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GROWTH Project GRD2-2000-30112 "ARCOP"

CURRENT HULL AND MACHINERY ICE CLASS RULES REQUIREMENTS AND IMPACT OF IACS POLAR RULES

WP2: Administrative measures for the marine transportation in the Arctic Russia

WP2.2: Rules and regulations

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DELIVERABLE SUMMARY SHEET

Short Description
Review of the Ice Class Rules for navigating in the Russian Arctic and comparison of IACS Polar Ship Rules and Ice Class Rules of the Russian Maritime Register of Shipping.

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DISCLAIMER

ARCOP W2.2.2 – Current Hull and Machinery Ice Class Rules Requirements and impact of IACS Polar Rules

Executive Summary

The following report describes the classification society ice class rules for navigation in the Russian Arctic, with particular emphasis on the ArcOp scenario of ship transportation in the Varanday region. Currently each Classification Society has a set of rules for the strengthening for navigation in ice, and these are now in the process of harmonisation with the introduction of the International Association of Classification Societies (IACS) Polar Ship Rules. The IACS Polar Ship Rules are created in line with the IMO Guidelines for Ships Operating in Arctic Ice Covered Waters to provide comprehensive requirements for the safe navigation of ships in Arctic waters. In addition, the Russian Maritime Register of Shipping (RMRS) will also retain rules for Arctic vessels, and the Finnish Swedish Ice Class Rules (FSICR) for first-year ice. The choice of ice class rules to be applied and equivalency between each set is investigated for the underlying assumptions within the IACS and RMRS ice class rules. This is further illustrated by practical application to three vessel designs.

Introduction

The Russian Arctic is viewed as a valuable resource, both for natural reserves of oil and gas, and as a transportation route between the North Atlantic and North Pacific, often referred to as the NSR, Northern Sea Route. The valuable reserves are seen as an exciting potential for exploitation in an ever increasing competitive search for exploration and development. But the region poses many barriers for transportation by sea, not lest the environmental conditions in the form of ice and cold temperatures. The region has also a sensitive environment, both for indigenous wildlife and inhabitants.

Ships are an efficient and effective mode of transport, although, most vessel designs are made on open water performance and due to the environmental conditions vessels intended to navigate in the Arctic Russia need to be specially equipped for these regions. To provide safety in operation and mitigate risks, Classification Societies have developed rules to enhance ship performance for these areas. These are dedicated vessels with special features, e.g. hull reinforcement, propeller increase and steering gear strengthening.

To protect the region from contamination, but allow industrial development, Arctic regulations are enforced. Classification Rules play a pivotal role in providing a level of safety and the Arctic region has seen a growth in international standardisation. The International Maritime Organisation, IMO, have recently developed standardised requirements for vessels entering these waters in the form of Guidelines for Ships Operating in Arctic Ice Covered Waters. The IMO guidelines cover many issues and reference the IACS Polar Rules for structural requirements. However the acceptance and implementation of these guidelines to the NSR by the Russian Administration is a task yet to be practised.

The IACS Polar Rules have been developed over many years and are now close to completion and will be implemented by most Classification Societies Rules. In addition to the IACS Polar Rules, the Russian Maritime Register of Shipping (RMRS) contains requirements for vessels intending to navigate in such waters. This is further compounded by the Finnish Swedish Ice Class Rules (FSICR) for vessels operating in the Northern Baltic in winter where these have become the de-facto standard for first-year ice class vessels. The existence of three sets of rules is due to variations in design conditions and assumptions used in the determination of requirements. The following document investigates the two different requirements, given by IACS and RMRS, to find whether common equivalency for safety can be established for both classes of vessels.

It should be noted that the following document is based on available information and there is no official endorsement by any Administrations or Classification Society involved. It should also be noted that, although the IACS Polar Rule requirements are currently near completion, they are still under development at time of writing and may be subject to alterations. Therefore comparisons can only be made with the current draft data present.

Classification Rules

Classification ice class rules are divided into various levels dependent on ice conditions. These are mainly based on the ice thickness the vessel is intended to navigate in. The thicker the ice, the more strength and power the vessel needs to navigate in these waters. This is somewhat compounded by the operational profile, such as independent or escorted navigation and vast variation in ice conditions, such as ice ridges, concentration, etc.

The IACS Polar Rules are based on both Arctic and Antarctic navigation, although the IMO Guidelines are presently for the Arctic only. They are also based on limited icebreaker assistance and hence, based on an interaction scenario of a glancing impact with an ice floe. The number and division of the IACS Polar Classes may be seen in the table below. The number of classes is intended to cover the full range of ships in operation, providing flexibility to designers without being too confusing to owners and operators. The lowest classes PC 6 and PC 7 have been aligned with the highest Finnish Swedish Ice Classes, 1AS and 1A respectively. The highest class has been based on the highest class of the Canadian Rules. The IACS Polar Rules are further divided into two sections, hull and machinery, to ensure a comprehensive set of requirements. The classes should increase in standard scantling jumps, say 30% increase with each ice class, but as the lower four are based on seasonal ice (where the ice is not so strong) there should be a difference in strength levels. However, the vessel speed may increase because of this, so that there is no appreciable difference.

Polar Class	**Ice Description** (Based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions.
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

The table below gives some of the characteristics of the RMRS ice classes. It can be seen that the description of service differs from that of the IACS Polar rules, as both independent ice navigation and icebreaker escorted navigation is covered in two seasonal periods, and numerical values for speeds and ice thickness are specified.

Ice class	Icebreaker escort			Independent navigation		
	Typical speed	Winter - spring	Summer - fall	Typical speed	Winter - spring	Summer - fall
		Typical ice thickness			Typical ice thickness	
Arctic ice class						
LU 9	6	3.4+	3.2+	12	3.5	4.0
LU 8	5	2.0 - 3.4	3.2+	10	2.1	3.1
LU 7	4	1.2 - 2.0	1.7 - 3.2	8	1.4	1.7
LU 6	4	0.9 - 1.2	1.2 - 1.7	8	1.1	1.3
LU 5	4	0.7 - 0.9	0.7 - 1.2	8	0.8	1.0
LU 4	3	0 - 0.7	0 - 1.0	8	0.6	0.8
Non arctic ice class						
LU 3	3	0.65		5	0.70	
LU 2	3	0.50		5	0.55	
LU 1	3	0.35		5	0.40	
Note, ice thickness given as guidance only						

In addition, the RMRS provide guidance to navigation regions, see tables below.

Ice Class	Ice Operation	Summer - fall																			
		Barents Sea				Kara Sea				Laptev Sea				East Siberian Sea				Chukchi Sea			
		Ex	H	M	Ea	Ex	H	M	Ea	Ex	H	M	Ea	Ex	H	M	Ea	Ex	H	M	Ea
LU 4	IIN	+	+	+	+	-	-	+	+	-	-	-	+	-	-	-	+	-	-	+	+
	IEN	+	+	+	+	*	+	+	+	-	-	+	+	-	*	+	+	-	*	+	+
LU 5	IIN	+	+	+	+	-	+	+	+	-	-	+	+	-	-	+	+	-	-	+	+
	IEN	+	+	+	+	*	+	+	+	*	+	+	+	*	+	+	+	*	+	+	+
LU6	IIN	+	+	+	+	+	+	+	+	-	+	+	+	-	+	+	+	-	+	+	+
	IEN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
LU 7	IIN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	IEN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
LU 8	IIN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	IEN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
LU 9	IIN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	IEN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

IIN	Independent Ice Navigation
IEN	Icebreaker Escorted Navigation
-	Impermissible service
*	Service with increased risk of damage
+	Permissible service
Ex, H, M, Ea	Extreme, Hard, Medium and Easy navigation

Ice Class	Ice Operation	Winter - spring																			
		Barents Sea				Kara Sea				Laptev Sea				East Siberian Sea				Chukchi Sea			
		Ex	H	M	Ea	Ex	H	M	Ea	Ex	H	M	Ea	Ex	H	M	Ea	Ex	H	M	Ea
LU4	IIN	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	IEN	-	*	+	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	*
LU5	IIN	-	-	+	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	IEN	*	+	+	+	-	-	*	+	-	-	-	+	-	-	-	+	-	-	*	+
LU6	IIN	*	+	+	+	-	-	-	+	-	-	-	+	-	-	-	+	-	-	-	+
	IEN	+	+	+	+	*	*	+	+	-	*	*	+	-	*	+	+	-	*	+	+
LU7	IIN	+	+	+	+	-	-	+	+	-	-	-	+	-	-	-	+	-	-	+	+
	IEN	+	+	+	+	+	+	+	+	*	+	+	+	*	+	+	+	*	+	+	+
LU8	IIN	+	+	+	+	+	+	+	+	-	*	+	+	-	*	+	+	*	+	+	+
	IEN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
LU9	IIN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	IEN	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

IIN	Independent Ice Navigation
IEN	Icebreaker Escorted Navigation
-	Impermissible service
*	Service with increased risk of damage
+	Permissible service
Ex, H, M, Ea	Extreme, Heavy, Medium and Easy navigation

The FSICR ice classes are given in the table below. Although not intended for multi-year (Arctic) ice conditions these are the de-facto standard for many vessels operating in ice. Due to the limited salt content of the Baltic a strong ice forms, resulting in high strength requirements for vessels operating in these waters. And regions within the NSR also have first-year ice present. For these reasons the IACS Polar Rules have been developed to give an equivalency with 1AS and 1A for PC 6 and PC 7 respectively. Also, due to the Administration requirements within this region, there are many underlying principals within the rules, for example, icebreaker escort is given for vessels navigating to Finnish or Swedish ports and therefore the majority of time of the ship is spent in a brash ice channel, hence the engine power requirements are based around this assumption. The Finnish and Swedish Maritime Administrations also provide navigational limitations, although on a weekly basis dependent on ice conditions.

Ice Class	Ice Description
1AS	First year ice thickness 1.0m
1A	First year ice thickness 0.8m
1B	First year ice thickness 0.6m
1C	First year ice thickness 0.4m

A general table of equivalency between classes is given below.

Helcom Equivalency	
FSICR	**RMRS**
	LU 9
	LU 8
	LU 7
	LU 6
1AS	LU 5
1A	LU 4
1B	LU 3
1C	LU 2
	LU 1

IACS Polar Rules
PC 1 ?
PC 2 ?
PC 3 ?
PC 4 ?
PC 5 ?
PC 6
PC 7

As can be seen, the notations used are confusing in that the IACS numbering system has higher class with a low number and increases with lower class. Whilst conversely, the RMRS has a higher class with a high number and decreases with lower class. Equally the description used for the intended ice class differs; with the RMRS ice class rules providing ice thickness and operation parameters, whilst the FSICR and IACS Polar Rules are less elaborate. At present this confusion in notations causes particular problems in comparisons and equivalency. A unified approach to notations and description of intended operations would give transparency to owners/builders/operators.

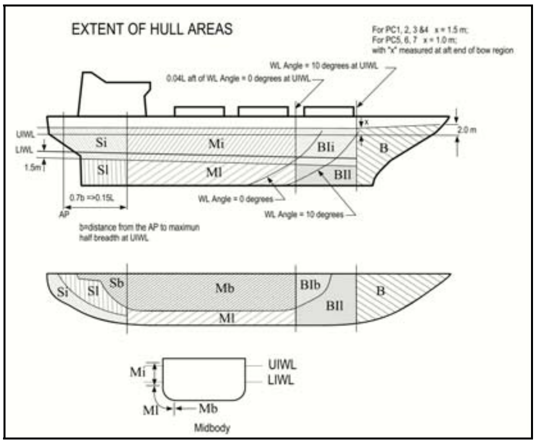
It is noted from the above that the acceptance of ice classes is based on a particular method of equivalency. At present there is no unified theory for the calculation of equivalency and this would need to be investigated further. Therefore, currently the range of equivalency of the IACS Polar Classes is dependent on the Administrations acceptance and equivalency method.

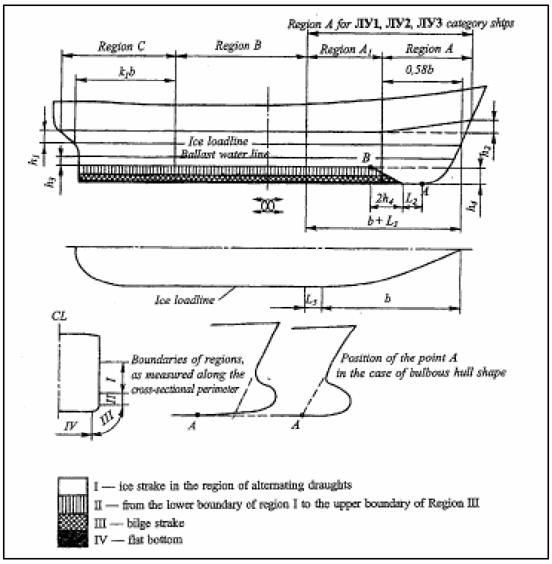
Rule Methodology

Due to the nature of ice, it is difficult to model and assess every design scenario, and therefore many rules have been based on damage statistics to circumvent such a situation. The IACS Polar Rules and RMRS ice class rules have taken a unique approach in specifying a particular scenario as a design basis, this being the glancing impact with a large ice floe. This is then refined from operational experience and damage statistics.

The determination of the extent of reinforcement is closely linked with the design scenario and the damage experience. For example, the RMRS use an icebreaker convoy system and these vessels will have different damages than Canadian ships where there is limited icebreaker escort, i.e. the ships are designed for differing operational uses and reinforced in areas that have experienced damage from this. The IACS Polar Rules extents have been developed in conjunction with scenarios for each region and the extent these would impinge on the hull.

The extent of reinforcement of the IACS Polar Rules and RMRS ice class rules are divided into four regions. The IACS Polar rule further subdivides the regions into three sections, lower, icebelt and bottom, whilst the RMRS ice class rules divides this into four to include the bilge, as shown below.





RMRS and IACS ice class rules have hull area factors associated with each region which are used to interpolate from the design bow impact pressure, since limited data is available for a scenario to be made for each location. Equally, both rules sets utilise a shape factor for the bow shape to account for the ice pressures resulting from the icebreaking capability.

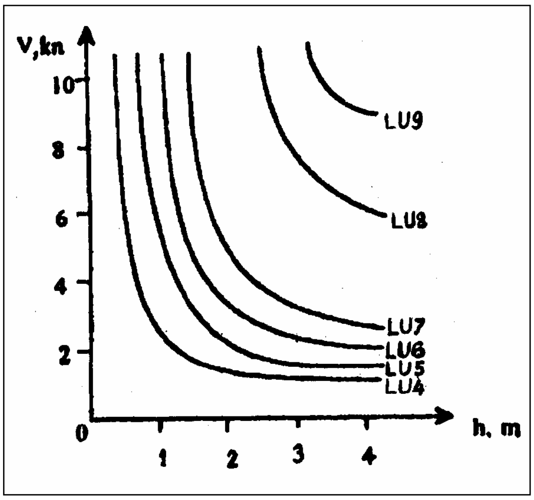
The IACS load calculation is based on an energy based model, i.e. the kinetic energy is equated to the ice crushing energy. During this interaction it is assumed the ship penetrates the ice and glances away. Note this scenario would be equally applicable to the aft end of a double acting vessel. From this an ice force acting on the hull is obtained from theoretical formula. The pressure area, or patch load, is then gained by assuming a rectangular ice loading applied to the ship. And also the load line pressure. These three values are then found for various locations around the bow and the largest values are selected from the ice force, patch pressure and load line pressure. These combine to form an overall patch pressure to be applied throughout the ship. The RMRS ice pressure is also based on an ice impact scenario. The method is similar to that of IACS Polar Rules, although noticeably uses the vessel displacement in ice pressure and patch area definition.

It should be noted that this may not represent the highest load that may be experienced by a ship. Ramming or icebreaking operations may well generate larger forces, but the vessel is likely to be going at lower speeds and the occurrence may be limited.

Implicitly within the IACS rules is the assumption of the speed of the ship. For the IACS Polar Rules the assumption is through the impact with an ice floe of infinite mass, i.e. the vessel will be moved and not the ice. This imparts high impact forces, where the greater the speed the greater the force. A table with the assumed speeds is given below.

Ice Class	Speed, knots	Thickness of ice ship impacts, m
PC 1	11.1	7.0
PC 2	8.6	6.0
PC 3	6.8	5.0
PC 4	5.3	4.0
PC 5	4.3	3.0
PC 6	4.3	2.8
PC 7	3.4	2.5

This is also present in the RMRS ice class rules, which employ a speed versus ice thickness plot into their rules, as seen below. This is further developed with the ice passport system*, whereupon the curves are plotted in detail for an individual ship with given specific structural arrangements and vessel dimensions.

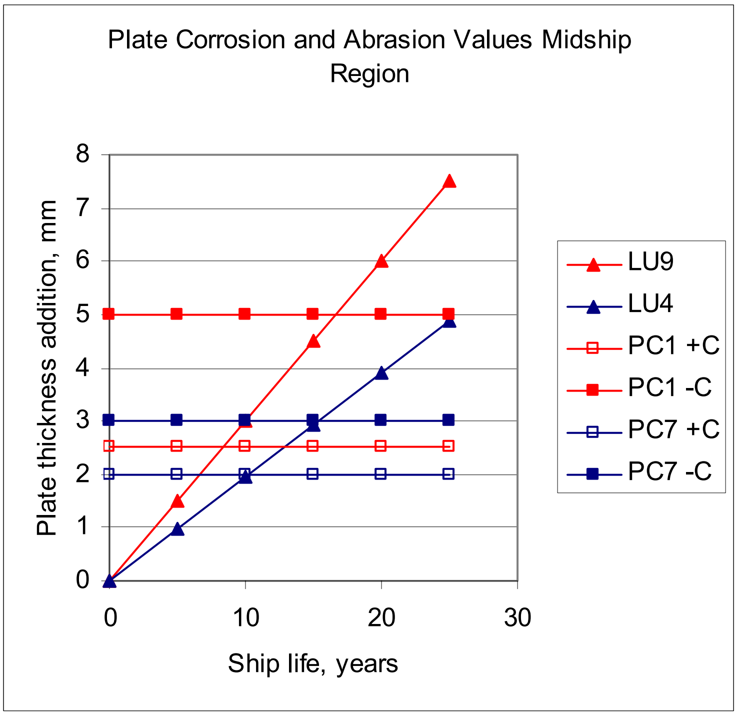


* Ice Passport System

An ice passport is a document that provides a plot of allowable speed versus ice conditions based on the ice capability of a particular vessel, given vessel principal particulars, hull scantling arrangements and engine power. The ice passport is issued by CNIIF, St. Petersburg.

For both the IACS and RMRS rules the loads are then applied in plastic formulae, although the models used in the application of the pressures differs slightly for each set of rules. The use of plastic formula is used due to acceptance of local deformations as the overall strength of ship is not diminished.

The shell plating thickness is of paramount importance and both the IACS and RMRS use ultimate strength criteria by assuming plastic hinges over the load patch area of the plate. Both rules have developed tables relating the plate thickness additions to the region of the vessel to account for corrosion and abrasion. The main difference being the RMRS has divided the value into the intended service life to allow greater flexibility, whilst the IACS Polar Rules divide the values into with and without effective protection. The corrosion and abrasion additions added to the plate structure are illustrated as shown below (+C denotes with effective protection coatings and –C without).



Both the IACS and RMRS also use plastic design for framing. This is because it allows the frames to be designed for ice loads where there may be extreme loads in excess of design. The IACS Polar Rules use energy methods, validated through non linear finite element methods, where it is assumed to be full end fixity of structure. The principal load cases are with the ice load applied at mid span, as well as the load concentrated towards one end of the frame. In addition there are stability requirements, i.e. for the web and flange of the stiffener.

The requirements for the hull materials for the IACS Polar Rules are defined for each ice class to ensure adequate toughness of the structure. The RMRS use a similar philosophy by specifying a minimum temperature, which in turn provides material requirements. Both RMRS and IACS are compatible with IACS UR S6 “Use of steel grades for various hull members - ships of 90 m length and above", although differences occur with respect to individual items based on previous experience of each.

Furthermore, IACS Polar Ship Rules have requirements for the global hull strength, which is not assessed by the RMRS ice class rules. Here the IACS Polar Ship Rules provide requirements for the longitudinal strength based on a ship ramming head on into ice, to ensure a minimum safe level of hull girder strength.

The IACS machinery design scenario is not the same as used in the hull, such that the most severe conditions for one are not the same for the other. For this reason the propeller ice interaction loads are based on an icebreaking mode of operation, relating ice block impacts to the propeller. It should also be noted that the powering requirement of the RMRS is to provide an icebreaking capability, whilst the IACS Polar Rules do not have such requirements leaving these to the determination of the builder/owner.

In addition, there are other minor requirements, such as for the termination of members, ballast tank heating, reduction gears, etc. But as can be seen, although the initial design scenario is similar, the method of application and assumptions of IACS Polar Rules and RMRS ice class rules differ. Further, the determination of patch loads and the application in plating and framing also use separate models. Due to this there is a difference in the formula for the resulting scantling equations. The end effect is that vessels optimised for design for each rule sets may give differing scantlings but similar abilities in ice conditions.

Rule Philosophy as Applied to the ArcOp Scenario

The Arcop scenario is based on the Varanday region in the Russian Arctic. The environmental and operational conditions in this region will have many aspects associated with this that will have implications on the vessel design and the ice class chosen.

Winter conditions in the region will be the deciding factor for the selection of ice class. The general ice conditions expected are given in the table below. Although the maximum ice conditions are usually the design consideration and in particular these may be dominated by the significant ridge size, masters, and in particular ice navigators, will sail the vessel in the safest and least resistance route. Circumventing thick ice patches and taking use of leads. Hence, the ice conditions the vessel is designed for requires a measure of knowledge of the intended use and a safety margin of operation. The intention of providing year round operation or seasonal service will also dictate the required ice class. A vessel entering the region in the summer half of the year only, will encounter different conditions to those entering in the winter half as well.

Parameter	**Units**	**Average**	**Maximum**
Air temperature	^{o}C	-19.2 (January) 8.9 (July)	-44 (January) 32 (July)
Ice period	days	240	275
Ice concentration	%	95 (winter) 40 (summer)	100 (winter) 100 (summer)
Ice ridge concentration	%	2	5
Drifting level ice thickness	m	0.7	1.5
Drifting rafted ice thickness	m	1.1	3.0
Uniaxial compressive strength, vertical	MPa	2.3	3.0
Uniaxial compressive strength, horzontal	MPa	1.8	2.5
Flexural strength	kPa	270	500
Ice ridge width	m	20-30	70
Ice ridge sail height	m	2.3	4.9
Ice ridge keel draught	m	7.0	14.0
Ice ridge porosity	%	20-30	35
Ice ridge consolidated layer thickness	m	2.0-3.0	6.0
Uniaxial compressive strength, vertical	MPa	1.6	2.0
Uniaxial compressive strength, horzontal	MPa	1.3	1.8
Flexural strength	kPa	240	300
Total ice drift speed	m/s	0.25	1.05
Prevailing ice drift direction	degrees	90-135	-

Ice conditions at the terminal will be predominantly formed of drifting ice floes and thick ice ridges giving additional design aspects for the navigation through these obstacles. The vessel will also be subject to rubble impacts whilst manoeuvring, in particular when berthing subject to ice floes trapped between the hull and berth and compressed. Most ice class rules do not account for this interaction.

It is assumed that the availability of icebreakers for escort operations will be limited, so the ship must therefore encounter ice conditions independently. As such the vessel would need to be fitted with an icebreaking bow, or with a double acting principle. However, when icebreaker service is present, the Russian system of icebreaker escort will be used which employs the use of vessels in a convoy. This results in loads being greater in the region aft of the forebody, rather than bow collisions typical in level ice. This will result in different pressures, and the locations of these, for each vessel dependent on the icebreaking operation, i.e. independent or escorted. Although, since the collision scenario is equally applicable to both these scenarios, the IACS Polar Rules and RMRS ice class rules will give realistic values for both modes of operation.

Limits to ice class are given by the RMRS for the Barents Sea region (see the table in the previous section). The region is close to the Kara Sea to the east. These regions are exposed to extreme storms causing high wind and wave conditions. A significant waveheight, $H_{1/3}$, of 7.8 m is expected in the region and maximum waveheight of 12.5 m. In addition, snow occurs, mainly in November to December, adding a 10-20 cm snow layer to the vessels topside weight. Therefore, stability calculations should be assessed for the increased loading and motions, and hull strengthened for increased wave impacts. Additionally de-icing equipment to remove ice and snow likely to cover the vessel may need to be fitted, where this is not usually covered in the ice class rules and is an optional extra.

In summary, the environment of Varanday produces a high standard of design and additional factors for the designer and Classification Society to ensure the safety of the vessel, environment and personnel.

Vessel Comparison

To illustrate the differences in the IACS Polar Rules and RMRS ice class rules in practical terms a comparison of typical vessels is made. Using the Arcop scenario, as given above, a range of vessels was chosen, a small, a medium and a large tanker. The ships have been chosen based on the following criteria:

- designed with an ice going capability
- to represent a significant range of size
- to represent typical vessels for the Arcop scenario
- the availability of data for the ships

Item	Vessel 1	Vessel 2	Vessel 3
Vessel type	Chemical Tanker	Tanker	Tanker
Ice class (FSICR)	1AS	1C	1AS
Length (LBP)	115	219	230
Breadth	18	32.24	44
Depth	10.9	20.4	22.5
Draught (Scant.)	7.6	13.85	15.3
Deadweight(Ton)	8,300	71,300	106,208

Vessel one is an 8300 deadweight Chemical/Oil tanker designed with a bulbous bow, a forecastle and a poop deck. The machinery installation is a single medium speed diesel engine coupled through a gear to a controllable pitch propeller. The cargo region is enclosed by double sides and a double bottom. The vessel is permitted to carry IMO 2 products with a specific gravity of up to 1.54t/m^3.

Vessel two is a 71,300 deadweight Panamax Crude Oil & Product Carrier designed with a bulbous bow. The machinery installation is a single low speed diesel engine with fixed pitch propeller. The cargo region is enclosed by double sides and a double bottom and consists of six (6) pairs of cargo tanks and slop tanks. The vessel is designed to carry maximum cargo specific gravity of 1.055t/m^3. Rule requirements 2003 for Ice Class 1C FS have been applied to the hull structures and machinery/propulsion requirements.

Vessel three is a 106,200 deadweight double acting type Aframax Crude Oil Tanker with a bulbous bow. The machinery installation is electric motor driven podded Azimuthing propulsion unit. The cargo region is enclosed by double sides and a double bottom and consists of six (6) pairs of cargo tanks and slop tanks. The vessel is designed to carry maximum cargo specific gravity of 1.025t/m^3. Rule requirements 1985 for Ice Class 1AS FS have been applied to the hull structures and machinery/propulsion requirements.

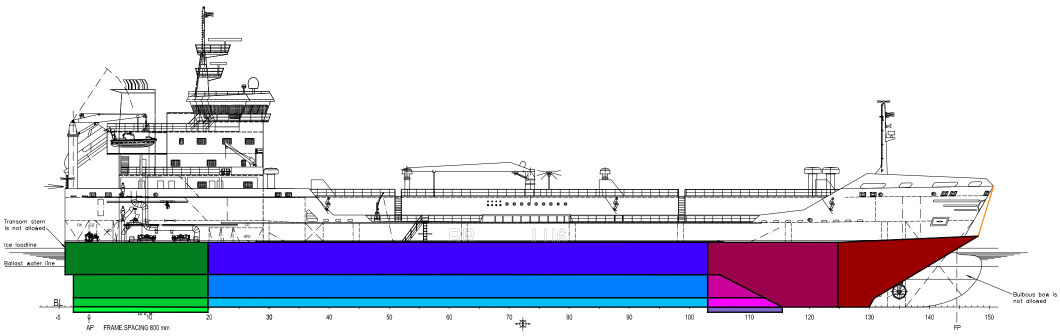
To show a range of possible types of operation, the investigation is centred on the consideration of six ice classes, PC4, PC5 and PC6, and LU6, LU5 and LU4. Further PC3 is included in the tables, to extend the comparing range between the IACS and the RMRS requirements.

Hull Requirements

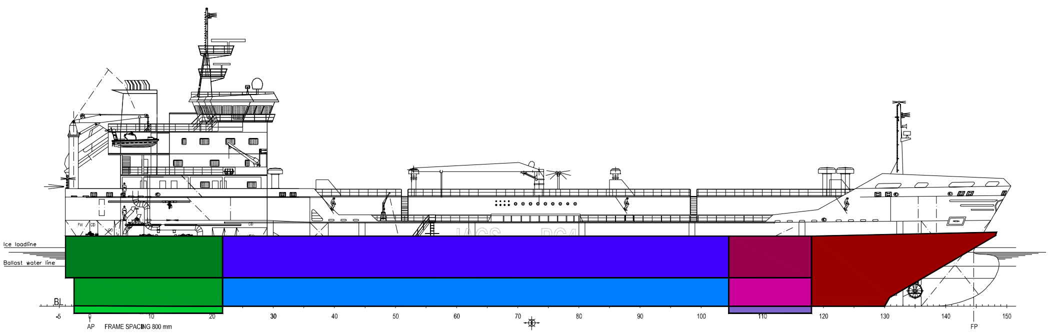
The comparison for hull scantling requirements is given in the figures and tables below. The first item to be investigated is the extents of ice strengthening. Although illustrated for vessel 1 only, the same extents would be applied to the other vessels also.

Colour Code	Aft	Midship	Bow intermediate	Bow
Ice belt				
Lower				
Bilge				
Bottom				

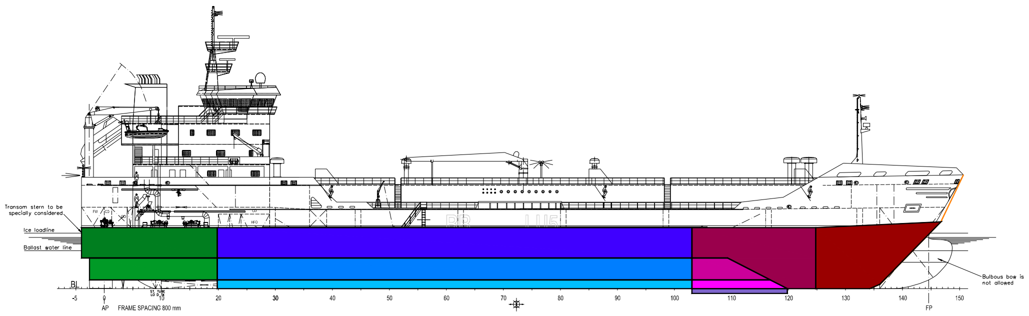
Russian Ice Class: LU6



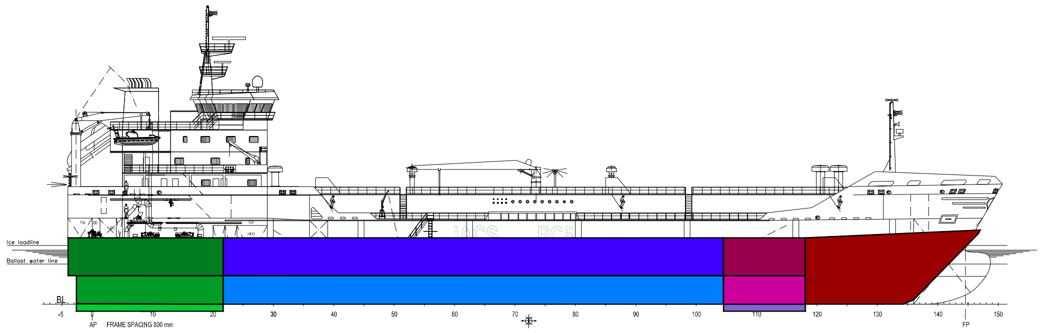
IACS Polar Class: PC4



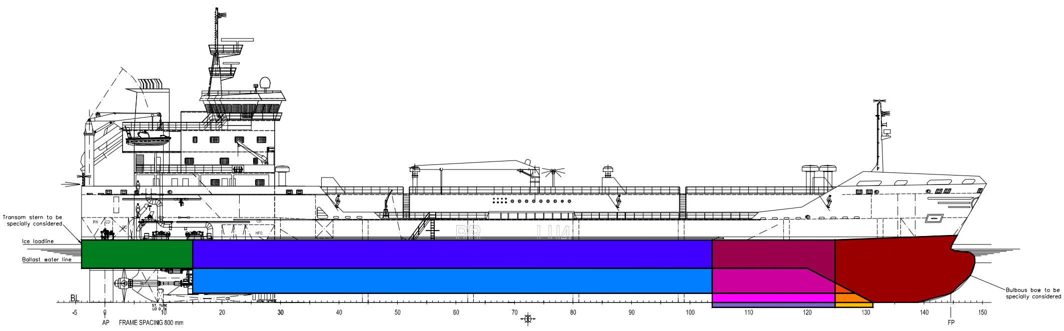
Russian Ice Class: LU5



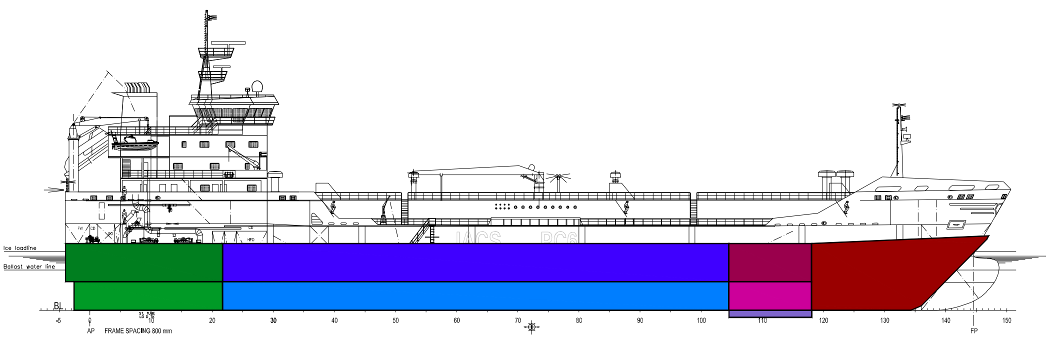
IACS Polar Class: PC5



Russian Ice Class: LU4



IACS Polar Class: PC6

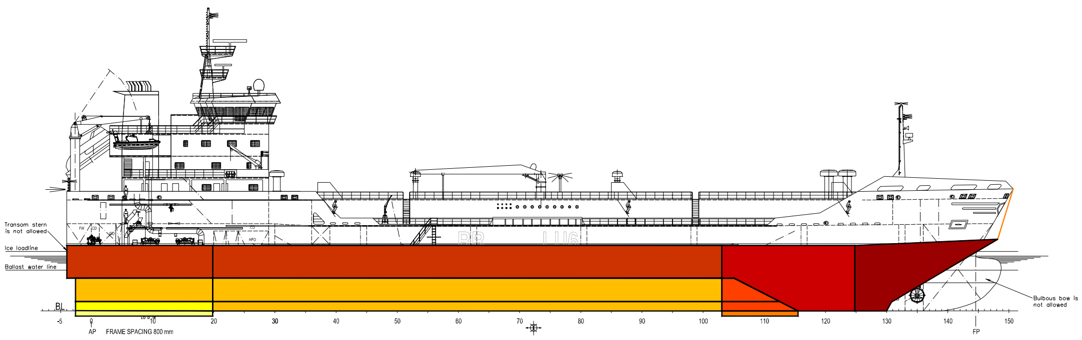


The design ice pressures are of principal importance. Vessel 1 is used as an example to illustrate the differences between ice classes given in the figures below.

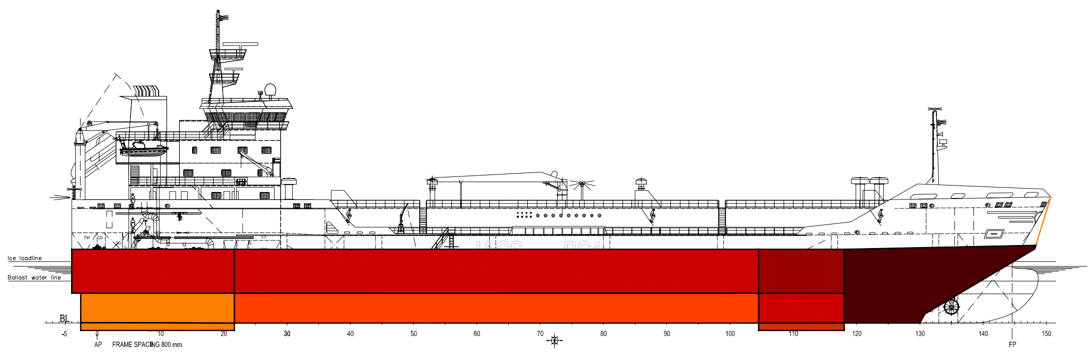
Ice pressure index

	(kPa)
	7000
	6500
	6000
	5500
	5000
	4500
	4000
	3500
	3000
	2500
	2000
	1500
	1000
	500
	0

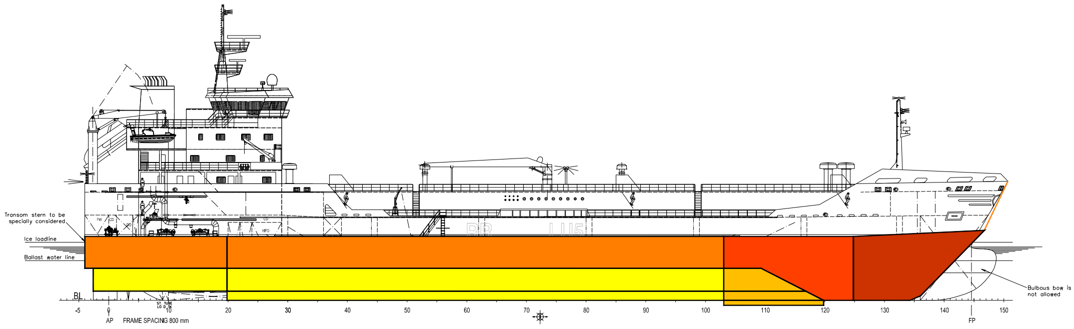
Russian Ice Class: LU6



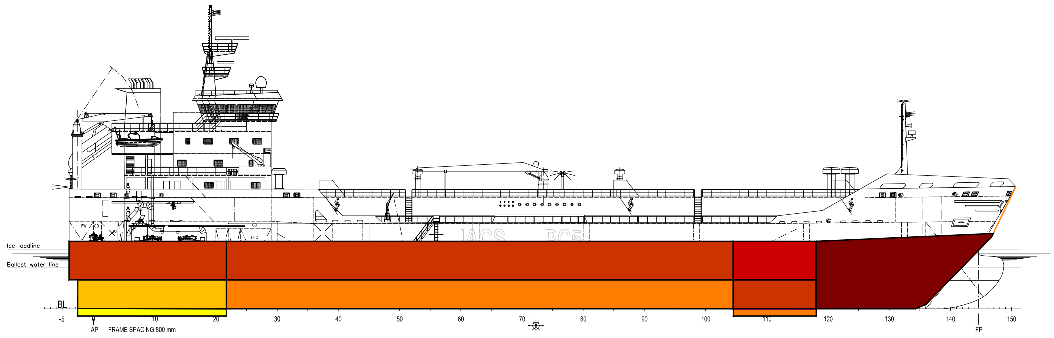
IACS Polar Class: PC4



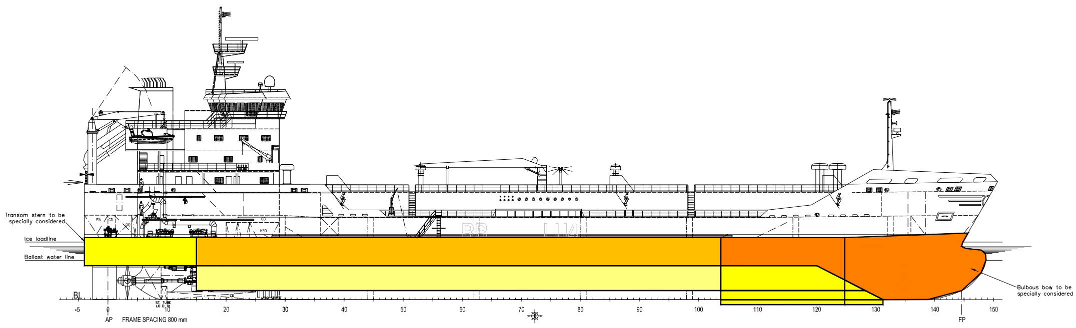
Russian Ice Class: LU5



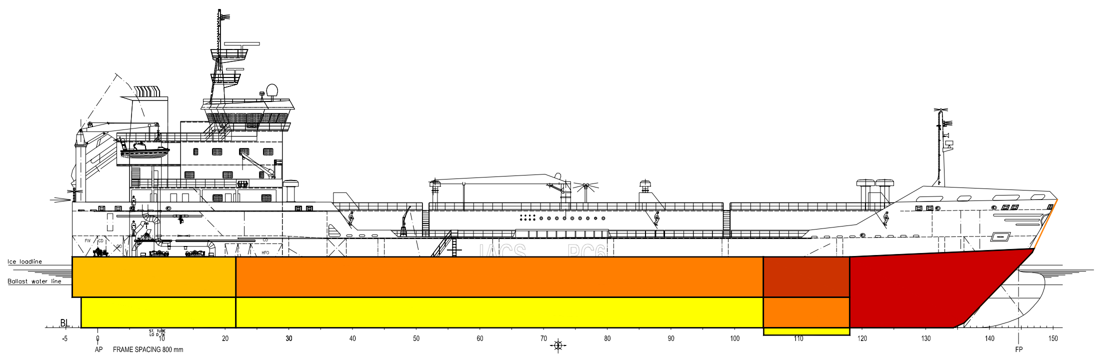
IACS Polar Class: PC5



Russian Ice Class: LU4



IACS Polar Class: PC6



The scantling investigation is shown below for the plate thickness on the basis of without effective protection for IACS Polar Rules and the planned ship life of 24 years for RMRS without special corrosion protection respectively.

The results for vessel 1 are shown below, with transverse frames at side (spacing 0.40 to 0.47m and span 2.35 to 4.00m), and longitudinal frames at bottom (spacing 0.685m and span 2.4m). HT36 material grade was used along the ship's length.

Item	Region		IACS Polar Rules				RMRS		
			PC3	PC4	PC5	PC6	LU6	LU5	LU4
Plating mm	Bow		35.6	30.5	27.4	23.5	29.1	23.8	20.1
	Bow intermediate	Icebelt	29.1	24.1	21.6	20.2	24.4	20.2	16.9
		Lower	34.6	29.2	24.8	21.2	20.8	17.4	13.9
		Bilge	-	-	-	-	30.2	24.6	17.0
		Bottom	34.9	29.1	24.5	19.7	28.9	22.9	18.2
	Midship	Icebelt	22.5	19.6	17.0	13.7	20.1	16.6	13.7
		Lower	26.7	21.8	18.0	14.5	15.8	13.2	10.4
		Bilge	-	-	-	-	21.5	17.4	-
		Bottom	26.9	-	-	-	-	-	-
	Stern	Icebelt	26.0	21.9	18.2	14.1	21.5	16.7	13.0
		Lower	26.4	21.4	17.5	15.1	22.4	17.2	-
		Bilge	-	-	-	-	20.4	-	-
		Bottom	23.1	18.4	13.1	-	14.6	-	-

The results for vessel 2 are shown below with the longitudinal spacing of 0.42m, 2.6m primary web spacing and HT36 material grade along the ship's length.

Item	Region		IACS Polar Rules				RMRS		
			PC3	PC4	PC5	PC6	LU6	LU5	LU4
Plating mm	Bow		40.7	35.3	31.8	27.3	42.5	34.3	29.3
	Bow intermediate	Icebelt	41.2	34.8	31.3	29.3	37.7	30.7	26.2
		Lower	34.9	29.8	25.8	21.8	31.8	26.1	20.4
		Bilge	-	-	-	-	31.8	26.1	19.0
		Bottom	28.8	23.6	19.9	15.9	28.8	22.8	18.1
	Midship	Icebelt	32.5	28.7	24.8	20.0	25.4	21.2	17.6
		Lower	27.5	22.7	19.1	15.1	19.6	16.5	12.9
		Bilge	-	-	-	-	18.1	15.3	-
		Bottom	22.1	-	-	-	-	-	-
	Stern	Icebelt	34.9	29.8	24.8	19.0	25.4	20.1	15.9
		Lower	26.0	21.3	17.7	15.1	19.6	15.7	-
		Bilge	-	-	-	-	17.3	-	-
		Bottom	23.8	19.2	13.9	-	12.6	-	-

The results for vessel 3 are shown below with the longitudinal spacing of 0.50m, 3.0m primary web spacing and HT36 material grade along the ship's length.

Item	Region		IACS Polar Rules				RMRS		
			PC3	PC4	PC5	PC6	LU6	LU5	LU4
Plating mm	Bow		47.0	40.9	36.8	31.6	50.5	40.6	34.5
	Bow intermediate	Icebelt	47.6	40.4	36.1	34.0	44.7	36.1	30.7
		Lower	40.5	34.7	29.8	25.2	37.4	30.4	23.6
		Bilge	-	-	-	-	37.4	30.4	21.8
		Bottom	33.1	27.5	23.1	18.4	33.7	26.5	20.8
	Midship	Icebelt	37.7	33.4	28.6	23.1	30.0	24.9	20.6
		Lower	31.9	26.4	22.1	17.5	22.8	19.1	14.7
		Bilge	-	-	-	-	21.0	17.6	-
		Bottom	25.5	-	-	-	-	-	-
	Stern	Icebelt	40.5	34.7	28.6	22.0	30.0	23.5	18.4
		Lower	30.1	24.7	20.4	17.5	22.8	18.1	-
		Bilge	-	-	-	-	20.0	-	-
		Bottom	27.6	22.3	16.0	-	14.1	-	-

The ultimate section modulus requirements for the stiffeners on the basis of the same assumption for the plating, of without effective protection for IACS PC Rules and the planned ship life of 24 years for RMRS without special corrosion protection respectively are shown below.

The results for vessel 1 are shown below.

Item	Region		IACS Polar Rules				RMRS		
			PC3	PC4	PC5	PC6	LU6	LU5	LU4
Stiffeners cm^3	Bow		3271	2442	1734	1312	4620	2842	1727
	Bow intermediate	Icebelt	2315	1647	1174	1109	2611	1593	937
		Lower	1805	1250	821	612	1827	1101	504
		Bilge	-	-	-	-	2559	1565	595
		Bottom	1665	1053	619	384	1972	1073	477
	Midship	Icebelt	1170	883	576	383	1808	1090	634
		Lower	826	541	329	203	944	562	277
		Bilge	-	-	-	-	1190	733	-
		Bottom	836	-	-	-	-	-	-
	Stern	Icebelt	2296	1605	965	572	2848	1457	743
		Lower	731	463	272	206	704	379	-
		Bilge	-	-	-	-	-	-	-
		Bottom	1039	620	242	-	479	-	-

The results for vessel 2 are shown below.

Item	Region		IACS Polar Rules				RMRS		
			PC3	PC4	PC5	PC6	LU6	LU5	LU4
Stiffeners cm^3	Bow		5485	4422	3455	2477	12362	7633	5313
	Bow intermediate	Icebelt	5325	4007	3049	2808	9257	5745	3961
		Lower	4063	2955	1972	1326	6136	3798	2049
		Bilge	-	-	-	-	6136	3798	1658
		Bottom	2760	1816	1133	662	4771	2693	1471
	Midship	Icebelt	3428	2682	1729	1052	3932	2579	1660
		Lower	2405	1556	953	540	2033	1336	714
		Bilge	-	-	-	-	1646	1086	-
		Bottom	1332	-	-	-	-	-	-
	Stern	Icebelt	4063	2955	1729	931	3850	2210	1245
		Lower	1978	1304	777	540	1991	1152	-
		Bilge	-	-	-	-	1430	-	-
		Bottom	1649	1015	420	-	650	-	-

The results for vessel 3 are shown below.

Item	Region		IACS Polar Rules				RMRS		
			PC3	PC4	PC5	PC6	LU6	LU5	LU4
Stiffeners cm^3	Bow		9150	7399	5765	4315	20591	12712	8796
	Bow intermediate	Icebelt	8811	6659	5069	4691	15415	9547	6544
		Lower	6751	5018	3224	2243	10163	6317	3377
		Bilge	-	-	-	-	10163	6317	2754
		Bottom	4637	3097	1882	1128	7910	4426	2410
	Midship	Icebelt	5684	4510	2899	1808	6442	4213	2715
		Lower	4014	2644	1576	889	3325	2189	1154
		Bilge	-	-	-	-	2711	1776	-
		Bottom	2255	-	-	-	-	-	-
	Stern	Icebelt	6751	5018	2899	1547	6312	3583	1982
		Lower	3404	2195	1276	889	3270	1873	-
		Bilge	-	-	-	-	2312	-	-
		Bottom	2812	1774	704	-	1053	-	-

Discussion on hull requirements

The following comments are made based on the process of application of each rule set and the resulting findings. It should be noted that the application of the RMRS ice class rules and the IACS Polar Ship rules have many hull requirements and criteria to be satisfied, and that the above review considers the principal scantlings only.

From examination of the extents diagrams it can be noted that there is a significant discrepancy in the relative values of hull extents to be reinforced. Principally this is related to the forward region to bow intermediate. In this respect the IACS Polar rules define a greater bow region and smaller intermediate region than the RMRS ice class rules. In addition the IACS Polar rules define a slightly greater vertical extension height. However the midship region and aft region are both fairly consistent.

The ice pressures in the RMRS rule are generally smaller than the IACS Polar rules, for the smallest vessel it is seen there is some connection with the requirement for plating, while for the larger vessel the requirements given by RMRS ice class rules seems to be higher in the bow area, and lesser in the midship/stern area relative to the IACS Polar Ship rules.

In general, it can be seen that the requirements of the framing by the RMRS ice class rules are considerably higher, relative to the requirements obtained by the IACS Polar rules. Although, it should be noted that the rules are based on a plan approval process, where the rules provide requirements that are compared with the as fitted scantlings. As such, a number of assumptions have been made in calculating the values. For example, the frame calculation was based on an iterative process to ensure the shear area and section modulus of the design for the IACS Polar rules and the RMRS ice class rules had the same utilisation of the section properties. Because of this there is vast scope of optimisation available. It should also be borne in mind that in the above tables the IACS lower extent covers the bilge area and values can be compared with RMRS values of these.

It can also be seen that, especially from the RMRS rules, relatively high requirements to the bow framing are obtained, this could be because the vessels are designed with a bulbous bow and not as recommended an icebreaking bow. The effect of the bow configuration could be subject to further studies.

Machinery requirements

As the IACS requirements for machinery is still under development, it is not possible to compare the machinery requirements of the IACS Polar Rules to the RMRS ice class requirements. However, the following general comments are made based on the developments so far.

There is no engine power requirement for the IACS Polar Ship Rules. One reason for this is that it is difficult to specify the required power for each vessel, i.e. a maximum or minimum. A minimum value might get the ship into thicker ice than designed for and conversely a maximum value may produce low engine power so the vessel is not be able to sail in ice. The power is also very dependent on hull form, propeller, etc. The FSICR include the engine power and displacement in the ice pressure calculation such that the pressure is related to the inertia of the vessel.

The main engine configuration is also important to ice performance and to allow good manoeuvrability in ice. CPP propellers, azipod, nozzles and other devices are all common on ice class vessels to achieve better capability in ice. The IACS Polar Rule requirements for propellers are still under development. They are based on finite element analysis of the blade, assuming loads from ice impacts with the propeller.

Other items which should be considered during the design include some of the following:

- Rudder
  Fitting of ice knife for protection when backing in ice.
- Steering gear
  Additional strength of rudder stock and steering gear.
- Sea chests
  Effective methods to prevent ice build up and provide continuous cooling water for main engines.
- De-icing
  Equipment fitted on deck rated for low temperature and icing operations.

Impact of the different ice classes on ship weight

The study presented above on the scantlings of the three different vessels designed in seven different ice classes is now used to determine the weight of the shell structure in each case. As the design cases cover just preliminary design, only the unit weights of the primary shell structure (plating and frames) is calculated. Additionally the weight of the midbody ice belt structure is calculated. This weight includes the weight of plating and main frames, not larger elements like stringers or webframes.

Several assumptions have been necessary in making the calculations. First of all, only the plating and frames have been included in the study of unit weights. This is because the larger structural elements (stringers and web frames) have not been decided at this stage. The corrosion allowance has been chosen as stated in the rules for each ice class. The frame profile has been assumed to be a bulb section even if in most cases the frame requirement is much larger than existing profiles. Also the requirement in the IACS and Russian Register rules is plastic section modulus. Here the relationship between the elastic (Z_e) and plastic (Z_p) section modulus is assumed to be:

$$Z_e = \frac{Z_p}{1.225 + \frac{h}{2000mm}}$$

where *h* is the height of the profile web. The weight of the profile is taken by extrapolating the weight of the smaller sections (using an effective plating of 600x15). The plot is given in Fig. 1. The frame spacing was taken as given for the vessels except that for vessel 1 the transverse frame spacing at the bow was taken as half of the nominal frame spacing i.e. ice frames were assumed to be installed at the bow and bow intermediate areas. The length of the midbody area was assumed to be 55 % of the ship length.

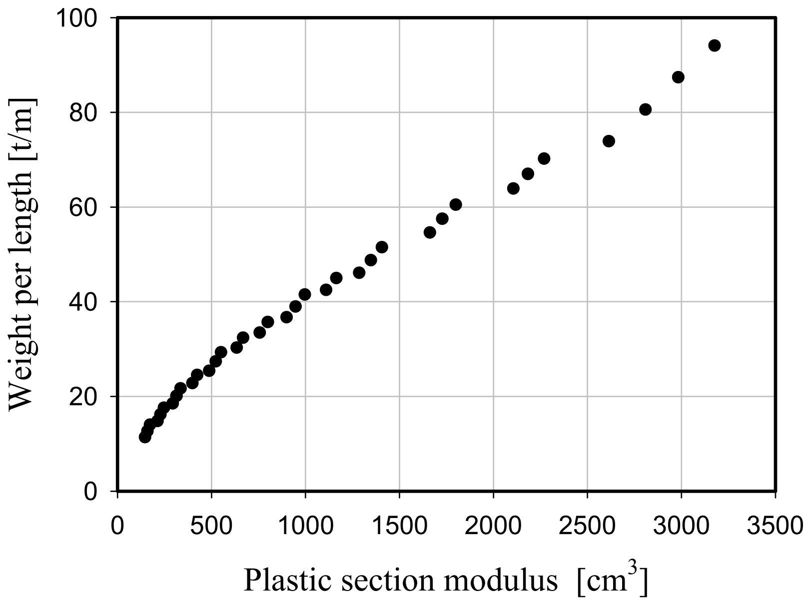


Fig. 1. The unit weight of bulb profiles versus the plastic section modulus assuming an effective plating of 600x15.

Unit weights

The results of the calculations are given in the Tables 1 to 3. These tables are somewhat uninformative as the total weights would be more interesting to compare. Once the values of the surface areas are available for the vessels, these can be calculated quickly.

Table 1. The unit shell structure weights for the vessel 1.

Ice class		IACS Polar Rules				RMRS		
Hull area		**PC3**	**PC4**	**PC5**	**PC6**	**LU6**	**LU5**	**LU4**
Bow	$[t/m^2]$	0.58	0.47	0.41	0.34	0.67	0.50	0.38
Bow Intermediate		0.47	0.39	0.32	0.30	0.47	0.37	0.30
Midship		0.26	0.22	0.19	0.16	0.30	0.23	0.19
Stern		0.33	0.27	0.22	0.17	0.34	0.25	0.19
Midship ice belt weight	t	144	122	93	78	118	91	64

Table 2. The unit shell structure weights for the vessel 2.

Ice class		IACS Polar Rules				RMRS		
Hull area		**PC3**	**PC4**	**PC5**	**PC6**	**LU6**	**LU5**	**LU4**
Bow	$[t/m^2]$	0.85	0.71	0.61	0.51	1.26	0.94	0.75
Bow Intermediate		0.82	0.68	0.58	0.54	1.10	0.79	0.64
Midship		0.51	0.43	0.35	0.27	0.50	0.38	0.31
Stern		0.56	0.46	0.35	0.26	0.50	0.37	0.27
Midship ice belt weight	t	1237	1043	806	622	1134	862	657

Table 3. The unit shell structure weights for the vessel 3.

Ice class		IACS Polar Rules				RMRS		
Hull area		**PC3**	**PC4**	**PC5**	**PC6**	**LU6**	**LU5**	**LU4**
Bow	[t/m^2]	0.80	0.69	0.60	0.50	1.19	0.89	0.72
Bow Intermediate		0.80	0.56	0.49	0.53	1.00	0.76	0.61
Midship		0.60	0.52	0.42	0.32	0.59	0.47	0.36
Stern		0.66	0.55	0.42	0.30	0.59	0.43	0.31
Midship ice belt weight	t	1494	1295	991	756	1460	1162	821

Even despite of the assumptions some conclusions can be made if the values for ice classes PC6 and LU5 are compared. Both these classes should nominally be equivalent to IA Super ice class. From the tables it is clear that the ships designed according to LU5 are heavier than the corresponding PC6 design. The reason for this is the much stronger frames in the LU5 – an effect which is somewhat compensated by more narrow ice belt for smaller vessel in the Russian rules.

The effect of ice class is large. One step towards higher ice class means a hull weight (ice strengthened area) increase of about 30 % in lower ice classes – the step between PC4 and PC3 not being this large. A very rough estimate of the hull weight change induced if the class is changed from PC6 to PC3 is made (this is based on very rough estimates on the LWL, BWL and hull surface areas) gives the results of 110 t, 590 t and 960 t weight increase for vessels 1, 2 and 3, respectively.

Longitudinal strength requirement

The longitudinal strength requirements are analysed next. In the Russain rules there is no longitudinal strength requirements specifically for ice but in the IACS harmonized rules there is. Here a comparison between the IACS shear force and bending moment requirements with the corresponding open water requirements is made, Table 4. The main assumption made in the comparison is that the block coefficient is assumed to be C_B=0.7 and waterplane area coefficient is assumed to be C_{WP}=0.75. The table shows that for larger vessels the open water requirements dominate, only in the case of shear force requirement for the smallest vessel, ice requirement dominates.

Table 4. The rule shear forces and bending moments for the three example vessels.

Hull Bending Moment and Shear Force						
		PC3	**PC4**	**PC5**	**PC6**	**OW**
Vessel 1	Shear Force [MN]	19.3	14.6	10.7	6.6	7.2*
	Bending Moment [MNm]	255	193	132	81	332
Vessel 2	Shear Force [MN]	25.4	16.2	10.8	6.6	29.7*
	Bending Moment [MNm]	639	408	254	155	1648
Vessel 3	Shear Force [MN]	25.4	16.2	10.8	6.6	43.2*
	Bending Moment [MNm]	671	428	266	163	5522
* Estimates						

Conclusion

The IACS Polar Ship Rules have been developed over many years in cooperation with industry, academics and Classification Societies and provide a significant step in the harmonisation of Classification Society requirements. The underlying feature of scenario based pressures provides a flexible approach that can be integrated with other rule sets.

Both the Russian Maritime Register of Shipping ice class rules and the IACS Polar Ship Rules provide a measure of safety for navigation in ice and an equivalency can be made between the two sets of scantlings resulting from each. Although, the principles for design differ, they aim to achieve a sufficient level of protection for navigation in ice.

The comparison made in this report covers the ArcOp scenario, for a specific location and as such the comparison is dependent on ice conditions prevalent. A complete equivalency of rules would require a range of variables covering ship sizes and structural arrangements. Equally it is difficult to fully standardise requirements for large regions due to the varied ice conditions and locations. At these locations specific Administration requirements will prevail. However, a general set of equivalency can be made for the purpose of Administration acceptance of classifications.

Vessels operating in this region will need special consideration with regard to ice class and fitting for operation at low temperatures. The hull form should be suitable for ice breaking and it is also noted that the double acting concept offers a viable alternative to operation in ice conditions. Owner should bear in mind the intended purpose of the vessel in the selection of ice class. The Arctic Russia offers valuable opportunity to develop resources and transportation links, though the design of the vessel should be such as to mitigate the risks to the ship, crew and environment.

References

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