hearth, basic-oxygen, or electric-furnace process
DEOXIDATION	Killed, fine grain practice		
HEAT TREATMENT	Quenched & tempered	Quenched & tempered	Quenched & tempered
CHEMICAL COMPOSITION (Ladle Analysis - %)			
Carbon (max.)	0.07	0.18	0.20
Manganese	0.40 - 0.70	0.10 - 0.40	0.10 - 0.40
Phosphorus (max.)	0.025	0.025	0.025
Sulphur (max.)	0.025	0.025	0.025
Silicon	0.40 max.	0.15 - 0.35	0.15 - 0.35
Chromium	0.60 - 0.90	1.00 - 1.80	1.00 - 1.80
Nickel	0.70 - 1.00	2.00 - 3.25	2.25 - 3.50
Molybdenum	0.15 - 0.25	0.20 - 0.60	0.20 - 0.60
Copper	1.00 - 1.30	0.25 max.	0.25 max.
Titanium		0.02 max.	0.02 max.
Vanadium		0.03 max.	0.03 max.
Aluminum			
Others	0.02 min. Cb		
Notes:			
TENSILE REQUIREMENTS	For 25.4 MM (1 IN) incl.		
Ultimate KG/MM^2 (KSI)	60 (85)	70 (100) min.	81 (115) min.
Yield (min.) KG/MM^2 (KSI)	53 (75)	56 (80)	70 (100)
Elongation (min.) % in 5.65 $\sqrt{A}$ MM (IN) or as noted (A=area of spe.)	20 51 MM (2 IN)	20 in 51 MM (2 IN)	18 in 51 MM (2 IN)
CHARPY V-NOTCH IMPACT TEST			
Temperature °C	-62	-84	-84
Energy, KG-M (FT-LB)	6.9 (50) Longitudinal 4.8 (35) Transverse	6.9 (50)	6.9 (50)
NDT TEMPERATURE °C	-73 aver.	-107 aver.	
DYNAMIC TEAR ENERGY IN KG-M (FT-LB) AT 24°C FOR 16 MM (5/8 IN) THICK SPECIMEN	140 (1012)		
ABRASION RESISTANCE AS BRINELL HARDNESS	170	201	233
REQUIRED WELDING AND FABRICATION TECHNIQUES	Little or no preheat requirements for welding. Special electrodes. Plates can be fabricated in the as-rolled condition.	Careful control of welding process. Costly electrodes. Additional forming power. Plate temp. for flame cutting not below 10°C.	Careful control of welding process. Costly electrodes. Additional forming power. Plate temp. for flame cutting not below 10°C.
RELATIVE COST FACTOR (Based on ABS Grade A)	2.51	3.11	3.23

APPENDIX B-4

TABULAR WEIGHT AND COST DATA

TABLE B-4.1
TYPICAL MIDBODY PANEL WEIGHTS & COSTS - POLAR STAR (Panel Height = 8.5 ft)

CLASS	STIFF. SPCG.	PLTG. THCK.	STIFF. S.M.	STIFFENER SIZE	% CHG. WGT.	% CHG. COST
ABS ✠A1, C; Lloyds 3; DNV ICE C; BV III; USSR A3,A4; PRC BIII	26	0.40	6	5" x 3-1/2" x 1/4" L	00	00
USSR A2; PRC BII; BV II	26	0.45	6	5" x 3-1/2" x 1/4" L	10.4	10.4
ABS IC	26	0.50	6	5" x 3-1/2" x 1/4" L	20.9	20.9
ABS B; Lloyds 2	26	0.55	6	5" x 3-1/2" x 1/4" L	31.3	31.3
ABS IB; NKK B,C	26	0.70	6	5" x 3-1/2" x 1/4" L	62.6	62.6
ASPPR 1; ABS IA	26	0.75	22	8" x 4" x 1/2" L	102.7	102.7
ABS IAA	26	1.00	22	8" x 4" x 1/2" L	136.9	136.9
ASPPR 2	26	1.55	87	13-3/4" x 8" x 48# I-T	301.3	301.3
ASPPR 4	26	2.00	145	16-3/8" x 10-1/4" x 67# I-T	423.1	423.1
ASPPR 7	26	2.25	186	21-1/4" x 8-1/4" x 73# I-T	496.9	496.9
ASPPR 10	26	2.35	208	21-3/8" x 8-3/8" x 83# I-T	533.9	533.9
ASPPR 1	16	0.60	15	7" x 4" x 3/8" L	77.1	77.9
NKK A	16	0.80	15	7" x 4" x 3/8" L	118.8	120.0
ASPPR 2; NKK AA	16	0.90	30	8" x 6" x 1/2" L	175.8	177.6
DNV Icebreaker	16	1.10	30	9" x 4" x 1/2" L	211.0	213.1
DNV Arctic Icebreaker	16	1.45	30	9" x 4" x 1/2" L	284.0	286.8
ASPPR 2	16	0.95	54	12-1/2" x 6-1/2" x 35# I-T	190.0	191.9
ASPPR 4	16	1.25	90	13-7/8" x 8" x 53# I-T	300.5	303.5
ASPPR 7	16	1.40	116	14" x 10" x 68# I-T	365.6	369.3
ASPPR 10	16	1.45	129	18-1/4" x 7-1/2" x 60# I-T	370.3	374.0
ABS A; Lloyds 1; USSR A1; BV I; PRC BI	13	0.50	6	4" x 3-1/2" x 3/8" L	47.2	48.1
Lloyds 1*; PRC BI*	13	0.55	6	5" x 3-1/2" x 1/4" L	47.6	48.6
BV I-Super	13	1.25	6	5" x 3" x 1/4" L	192.0	195.8
USSR YA	13	0.55	10	6" x 4" x 5/16" L	63.4	64.7

TABLE B-4.2
TYPICAL MIDBODY PANEL WEIGHTS & COSTS - MV ARCTIC (Panel Height = 27 ft)

CLASS	STIFF. SPCG.	PLTG. THCK.	STIFF. S.M.	STIFFENER SIZE	% CHG. WGT.	% CHG. COST
ABS ✠A1, C, IC; Lloyds 2, 3; DNV ICE C; BV III; USSR A3, A4; NKK C; PRC BIII	33	0.67	117	18-1/8" x 7-1/2" x 55# I-T	00	00
BV II; USSR A2; PRC BII	33	0.75	117	18-1/8" x 7-1/2" x 55# I-T	7.8	7.8
ABS B, IB; NKK B	33	0.90	117	18-1/8" x 7-1/2" x 55# I-T	22.3	22.3
ASPPR 1	33	1.00	117	18-1/8" x 7-1/2" x 55# I-T	32.1	32.1
ABS IA	33	1.05	117	18-1/8" x 7-1/2" x 55# I-T	36.9	36.9
ABS IAA	33	1.15	122	18-1/8" x 7-1/2" x 55# I-T	46.6	46.6
ASPPR 2	33	1.60	260	24-1/4" x 9-1/8" x 94# I-T	115.8	115.8
ASPPR 4	33	2.25	530	33-1/4" x 11-1/2" x 141# I-T	211.0	211.0
ASPPR 7	33	2.70	750	36-3/8" x 12-1/8" x 182# I-T	282.3	282.3
ASPPR 10	33	3.00	950	35-7/8" x 16-1/2" x 230# I-T	334.6	334.6
DNV Icebreaker	20	0.70	1161	T-52" x 1" Web, 11-1/2" x 1-1/4" Flg.	290.6	299.4
DNV Arctic Icebreaker	20	1.00	1451	T-52" x 1" Web, 11-1/2" x 1-3/4" Flg.	347.7	358.2
ASPPR 1	17	0.50	50	12" x 9" x 15.3# Flg. Plt.	- 7.2	- 5.3
USSR A2	17	0.85	80	13-5/8" x 8" x 43# I-T	38.1	38.9
NKK A	17	0.95	90	16-1/4" x 7-1/8" x 50# I-T	48.4	49.4
Lloyds 1	17	0.67	117	15" x 8" x 30.6# Flg. Plt.	60.5	61.7
Lloyds 1*	17	0.75	117	15" x 8" x 30.6# Flg. Plt.	68.3	69.7
PRC BI; BV I	17	0.80	117	18-1/4" x 7-1/2" x 60# I-T	51.3	52.3
ABS A; USSR YA; PRC BI*	17	0.85	117	18-1/4" x 7-1/2" x 60# I-T	56.2	57.3
BV I-Super	17	1.20	117	18-1/8" x 7-1/2" x 55# I-T	84.3	86.0
ASPPR 2	17	0.80	130	18" x 8" x 25.5# Flg. Plt.	68.4	69.8
NKK AA	17	1.05	130	24" x 6" x 17.85# Flg. Plt.	76.1	77.6
ASPPR 4	17	1.15	266	T-15" x 1" Web, 8" x 2" Flg.	189.0	196.6
ASPPR 7	17	1.35	376	T-20" x 1" Web, 8" x 2" Flg.	237.0	246.6
ASPPR 10	17	1.50	476	T-22" x 1" Web, 8" x 2-1/4"	274.5	285.6

TABLE B-4.3
TYPICAL MIDBODY PANEL WEIGHTS & COSTS - ARCTIC TANKER (Panel Height = 7.5 ft)

CLASS	STIFF. SPCG.	PLTG. THCK.	STIFF. S.M.	STIFFENER SIZE	% CHG. WGT.	% CHG. COST
ABS +A1, B, C, 1B, 1C; Lloyds 2, 3; DNV ICE C; BV II, III; USSR A2, A3, A4; NKK C; PRC BIII	40	1.05	38	10-1/2" x 5-3/4" x 30# I-T	00	00
NKK B	40	1.10	38	10-1/2" x 5-3/4" x 30# I-T	4.2	4.2
PRC BII	40	1.15	38	10-1/2" x 5-3/4" x 30# I-T	8.3	8.3
ABS 1A; ASPPR 1	40	1.20	38	10-1/2" x 5-3/4" x 30# I-T	12.5	12.5
ABS 1AA	40	1.35	38	10-1/2" x 5-3/4" x 30# I-T	25.0	25.0
ASPPR 2	40	2.35	106	18" x 6" x 20.4# Flg. Plt.	119.9	119.9
ASPPR 4	40	3.05	175	21" x 8-1/4" x 62# I-T	181.9	181.9
ASPPR 7	40	3.45	226	23-7/8" x 9" x 76# I-T	221.7	221.7
ASPPR 10	40	3.65	252	24-1/8" x 9" x 84# I-T	246.2	246.2
DNV Icebreaker	28	2.55	61	12" x 8" x 40# I-T	135.5	136.9
DNV Arctic Icebreaker	28	3.60	77	15" x 3-3/8" x 40# C-L	228.7	231.0
ASPPR 1	20	1.05	13	8" x 4" x 13" I-T	- 0.7	1.3
ABS A; Lloyds 1; BV I	20	1.05	38	12-1/4" x 6-1/2" x 26# I-T	11.2	11.4
Lloyds 1*; BV 1-Super; PRC BI, BI*	20	1.25	38	12-1/4" x 6-1/2" x 26# I-T	27.9	28.5
USSR A1	20	1.35	38	12-1/4" x 6-1/2" x 26# I-T	36.2	36.9
ASPPR 2	20	1.20	53	9-1/8" x 7-1/2" x 30# T	36.5	37.2
NKK A	20	1.20	66	14-1/8" x 6-3/4" x 38# I-T	32.9	33.6
ASPPR 4	20	1.50	88	12" x 9" x 38# T	71.3	72.7
NKK AA; USSR YA	20	1.30	99	18" x 6" x 20.4# Flg. Plt.	57.0	58.1
ASPPR 7	20	1.70	113	16-3/8" x 7-1/8" x 57# I-T	92.2	94.0
ASPPR 10	20	1.80	127	21" x 6" x 20.4# Flg. Plt.	104.8	106.9

APPENDIX C

REVIEW OF METHODS FOR DAMAGE ANALYSIS

1. INTRODUCTION

The objective of this part of the study is to identify and review currently available methods for analyzing ship damage; that is to determine the external ice loads which caused the hull failure. A complete identification of such loads acting normal to the shell plating requires knowledge of:

- the area of action
- the pressure distribution within this area.

These variables can be used to calculate the average pressure distribution and the total load.

There is no method, within the state-of-the-art, which can be used to determine the ice pressure distribution. Therefore, it is common to assume a uniform pressure within the contact area. Nonetheless, the influence of pressure distribution is thought to have significant effects on the unevenness of load distribution on the hull structure. The assumption of uniform pressure on a small plate panel is, on the other hand, quite acceptable.

In most damage incidents, if not all of them, an analyst is bound to make some assumptions as to how the damage occurred. Although simple damage analysis techniques do not require elaborate data and it is often sufficient to have the structural detail, knowledge of the damage circumstances is essential to the understanding of such occurrences. For instance, in order to justify the damage location, one should know the operating draft and trim of the ship, ice thickness, type of ice, and possible physical description.

The review of damage analysis methods is divided into two sections: the first is concerned with simple techniques which attempt to predict the uniform failure pressures without regard to how it occurred, while the second section is devoted to proposing a more detailed approach to study ice damage.

2. SIMPLE METHODS

The simplest approach considers the failure of basic components of the hull under uniform pressure. For instance, consider a long plate panel supported along its four sides by frames and stringers and subjected to uniform lateral pressure. The maximum pressure required to cause one of the following conditions can be estimated:

- reach the elastic limit,
- cause one plastic hinge at the center,
- cause two plastic hinges at the supports,
- cause three plastic hinges, one at the center and two at the supports,
- cause plate rupture due to membrane tension, etc.

Therefore, the criterion of failure is important to define and various methods will now be reviewed.

2.1 Elastic Method

Considering the standard plate panel fixed at all edges and subjected to uniform pressure over the entire plate, the maximum pressure for the stress at the center of the support, not to exceed the elasticity limit, is given in any standard elasticity handbook, e.g. [E-27], as follows:

$$p = \frac{1}{\beta}\,\sigma_y \cdot \left(\frac{t}{s}\right)^2$$

where σ_y = the yield strength of the material (2400 kp/cm^2 for structural steel $\simeq$ 35000 psi)

t = the plate thickness

s = the spacing between long edges or frames

β = is a coefficient = 0.5 for an aspect ratio > 2

Therefore,

$$p = 2\,\sigma_y \left(\frac{t}{s}\right)^2 \qquad \text{(C.1)}$$

2.2 Elastic - Perfectly Plastic

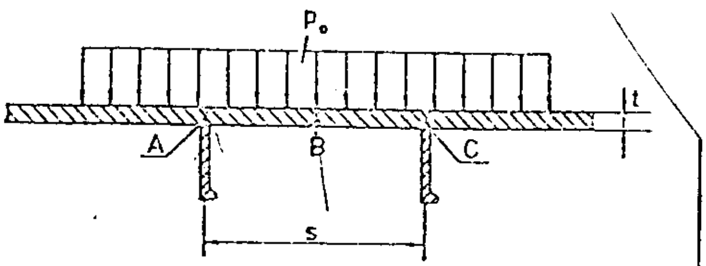
The simplest method for damage analysis is the so-called plastic method proposed by Johansson in 1967 [E-13]. The method is based on the premise that a permanent set does not occur until three plastic hinges develop; one at each support and one at the center of the plate as shown in Figure D.1a. The minimum uniformly distributed pressure, p, required to satisfy this condition, is given by:

$$p = 4\,\sigma_y \frac{t^2}{s^2} \cdot \frac{1}{f_d} \qquad \text{(C.2)}$$

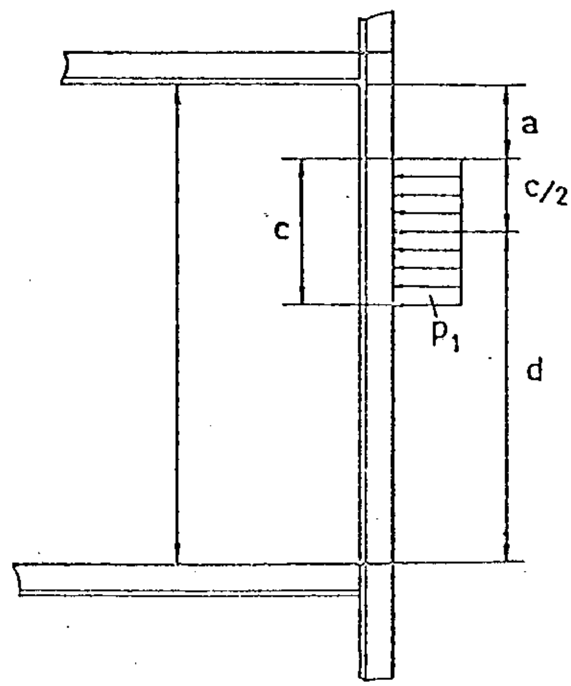
FIGURE D.1

PLASTICITY METHOD FOR DAMAGE ANALYSIS

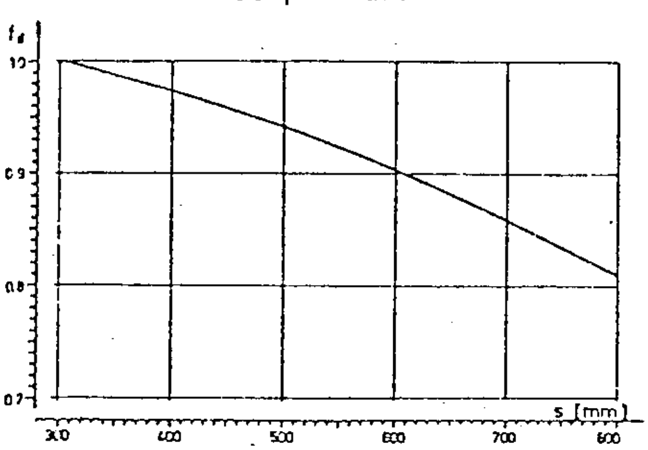
(a) Definition of Plate Calculations



(c) Definitions of Frame Calculations



(b) The Coefficient f_d gives the reduction in the plating stress, because of the distributing effect due to the limited vertical extension of the ice-pressure



where p = the maximum pressure the plating can carry without onset of plastic deformation, kp/cm^2

σ_y = the yield strength of the plate material, kp/cm^2 ($\approx$2400 kp/cm for mild steel)

t = the plate thickness, mm

s = the frame spacing, mm

f_d = a correction factor which accounts for frame spacing and is given in Figure C.1(b).

The maximum pressure the frames can accommodate without plastic hinge formation, p_1, is expressed by:

$$p_1 = \frac{2000\ \sigma_y\ W_p\ \ell}{c.s.d.\ (a + c.d/2\ell)} \qquad \text{(C.3)}$$

where W_p = the plastic section modulus, cm^3 (which includes plate portion)

ℓ = the span of the frame, m

c = the width of ice pressure, usually taken as maximum ice thickness, mm

a & d are illustrated in Figure C.1(c)

For $d = \ell/2$, the frame stresses will be maximum and the pressure reduces to:

$$p_1 = \frac{16000\ \sigma_y \cdot W_p}{c.s\ (2\ell - c)} \qquad \text{(C.4)}$$

Johansson used this method to determine the maximum pressure which would have caused hull damage for 200 ship damage cases. The damage pressure estimated by this method is based on an assumed standard contact area extending over at least two frame spacings and the full depth of ice assumed to be 800 mm.

The major criticism for this method is the fact that it does not take into account in-plane tension or membrane effects of the plate.

2.3 Plastic Method with Membrane Effect

This method was proposed by Clarkson [E-6] in 1956. It is applicable to plate design and retains the influence of geometry changes and thus, takes into account membrane forces and their effect on increasing the load carrying capacity. Assuming uniformity, the pressure corresponding to one plastic hinge is given by:

$$p = 4.56\ [\sigma_y^{4/3}/E^{1/3}] \cdot (\frac{t}{s})^{4/3} \qquad \text{(C.5)}$$

where E = the elastic modulus of the hull plate material and other variables are previously defined.

Archtarides [E-1] used the data reported by Johansson [E-13] to calculate (t/s) and, then, used equation (C.5) to estimate ice pressures and propose different design curves.

In fact, a direct comparison between equations (C.5) and (C.2) is not possible because each one is based on different failure criterion. For the pressure to cause three plastic hinges with consideration of membrane effect, equation (C.5) should be corrected by approximately a factor of 2 to read:

$$p = 9.12\ [\sigma_y^{4/3}/E^{1/3}] \cdot (\frac{t}{s})^{4/3} \qquad \text{(C.6)a}$$

Rearranging (.6)a obtain:

$$p = \left\{4\ \sigma_y\ (\frac{t}{s})^2\right\} \cdot \left\{2.28 \sqrt[3]{(\frac{\sigma_y}{E}) \cdot (\frac{s}{t})^2}\right\} \qquad \text{(C.6)b}$$

Comparing (C.6) with (C.2) for structural steel and $S/t \simeq 10$ it appears that consideration of membrane effects increases the pressure load capacity by approximately 11-12%. This ratio would increase for high strength steels as well as higher spacing to thickness ratios. It is equally true that for thick steel with closely spaced framing, the membrane effects will be negligible.

2.4 Empirical Pressure Distribution Method

This method is based on empirical grounds proposed by Kheysin [B-18]. He suggests that due to the flexibility of the shell, ice pressure will be distributed as illustrated in Figure C.2. The maximum load on transverse frames is:

$$P = q_o \cdot a \qquad \text{(C.7)}$$

where $q_o = \sigma_c \cdot h/2$; σ_c = ice crushing strength

h = thickness

$a = 3.3 \sqrt[3]{\frac{E_s}{E_i} \cdot \frac{I_s}{\ell}}$; E_s = elasticity of the hull steel

E_i = elasticity of ice

I_s = section moment of inertia of the stringer

ℓ = spacing between bulkheads

This method can be used to assess the pressure distribution that caused damage if used in conjunction with a plastic failure criterion such as Johansson's. We should write:

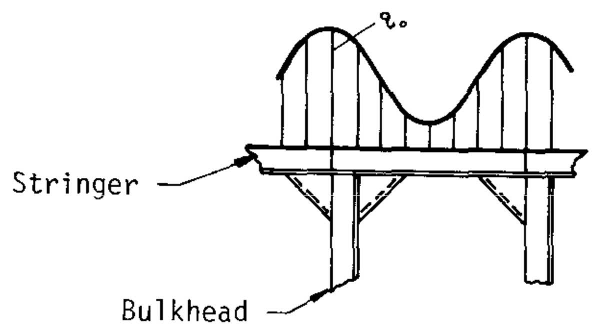
$$P = p_1 \cdot h \cdot S \qquad \text{(C.8)}$$

where p_1 can be obtained from equation (C.4). By working back a, obtain q_o and estimate σ_c under actual conditions of interaction. However, it should be noted that the method pertains to bulkheads and stringers in the middle body of a ship, and it is not clear to us how this method can be applied to analysis of main frames with

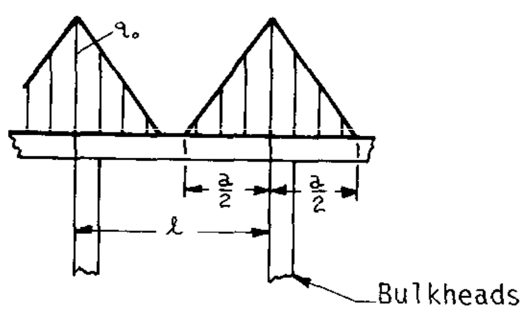
FIGURE C.2

ICE PRESSURES ON THE HULL

(a) Actual Pressure Distribution



(b) Idealized Distribution



proper account of pressure distribution effects. One possible way is to set limits on the value of a in equation (C.7).

2.5 Plastic Energy Method

Plastic analysis procedure was developed by McDermott, et al [E 24] for the analysis of tanker collision. Although the procedure, which is based on model tests and inspection of collision damage, was never extended to ice damage, it is potentially useful in this regard. The approach is based on the calculation of plastic energy components up to the incidence of hull rupture. This primarily involves three phenomena producing plastic deformation: longitudinal plastic bending of the stiffened hull plating, plastic membrane tension in the stiffened hull plating, and yield or buckling of the web frames (and/or swash bulkheads). Figure C.3 shows the possible sequences of these three phenomena for a single hull ship while Figure C.4 is concerned with a double hull ship. The authors suggested that most of the energy absorbed in collision (67 to 90%) is due to membrane tension in the stiffened hull. Therefore, damage is expected to initiate where less energy is required, e.g. bend and buckle stiffeners. The latter would enhance plate deformation through a loss of support and ultimately lead to shell failure. This scenario can be supported by the nature of damage due to ice observed on the MV ARCTIC.

Unfortunately, the formulas provided by McDermott,et al are only applicable to concentrated line load (due to ship incursion into another) and it is not suitable for any damage analysis due to ice. Attempts to test his method in case of ice damage proved it to produce unrealistic estimates of ice pressures and tremendous loads which can only exist in ship collision situations.

Nonetheless, his approach is one step ahead as he incorporates the effects of in-plane membrane effects. This leads to a higher hull loading capacity and within the context of damage analysis should produce higher ice pressure estimates.

Further development of plastic damage analysis procedures along these lines is highly recommended.

2.6 Case Study

The foregoing discussion is limited to one approach to the problem which uses *the reverse* of design criteria. It is capable only of suggesting what uniform pressure applied in a prescribed fashion on the hull plating would have caused structural failure. However, it remains the simplest and it can lead to some explanation of failure incidents.

To illustrate this, let us examine the damage inflicted by ice on the MV ARCTIC and attempt to predict ice pressures in accordance with the methods described in this section.

The damage is described by Laskey [G-11] and reproduced in the sketch shown in Figure C.5. The following details may be used:

t = 1.063"

S = 12.0" (for intermediate frames)

W_p = 94.7 in^3

FIGURE C.3

FLOW DIAGRAM FOR SIDE-COLLISION PLASTIC-ENERGY ANALYSIS OF SINGLE-HULL SHIP

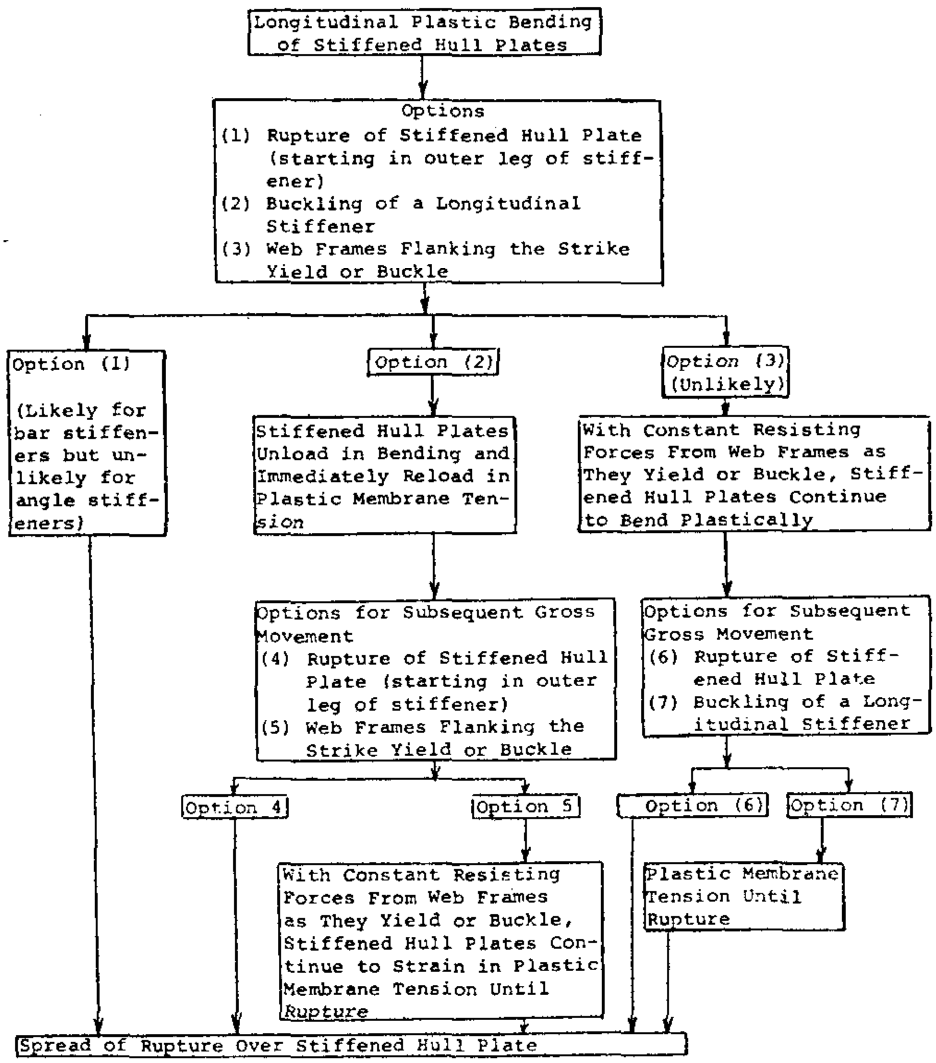


FIGURE C.4

FLOW DIAGRAM FOR SIDE-COLLISION PLASTIC-ENERGY ANALYSIS OF A DOUBLE-HULL SHIP

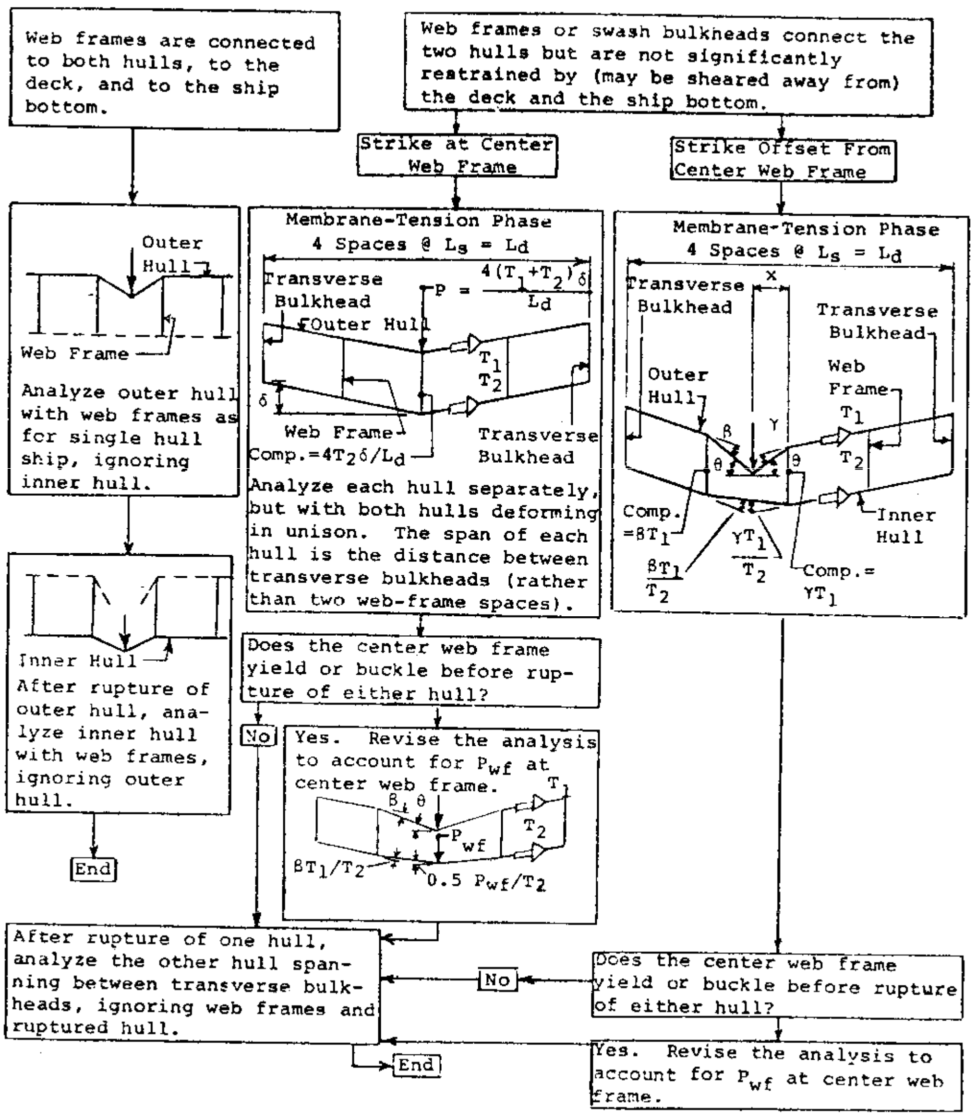
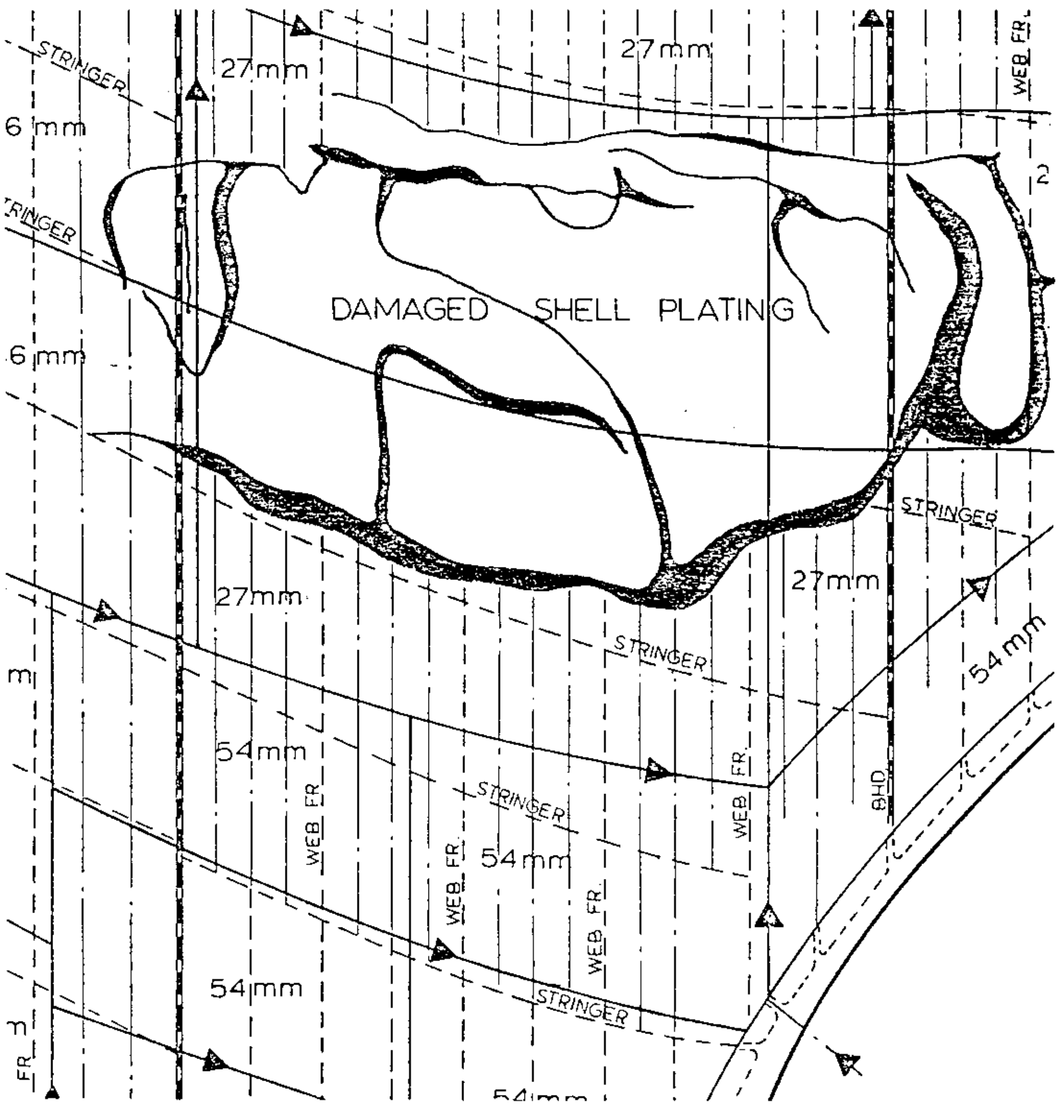


FIGURE C.5

SKETCH OF DAMAGE TO THE BOW OF MV ARCTIC



$\ell = 48''$

$\sigma_y \simeq 35{,}000$ psi

$f_d = 1$

$h \simeq 40''$

Obtain from equation (C.1)	elastic method	$p =$ 549 psi (3.79 MPa)
(C.2)	Johansson's (plate)	1099 psi (7.75 MPa)
(C.4)	Johansson's (frames)	2019 psi (13.9 MPa)
(C.5)	Clarkson's method [21% higher than Eq.(C.2)	1327 psi (9.15 MPa)

Therefore, the ice pressure which can cause failure to the plates is 1327 psi according to Clarkson while that required to cause frame damage, is 2019 psi. These figures are well in excess of the maximum rule design pressure of 600 psi set by ASPPR for Arctic Class 2 ships. While ice pressures of the order of 600 psi would not cause any structural damage or permanent deformation, it is obvious that the ship was subjected to an overload.

These results, obtained in comparison with the most conservative and most comprehensive design rules, i.e. the Canadian ASPPR, raise some questions relating to the adequacy of design pressures. However, it is essential to complete the entire scenario which gave rise to such high pressure. It may, indeed, have been a collision case with a fairly low probability of occurrence.

This leads us to the brief introduction of an alternative approach which is more detailed and it takes into consideration the scenario and circumstances of damage incident.

3. ALTERNATIVE APPROACH

This approach consists of several steps:

(1) Identify possible scenarios of interaction between ship and ice feature as well as data on ice type, strength, size, shape, etc.

(2) Run a computer simulation of the interaction scenario with proper input data and variations of angle of impact, most probable speeds at the time of impact, possible strengths of the ice, etc. The simulation should produce an estimate of the ice impact load as well as the average ice pressure on the hull. To the best of our knowledge there is one commercially available program at ARCTEC CANADA Limited; another version has been developed by Melville Shipping Ltd. of Montreal for internal use. The most useful data which can be obtained from this program are:

- the total impact load
- the average ice pressure
- the extent of contact of ice, i.e. shape and size of the area of contact
- where this area is located on the hull.

Several runs may be required to adjust the contact area with the damage location. The availability of more definitive data on the damage circumstances would help in providing a more realistic estimate of the load, pressure, and area of ice contact. It should be noted that the order of magnitude of ice crushing strength should be equivalent to estimates of ice pressure obtained by simple methods. For further information on such simulation methods, reference may be made to papers by Major, et al [B-26] and Noble, et al [B-36].

(3) Compare extent of ice load with the hull structural details and determine boundaries of a segment of the structure to be modeled. These boundaries should preferably be most rigid, e.g. bulkheads and floors. Establish necessary boundary conditions.

(4) Prepare a finite element model of the structure (3D model is preferred but a 2D model with lumped stiffeners may be accepted). A simplified ship structure segment as modeled by the finite element method is shown in Figure C.6. Apply external ice loads which have been determined earlier and estimate the "elastic" stresses and strains in various components. Output can be obtained with aid of standard graphics such as principal stress contours in both the shell and frames. Figure C.7 is an example of major principal stress contours in a typical structure. Such stresses can be examined to determine whether or not elastic limits were exceeded. This type of simple, inexpensive elastic finite element solution can produce a fairly good idea about where damage would start. Examination of stress levels would indicate locations on the shell and frames which will likely experience highest stresses. Some approximate correlations with the nature of observed damage can be made at this stage. There are a number of commercially available finite element programs which can be used for this purpose. To list a few:

FIGURE C.6

SIMPLIFIED FINITE-ELEMENT MODEL FOR TYPICAL STRUCTURE

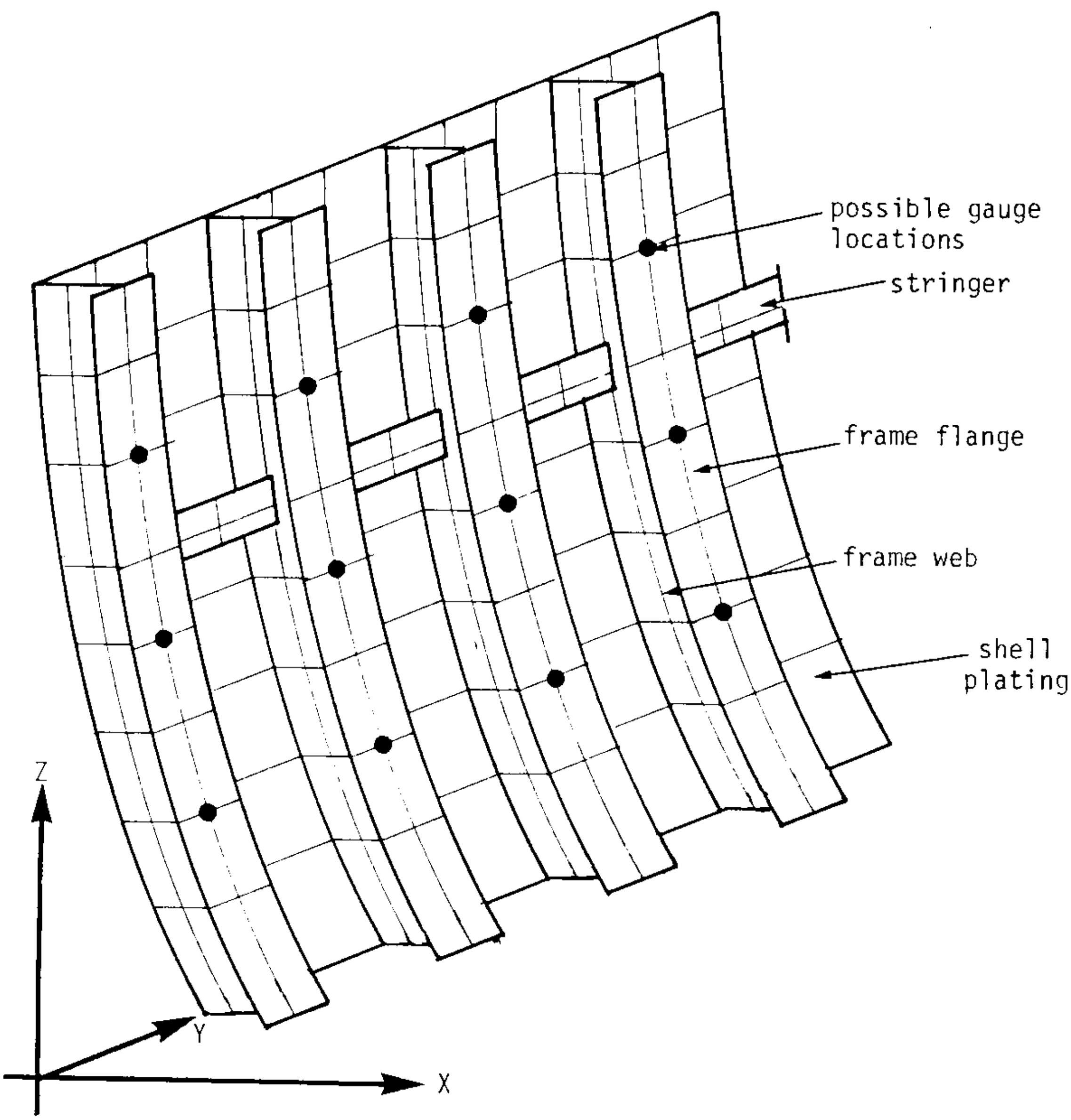
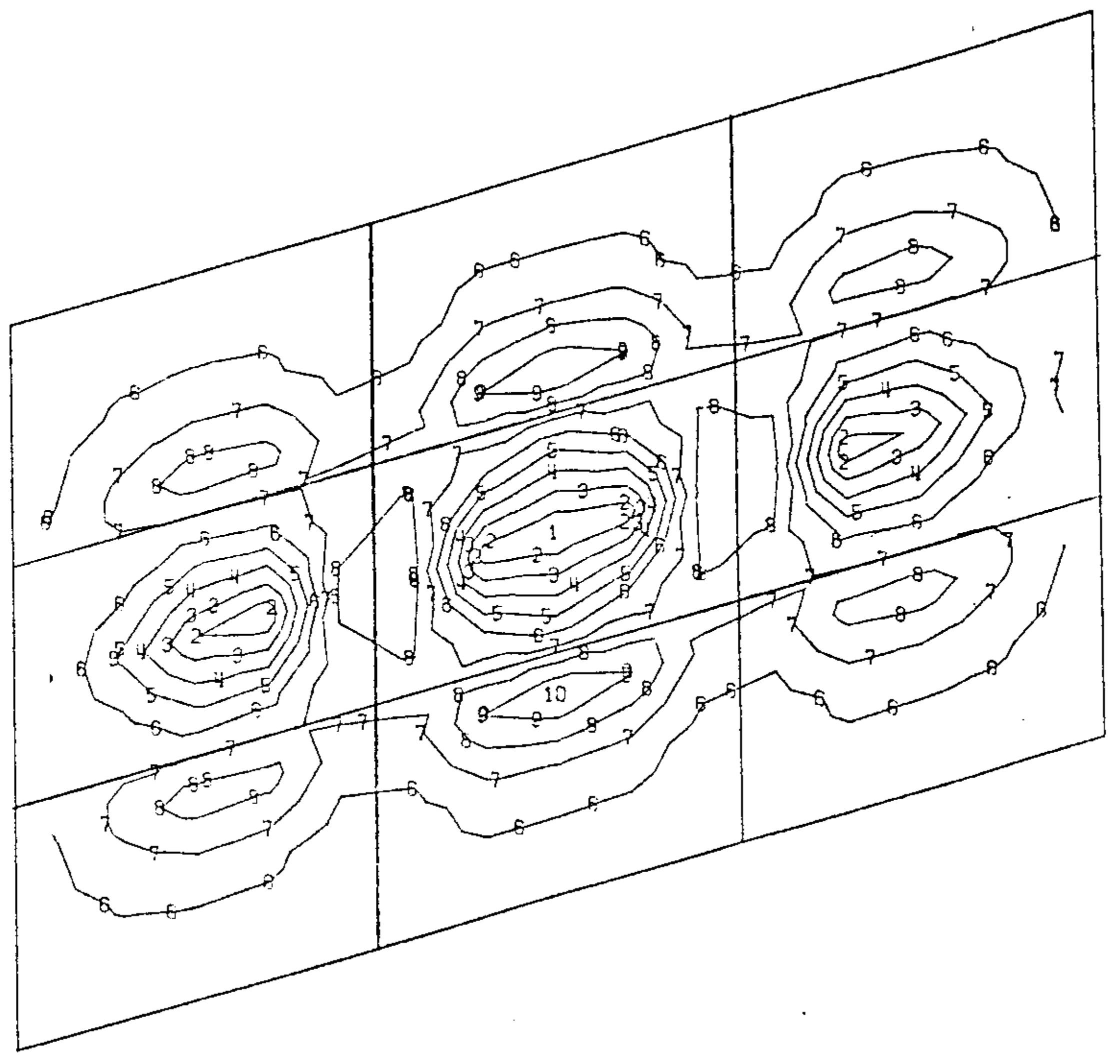


FIGURE C.7

STRESSES IN THE SHELL OF TYPICAL HULL STRUCTURE



SYMBOL	MAJOR STRESS
1	-2.23E+2
2	-1.74E+2
3	-1.25E+2
4	-7.64E+1
5	-2.73E+1
6	2.17E+1
7	7.08E+1
8	1.19E+2
9	1.69E+2
10	2.18E+2

- NASTRAN
- ANSYS
- STARDYNE
- STRESS
- MARC

All of these are available world-wide, and further information may be obtained from major suppliers, such as Control Data, Multiple Access, or General Electric.

(5) A more advanced and much more expensive step is to allow the hull material to yield in accordance with a selected bilinear stress-strain relationship. In this case, continuous updating of the stiffness matrix will be maintained to account for the yielding of plate or frame elements of the structure. The cost of this updating is quite high, particularly if a complete solution is desired. For a moderate size model (say 500-1000 elements), consideration of plastic flow can easily increase the cost by ten-fold.

(6) A study of the influence of ice pressure distribution on the stress distribution and possibilities of failure of the structure can be done by arbitrarily structuring a stepped pressure distribution within the contact area without altering average value or the total ice load. This technique has been used successfully to analyze the structure of the CCGS LOUIS S. ST. LAURENT with some interesting results as to the effect of pressure distribution. These results are illustrated in Figure C.8.

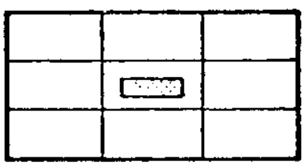
The utilization of elastic solution may be satisfactory to the requirements of damage analysis where the available data on the damage is sketchy. However, more sophisticated evaluation using plastic yield of the material should be appropriate and is justified for situations where more accurate data is available on the damage incident. In fact, a combination of both would be necessary since the economic restraints could only allow one or two runs with plastic yielding in addition to several elastic runs to select the loading conditions for these two.

To date, there has been no complete and documented utilization of the procedure proposed herein. However, several studies have been conducted to investigate stresses and strains in different hull structural components by using FEM. The results appear to be quite informative and useful, suggesting that using the FEM to conduct damage analysis can produce better insight into the nature of stressing of the hull, under variable loading conditions. This can ultimately lead to the understanding of how damage initiates and propagates within the structure and hence, to some informed guidelines for better design of hull structures to withstand extreme ice load with minimal penalty on the weight and cost of the ship.

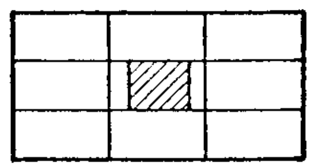
FIGURE C.8

EFFECT OF CHANGING PRESSURE DISTRIBUTION
ON STRESSES IN SHELL AND FRAMES

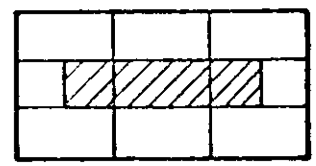
CASE #1



CASE #2

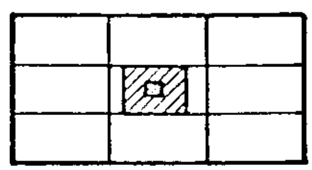


CASE #3

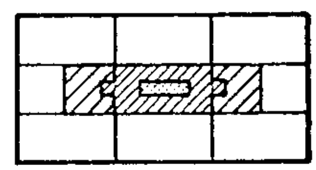


SCHEMATIC DESCRIPTION OF LOADED AREA AND PRESSURE DISTRIBUTION

CASE #4



CASE #5



CASES COMPARED	CONDITION	STRESS CHANGE
1-2	Equal total loads, increased area, even distribution	-35% plate 0 frame
2-4	Equal total load, same area, changed distribution	+22% plate + 3% frame
3-5	Equal total load, same area, changed distribution	+77% plate +15% frame
4-5	Equal central pressure, changed area, increased total	+51% plate +224% frame

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SHIP STRUCTURE COMMITTEE PUBLICATIONS

These documents are distributed by the National Technical Information Service, Springfield, VA 22314. These documents have been announced in the Clearinghouse Journal U. S. Government Research & Development Reports (USGRDR) under the indicated AD numbers.

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