RULES
FOR THE CLASSIFICATION OF SHIPS

Part 29 – POLAR CLASS SHIPS AND ICE CLASS SHIPS

2019

CROATIAN REGISTER OF SHIPPING

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By the decision of the General Committee of Croatian Register of Shipping,

RULES FOR THE CLASSIFICATION OF SHIPS
Part 29 – POLAR CLASS SHIPS AND ICE CLASS SHIPS

have been adopted on 21st December 2018 and shall enter into force on 1st January 2019

REVIEW OF AMENDMENTS IN RELATION TO 2018 EDITION

RULES FOR THE CLASSIFICATION OF SHIPS
PART 29 – POLAR CLASS SHIPS AND ICE CLASS SHIPS

All major changes throughout the text in respect to the 2018 edition are shaded (if any).

The grammatical and print errors, have also been corrected throughout the text of the subject Rules but are not indicated as a correction.

The subject Rules include the requirements of the following international Organisations::

International Maritime Organization (IMO)

Conventions:	International Convention for the Safety of Life at Sea 1974 (SOLAS 1974), Ch. XIV, as adopted by resolution MSC.386(94)
Codes:	International Code for Ships Operating in Polar Waters (Polar Code), as adopted by resolutions MSC.385(94) and MEPC.264(68)
Circulars:	MSC/Circ.504, MSC.1/Circ.1519

International Association of Classification Societies (IACS)

Unified Requirements (UR):	I1 (Rev.2, 2016), I2 (Rev.3, 2016), I3 (Rev.1, Corr.1, 2007), S6 (Rev.9, 2018)
Other requirements	Finnish-Swedish Ice Class Rules, 2017 Guidelines for the Application of the Finnish - Swedish Ice Class Rules, 14 November 2017

Contents

1 GENERAL

1.1 GENERAL REQUIREMENTS

1.1.1 General

Subject *Rules for the classification of ships, Part 29 - Polar class ships and ice class ships* (hereafter referred to as: the Rules) of CROATIAN REGISTER OF SHIPPING (hereafter referred to as: the *Register*) are incorporating the requirements of the IMO Resolution MSC.385(94) ñInternational Code for Ships Operating in Polar Waters (Polar Code)ò as may be amended as well as the *Finnish-Swedish Ice Class Rules* 2017.

1.1.2 Application

1.1.2.1 The requirements in these Rules apply to ships constructed of steel and intended for independent navigation in polar waters or ice-infested waters.

1.1.2.2 The materials, hull structures, equipment, machinery, etc. of ships operating in polar waters as defined in 1.2.1 are to be in accordance with the requirements in Section 1 to Section 7 of these Rules in addition to those in other parts of the Rules for the classification of ships and in addition to the *Rules for technical supervision of sea-going ships, Part 29 - Polar class ships and ice class ships* (guidance for the application of relevant statutory requirements).

1.1.2.3 Where a ship is intended to be registered as an ice class ship for navigation in the Northern Baltic complying with the *Finnish-Swedish Ice Class Rules*, 2017, the materials, hull structures, equipment and machinery of the ship are to be in accordance with the requirements in Section 1 except for 1.4 to 1.7 and Section 8 of these Rules in addition to those in other applicable parts of the Rules of the *Register*.

1.1.3 Equivalency

1.1.3.1 An alternative hull construction, equipment, etc. which does not fall under the provisions of Sections 3, 6 and 7 of these Rules will be accepted by the *Register*, provided that such construction, equipment, etc. is considered to be equivalent to that required by these Rules in accordance with SOLAS Chapter XIV, Regulation 4. See also 3.15 of these Rules.

1.1.3.2 An alternative hull construction, equipment, etc. which does not fall under the provisions of Section 8 of these Rules may be accepted by the *Register*, provided that the *Register* is satisfied that such construction, equipment, etc. is considered to be equivalent to that required by Section 8 of these Rules.

1.2 DEFINITIONS

The definitions of terms which appear in section 2 to 7 of these Rules are to be as specified below. Definitions relevant for Section 7 are contained in that Section.

1.2.1 **Polar waters** is Arctic waters and/or the Antarctic area.

1.2.2 **Antarctic area** is the sea area south of latitude 60º S. (see Fig. 1.2.2).

1.2.3 **Arctic waters** is those waters which are located north of a line from the latitude 58º00 .0 N and longitude 042º00 .0 W to latitude 64º37 .0 N, longitude 035º27 .0 W and thence by a rhumb line to latitude 67º03 .9 N, longitude 026º33 .4 W and thence by a rhumb line to the latitude 70º49 .56 N and longitude 008º59 .61 W (Sørkapp, Jan Mayen) and by the southern shore of Jan Mayen to 73º31'.6 N and 019º01'.0 E by the Island of Bjørnøya, and thence by a great circle line to the latitude 68º38 .29 N and longitude 043º23 .08 E (Cape Kanin Nos) and hence by the northern shore of the Asian Continent eastward to the Bering Strait and thence from the Bering Strait westward to latitude 60º N as far as Il'pyrskiy and following the 60th North parallel eastward as far as and including Etolin Strait and thence by the northern shore of the North American continent as far south as latitude 60º N and thence eastward along parallel of latitude 60º N, to longitude 056º37 .1 W and thence to the latitude 58º00 .0 N, longitude 042º00 .0 W. (see Fig. 1.2.3).

1.2.4 **Category A ship** is a ship designed for operation in polar waters in at least medium first-year ice, which may include old ice inclusions.

1.2.5 **Category B ship** is a ship designed for operation in polar waters in at least thin first-year ice, which may include old ice inclusions.

1.2.6 **Category C ship** is a ship designed to operate in open water or in ice conditions less severe than those included in categories A and B.

1.2.7 **First-year ice** is sea ice of not more than one winter growth developing from young ice with thickness from 0,3 m to 2,0 m.

1.2.8 **Ice free waters** is no ice present. If ice of any kind is present this term is not to be used.

1.2.9 **Ice of land origin** is ice formed on land or in an ice shelf, found floating in water.

1.2.10 **Medium first-year ice** is first-year ice of 70 cm to 120 cm thickness.

1.2.11 **Old ice** is sea ice which has survived at least one summer s melt; typical thickness up to 3 m or more. It is subdivided into residual first-year ice, second-year ice and multi-year ice.

1.2.12 **Open water** is a large area of freely navigable water in which sea ice is present in concentrations less than 1/10. No ice of land origin is present.

1.2.13 **Sea ice** is any form of ice found at sea which has originated from the freezing of sea water.

1.2.14 **Thin first-year ice** is first-year ice 30 cm to 70 cm thick.

1.2.15 **Bergy waters** is an area of freely navigable water in which ice of land origin is present in concentrations less than 1/10. There may be sea ice present, although the total concentration of all ice is not to exceed 1/10.

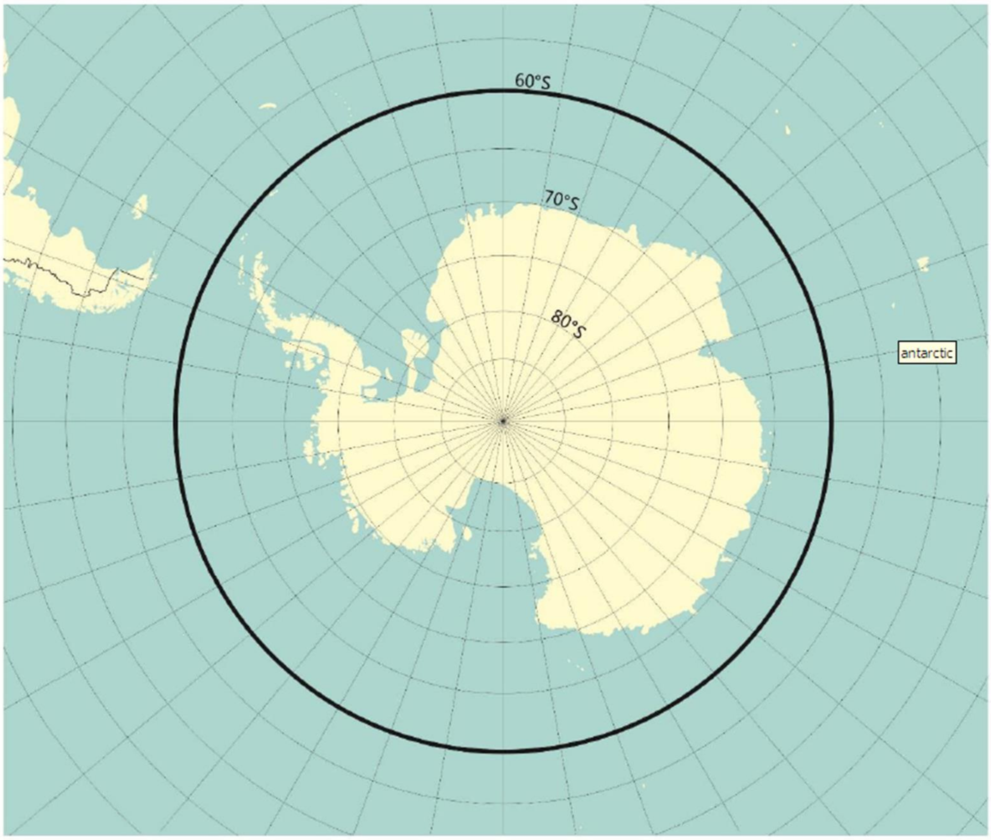


Figure 1.2.2 - Maximum extent of Antarctic area application

Figure 1.2.3 - Maximum extent of Arctic waters application
(for illustrative purpose only)

1.2.16 **Escort ship** is any ship with superior ice capability in transit with another ship.

1.2.17 **Escorted operation** is any operation in which a ship s movement is facilitated through the intervention of an escort.

1.2.18 **Habitable environment** is a ventilated environment that will protect against hypothermia.

1.2.19 **Icebreaker** is any ship whose operational profile may include escort or ice management functions, whose powering and dimensions allow it to undertake aggressive operations in ice-covered waters.

1.2.20 **Maximum expected time of rescue** is the time adopted for the design of equipment and system that provide survival support. It is never to be less than 5 days.

1.2.21 **Machinery installations** are equipment and machinery and its associated piping and cabling, which is necessary for the safe operation of the ship.

1.2.22 **Mean daily low temperature (MDLT)** is the mean value of the daily low temperature for each day of the year over a minimum 10 year period. A data set acceptable to the *Register* may be used if 10 years of data is not available (see Fig. 1.2.22).

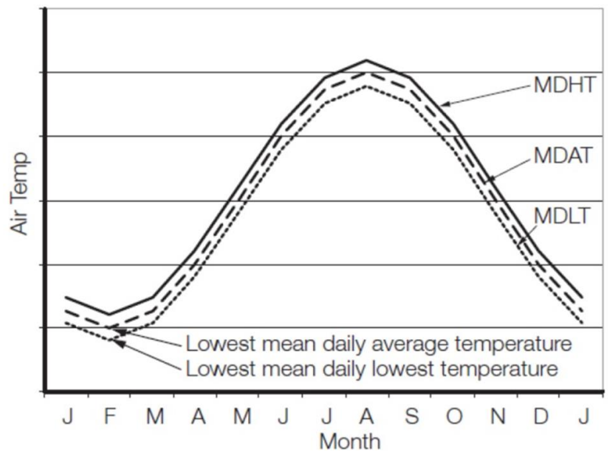


Figure 1.2.22 - Mean daily low temperature (MDLT)

NOTES:

a) Definitions used in the figure above
   MDHT ï Mean daily high temperature
   MDAT ï Mean daily average temperature
   MDLT ï Mean daily low temperature

b) Guidance instructions for determining MDLT:
   - Determine the daily low temperature for each day for a 10 year period.
   - Determine the average of the values over the 10 year period for each day.
   - Plot the daily averages over the year.
   - Take the lowest of the averages for the season of operation.

1.2.23 **Polar service temperature (PST)** is a temperature specified for a ship which is intended to operate in low air temperature, which shall be set at least 10 ^{o}C below the lowest MDLT for the intended area and season of operation in polar waters.

1.2.24 **Ship intended to operate in low air temperature** is a ship which is intended to undertake voyages to or through areas where the lowest mean daily low temperature (MDLT) is below ï 10 ^{o}C.

1.2.25 **Upper ice waterline** is the waterline defined by the maximum draughts forward and aft for operation in ice.

1.2.26 **Tankers** is oil tankers as defined in SOLAS regulation II-1/2.22, chemical tankers as defined in SOLAS regulation II-1/3.19 and gas carriers as defined in SOLAS regulation VII/11.2.

1.3 POLAR CLASS AND ICE CLASS NOTATION ASSIGNMENT

1.3.1 General

The *Register* will assign an appropriate class notation to the ship which meets the requirements of these Rules. In addition to the below stated class notations a descriptive note(s) may be added in Certificate of class.

1.3.2 Polar class assignment

1.3.2.1 General provisions

1.3.2.1.1 The polar class (PC) notations and descriptions are given in Table 1.3.2.1. It is the responsibility of the owner to select an appropriate polar class. The descriptions in Table 1.3.2.1 are intended to guide owners, designers and administrations in selecting an appropriate polar class to match the requirements for the ship with its intended voyage or service.

1.3.2.1.2 If the hull and machinery are constructed such as to comply with the requirements of different polar classes, then both the hull and machinery are to be assigned the lower of these classes in the Certificate of class. Compliance of the hull or machinery with the requirements of a higher polar class is also to be indicated in the Certificate of class as descriptive note.

1.3.2.1.3 For ships which are assigned a polar class notation PC 1 through PC 5, bows with vertical sides, and bulbous bows are generally to be avoided. Bow angles should in general be within the range specified in 3.3.1.5.

1.3.2.1.4 For ships which are assigned a polar class notation PC 6 and PC 7, and are designed with a bow with vertical sides or bulbous bows, operational limitations (restricted from intentional ramming) in design conditions are to be stated in the Certificate of class as descriptive note.

Table 1.3.2.1 - Polar class descriptions

Polar Class	**Ice descriptions (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 multiyear 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

NOTES (based on WMO Sea Ice Nomenclature):

Multi-year ice: old ice which has survived at least two summer' s melt.

Second-year ice: Sea ice which has survived only one summer' s melt.

First-year ice: Sea ice of not more than one winter s growth, developing from young ice.

Thick first-year ice: first-year ice of about 120-250 cm in thickness and which has a high strength. Only when strong pressure is received, this ice forms an ice hill of about 150-250 cm in height.

Medium first-year ice: first-year ice of about 70-120 cm in thickness. In the ice water regions other than Polar Regions, this kind of one-year ice is a limit stage of growth, and it is formed in the severest winter. In this kind of ice, there might be a lot of intersecting ice hills, and the height of the ice hill reaches 170 cm. This kind of ice melts in summer and disappears almost completely.

Thin first-year ice: first-year ice of about 30-70 cm in thickness. In this kind of ice, there might be straight ice hills, and the height of the ice hill reaches 30-75 cm on the average. Thin first-year ice may be subdivided to the thin fires-year in the first stage (30-50 cm in thickness) and second stages (50-70 cm in thickness).

1.3.3 Ice class notation

1.3.3.1 Ice class of the *Register*

The following five classes are comprised with ice class of the *Register*.

It is the responsibility of the owner to determine which class is most suitable for his requirements.

1.3.3.1.1 Ice class 1AS - ships with such structure, engine output and other properties that they are normally capable of navigating in difficult ice conditions without the assistance of icebreakers.

1.3.3.1.2 Ice class 1A - ships with such structure, engine output and other properties that they are capable of navigating in difficult ice conditions, with the assistance of icebreakers when necessary.

1.3.3.1.3 Ice class 1B - ships with such structure, engine output and other properties that they are capable of navigating in moderate ice conditions, with the assistance of icebreakers when necessary.

1.3.3.1.4 Ice class 1C - ships with such structure, engine output and other properties that they are capable of navigating in light ice conditions, with the assistance of icebreakers when necessary.

1.3.3.1.5 Ice class 1D - ships that have a steel hull and that are structurally fit for navigation in the open sea and that, despite not being strengthened for navigation in ice, are capable of navigating in very light ice conditions with their own propulsion machinery.

1.3.4 Equivalence between ice classes

1.3.4.1 The equivalence of ice classes of the *Register* specified in 1.3.3.1 with those in the *Finnish-Swedish Ice Class Rules 2017* is given in Table 1.3.4.1.

Table 1.3.4.1 - The equivalence of ice classes between the Rules and the *Finnish-Swedish Ice Class Rules 2017*

Ice class of the Finnish-Swedish ice class Rules 2017	**Ice class of the *Register***
IA Super	1AS
IA	1A
IB	1B
IC	1C
II	1D No ice class

1.3.4.2 The equivalence of ice classes of the *Register* specified in 1.3.3.1 with those in the *Canadian Arctic Shipping Safety and Pollution Prevention Regulations* is as given in Table 1.3.4.2.

Table 1.3.4.2 - The equivalence of ice classes between the Rules and the *Canadian Arctic Shipping Safety and Pollution Prevention Regulations*

Ice class of the Arctic shipping safety and pollution prevention regulations	**Ice class of the *Register***
Type A	1AS
Type B	1A
Type C	1B
Type D	1C 1D
Type E	No ice class

1.4 SHIPS OPERATING IN LOW AIR TEMPERATURE

1.4.1 Ships that operate in areas and seasons where the lowest MDLT is below ï 10 °C are considered to be operating in low air temperature and PST as defined in 1.2.23 must be specified. Materials, structures, systems and equipment required by Section 2 to Section 7 of these Rules are to be fully functional at the specified PST.

1.4.2 For ships operating in low air temperature, survival systems and equipment required by Section 8 of the *Rules for technical supervision of sea-going ships, Part 29 - Polar class ships and ice class ships* of the *Register* are to be fully operational at the polar service temperature during the maximum expected rescue time.

1.5 SOURCES OF HAZARDS

1.5.1 The provisions of the Section 2 to Section 7 of these Rules and the *Rules for technical supervision of sea-going ships, Part 29 - Polar class ships and ice class ships* considers hazards as specified below which may lead to elevated levels of risk due to increased probability of occurrence, more severe consequences, or both for:

.1 Ice, as it may affect hull structure, stability characteristics, machinery systems, navigation, the outdoor working environment, maintenance and emergency preparedness tasks and malfunction of safety equipment and systems;
.2 experiencing topside icing, with potential reduction of stability and equipment functionality;
.3 low temperature, as it affects the working environment and human performance, maintenance and emergency preparedness tasks, material properties and equipment efficiency, survival time and performance of safety equipment and systems;
.4 extended periods of darkness or daylight as it may affect navigation and human performance;
.5 high latitude, as it affects navigation systems, communication systems and the quality of ice imagery information;
.6 remoteness and possible lack of accurate and complete hydrographic data and information, reduced availability of navigational aids and seamarks with increased potential for groundings compounded by remoteness, limited readily deployable SAR facilities, delays in emergency response and limited communications capability, with the potential to affect incident response;
.7 potential lack of ship crew experience in polar operations, with potential for human error;
.8 potential lack of suitable emergency response equipment, with the potential for limiting the effectiveness of mitigation measures;
.9 rapidly changing and severe weather conditions, with the potential for escalation of incidents;
.10 the environment with respect to sensitivity to harmful substances and other environmental impacts and its need for longer restoration.

1.5.2 The risk level within polar waters may differ depending on the geographical location, time of the year with respect to daylight, ice-coverage, etc. Thus, the mitigating measures required to address the above specific hazards may vary within polar waters and may be different in Arctic and Antarctic waters.

1.6 OPERATIONAL ASSESSMENT

1.6.1 General

In order to establish procedures or operational limitations, an assessment of the ship and its equipment is to be carried out, taking into consideration the following .1 to .3. The *Register* may require submission of data regarding the assessment.

.1 The anticipated range of operating and environmental conditions, such as stated in 1.1 to 1.4 below:
1.1 Operation in low air temperature,
1.2 Operation in ice,
1.3 Operation in high latitude,
1.4 Potential for abandonment onto ice or land.
.2 Hazards, as listed in 1.5, as applicable.
.3 Additional hazards, if identified.

1.6.2 Steps for an operational assessment

The Operational Assessment specified in 1.6.1, is to be carried out by following steps:

.1 identify relevant hazards specified in 1.5.1 and other hazards based on a review of the intended operations;
.2 develop a model, which is to refer to Appendix 3 of MSC-MEPC.2/Circ.12 ñRevised Guidelines for Formal Safety Assessment (FSA) for use in the IMO Rule-Making Processò and standard IEC/ISO 31010 ñRisk management Risk assessment techniquesò, to analyse risks considering:
a) development of accident scenarios;
b) probability of events in each accident scenario; and
c) consequence of end states in each scenario;
.3 assess risks and determine acceptability:
a) estimate risk levels in accordance with the selected modelling approach; and
b) assess whether risk levels are acceptable; and
.4 in the event that risk levels determined in steps .1 to .3 are considered to be too high, identify current or develop new risk control options that aim to achieve one or more of the following:
a) reduce the frequency of failures through better design, procedures, training, etc.;
b) mitigate the effect of failures in order to prevent accidents;
c) limit the circumstances in which failures may occur; or
d) mitigate consequences of accidents; and
e) incorporate risk control options for design, procedures, training and limitations, as applicable.

1.7 POLAR WATER OPERATIONAL MANUAL (PWOM)

1.7.1 Goal

The goal of this head is to provide the owner, operator, master and crew with sufficient information regarding the ship s operational capabilities and limitations in order to support their decision-making process.

1.7.2 Functional requirements

In order to achieve the goal set out in 1.7.1 above, the following functional requirements are embodied in the provisions of this Head.

.1 The Manual is to include information on the ship-specific capabilities and limitations in relation to the assessment required under 1.6.

.2 The Manual is to include or refer to specific procedures to be followed in normal operations and in order to avoid encountering conditions that exceed the ship s capabilities.

.3 The Manual is to include or refer to specific procedures to be followed in the event of incidents in polar waters.

.4 The Manual is to include or refer to specific procedures to be followed in the event that conditions are encountered which exceed the ship s specific capabilities and limitations in .1.

.5 The Manual is to include or refer to procedures to be followed when using icebreaker assistance, as applicable.

1.7.3 Regulations

1.7.3.1 Polar water operational manual

In order to comply with the functional requirements of 1.7.2, the Manual is to be carried on board.

1.7.3.2 Operational assessment

In order to comply with the functional requirements of 1.7.2.1, the Manual is to contain, where applicable, the methodology used to determine capabilities and limitations in ice.

1.7.3.3 Procedures for normal operations

In order to comply with the functional requirements of 1.7.2.2, the Manual is to include risk-based procedures for the following:

.1 voyage planning to avoid ice and/or temperatures that exceed the ship s design capabilities or limitations;

.2 arrangements for receiving forecasts of the environmental conditions;

.3 means of addressing any limitations of the hydrographic, meteorological and navigational information available;

.4 operation of equipment required under other Sections of these Rules and the *Rules for technical supervision of sea-going ships, Part 29 - Polar class ships and ice class ships*; and

.5 implementation of special measures to maintain equipment and system functionality under low temperatures, topside icing and the presence of sea ice, as applicable.

1.7.3.4 Procedures for incidents in polar waters

In order to comply with the functional requirements of 1.7.2.3, the Manual is to include risk-based procedures to be followed for:

.1 contacting emergency response providers for salvage, search and rescue (SAR), spill response, etc., as applicable; and

.2 in the case of ships ice strengthened in accordance with Section 3 of these Rules, procedures for maintaining life support and ship integrity in the event of prolonged entrapment by ice.

1.7.3.5 Procedures for conditions exceeding ship design capabilities and limitations

In order to comply with the functional requirements of 1.7.2.4, the Manual is to include risk-based procedures to be followed for measures to be taken in the event of encountering ice and/or temperatures which exceed the shipǒs design capabilities or limitations.

1.7.3.6 Procedures for icebreaker assistance

In order to comply with the functional requirements of 1.7.2.5, the Manual is to include risk-based procedures for monitoring and maintaining safety during operations in ice, as applicable, including any requirements for escort operations or icebreaker assistance. Different operational limitations may apply depending on whether the ship is operating independently or with icebreaker escort. Where appropriate, the PWOM is to specify both options.

2 MATERIALS AND WELDING

2.1 MATERIALS

2.1.1 Steel grades of plating for hull structures are to be not less than those given in Tables 2.1.1 based on the as-built thickness, the Polar class and the material class of structural members according to 2.1.2.

Table 2.1.1 Material classes for structural members

Structural members	Material class
Shell plating within the bow and bow intermediate icebelt hull areas (B, B_{Ii})	II
All weather and sea exposed SECONDARY and PRIMARY, as defined in Table 1.4.2.3 of the *Rules for the classification of ships, Part 2 - Hull*, structural members outside 0.4L amidships	I
Plating materials for stem and stern frames, rudder horn, rudder, propeller nozzle, shaft brackets, ice skeg, ice knife and other appendages subject to ice impact loads	II
All inboard framing members attached to the weather and sea-exposed plating, including any contiguous inboard member within 600 mm of the plating	I
Weather-exposed plating and attached framing in cargo holds of ships which by nature of their trade have their cargo hold hatches open during cold weather operations	I
All weather and sea exposed SPECIAL, as defined in Table 1.4.2.3 of the *Rules for the classification of ships, Part 2 - Hull*, structural members within 0,2L from FP	II

2.1.2 Material classes specified in Table 1.4.2.3 of the *Rules for the classification of ships, Part 2 - Hull*, are applicable to Polar class ships regardless of the shipôs length. In addition, material classes for weather and sea exposed structural members and for members attached to the weather and sea exposed plating are given in Table 2.1.1. Where the material classes in Table 2.1.1 and those in Table 1.4.2.3 of the *Rules for the classification of ships, Part 2 - Hull* differ, the higher material class is to be applied.

2.1.3 Steel grades for all plating and attached framing of hull structures and appendages situated below the level of 0,3 m below the lower waterline, as shown in Fig. 2.1.3, are to be obtained from Table 1.4.2.7 and Table 1.4.2.1 of the *Rules for the classification of ships, Part 2 - Hull* based on the material class for structural members in Table 2.1.1, regardless of Polar class.

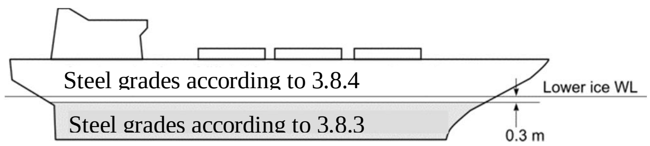


Figure 2.1.3 - Steel grade requirements for submerged and weather exposed shell plating

2.1.4 Steel grades for all weather exposed plating of hull structures and appendages situated above the level of 0,3 m below the lower ice waterline, as shown in Fig. 2.1.3 are to be not less than given in Table 2.1.4.

2.1.5 Castings are to have specified properties consistent with the expected service temperature for the cast component.

2.2 WELDING

2.2.1 All welding within ice-strengthened areas is to be of the double continuous type.

2.2.2 Continuity of strength is to be ensured at all structural connections.

Table 2.1.4 - Steel grades for weather exposed plating

Thickness, t [mm]	Material class I				Material class II				Material class III					
	PC1-5		PC6&7		PC1-5		PC6&7		PC1-3		PC4&5		PC6&7	
	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT
t ≤ 10	B	AH	B	AH	B	AH	B	AH	E	EH	E	EH	B	AH
10 < t ≤ 15	B	AH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
15 < t ≤ 20	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
20 < t ≤ 25	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
25 < t ≤ 30	D	DH	B	AH	E	EH2	D	DH	E	EH	E	EH	E	EH
30 < t ≤ 35	D	DH	B	AH	E	EH	D	DH	E	EH	E	EH	E	EH
35 < t ≤ 40	D	DH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
40 < t ≤ 45	E	EH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
45 < t ≤ 50	E	EH	D	DH	E	EH	D	DH	F	FH	F	FH	E	EH

Notes to Table 2.1.4:
1) Includes weather-exposed plating of hull structures and appendages, as well as their outboard framing members, situated above a level of 0,3 m below the lowest ice waterline.
2) Grades D, DH are allowed for a single strake of side shell plating not more than 1,8 m wide from 0,3 m below the lowest ice waterline.

3 SHIP STRUCTURE AND HULL EQUIPMENT

3.1 GENERAL

3.1.1 Goal

The goal of this Section is to provide that the material and scantlings of the structure retain their structural integrity based on global and local response due to environmental loads and conditions.

3.1.2 General requirements

In order to achieve the goal set out in 3.1.1 above, the following functional requirements are embodied in the regulations of this Section:

.1 for ships intended to operate in low air temperature, materials used are to be suitable for operation at the ships polar service temperature; and

.2 in ice strengthened ships, the structure of the ship is to be designed to resist both global and local structural loads anticipated under the foreseen ice conditions.

3.1.3 Materials of structures

In order to comply with the functional requirements of 3.1.2 above, materials of exposed structures in ships are to be approved by the *Register* taking into account provisions of Section 2 of these Rules or other standards offering an equivalent level of safety based on the polar service temperature.

3.1.4 Hull structures

In order to comply with the functional requirements of 3.1.2 above, the following apply:

3.1.4.1 Scantlings of category A ships are to comply with the following .1 or .2 below.

.1 The scantlings are to comply with the requirements regarding to hull structures for any Polar class PC1 to PC5 and be approved by the *Register*.

.2 The scantlings are to comply with other standards offering an equivalent level of safety and be approved by the *Register*.

3.1.4.2 Scantlings of category B ships are to comply with the following .1 or .2 below.

.1 The scantlings are to comply with the requirements regarding to hull structures for Polar class PC6 or PC7 and be approved by the *Register*.

.2 The scantlings are to comply with other standards offering an equivalent level of safety and be approved by the *Register*.

3.1.4.3 The scantlings of ice strengthened category C ships are to be approved by the *Register*, taking into account acceptable standards adequate for the ice types and concentrations encountered in the area of operation; and

3.1.4.4 A category C ship need not be ice strengthened if, in the opinion of the *Register*, the ship s structure is adequate for its intended operation.

3.1.5 Equivalent standards

For the purpose of 3.1.3, 3.1.4.1.2 and 3.1.4.2.2 above, ñother standards offering an equivalent level of safetyò are to comply with the Section 2.1 of these Rules.

3.1.6 Upper and lower ice waterlines

3.1.6.1 The upper and lower ice waterlines upon which the design of the ship has been based is to be indicated in the Certificate of classification. The upper ice waterline (UIWL) is to be defined by the maximum draughts fore, amidships and aft. The lower ice waterline (LIWL) is to be defined by the minimum draughts fore, amidships and aft.

3.1.6.2 The lower ice waterline is to be determined with due regard to the shipôs ice-going capability in the ballast loading conditions. The propeller is to be fully submerged at the lower ice waterline.

3.2 HULL AREAS

3.2.1 Load on weather deck

3.2.1.1 The hull of Polar class ships is divided into areas reflecting the magnitude of the loads that are expected to act upon them. In the longitudinal direction, there are four regions: Bow, Bow intermediate, Midbody and Stern. The Bow intermediate, Midbody and Stern regions are further divided in the vertical direction into the Bottom, Lower and Icebelt regions. The extent of each hull area is illustrated in Fig. 3.2.1.1.

3.2.1.2 The upper ice waterline (UIWL) and lower ice waterline (LIWL) are as defined in 3.1.6.

3.2.1.3 Fig. 3.2.1.1 notwithstanding, at no time is the boundary between the Bow and Bow intermediate regions to be forward of the intersection point of the line of the stem and the ship baseline.

3.2.1.4 Fig. 3.2.1.1 notwithstanding, the aft boundary of the Bow region need not be more than 0,45 L aft of the forward perpendicular (FP).

3.2.1.5 The boundary between the bottom and lower regions is to be taken at the point where the shell is inclined 7° from horizontal.

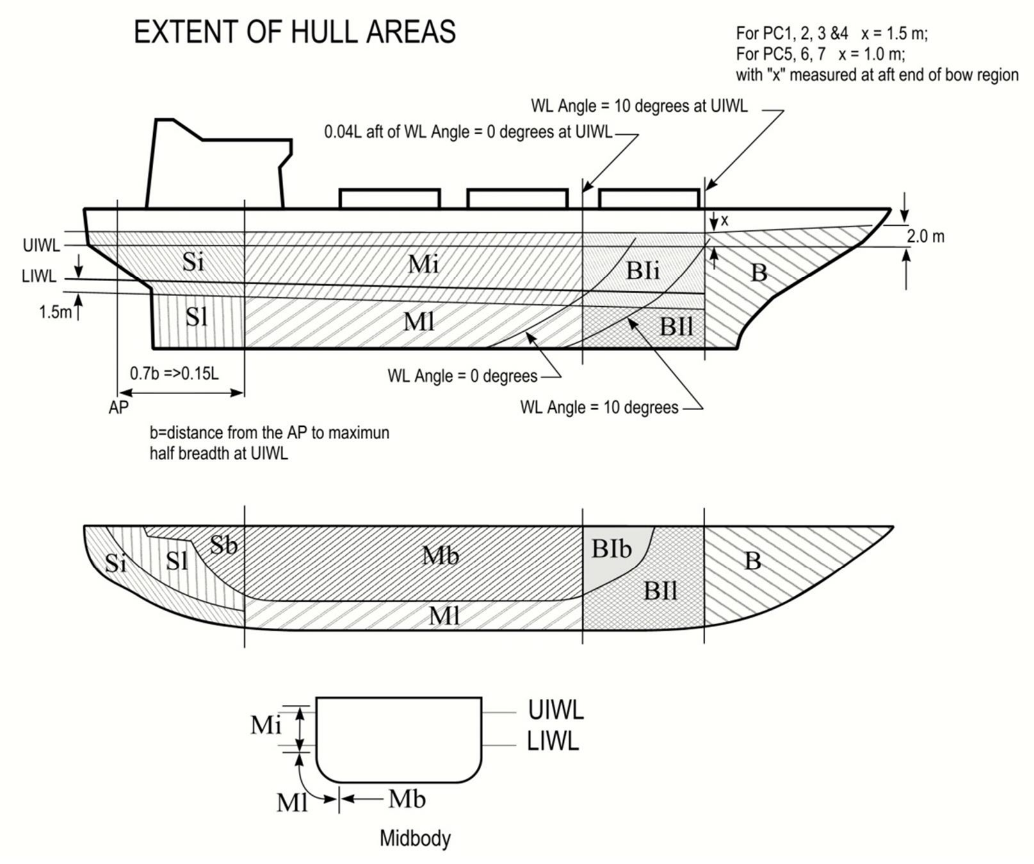


Figure 3.2.1.1 Hull area extents

3.2.1.6 If a ship is intended to operate astern in ice regions, the aft section of the ship is to be designed using the Bow and Bow Intermediate hull area requirements.

3.2.1.7 Fig. 3.2.1.1 notwithstanding, if the ship is assigned the additional notation ñIcebreakerò, the forward boundary of the stern region is to be at least 0,04 *L* forward of the section where the parallel ship side at the upper ice waterline (UIWL) ends.

3.3 DESIGN ICE LOADS

3.3.1 General

3.3.1.1 A glancing impact on the bow is the design scenario for determining the scantlings required to resist ice loads.

3.3.1.2 The design ice load is characterized by an average pressure (P_{avg}) uniformly distributed over a rectangular load patch of height (b) and width (w).

3.3.1.3 Within the Bow area of all Polar class ships, and within the Bow intermediate icebelt area of Polar class PC6 and PC7, the ice load parameters are functions of the actual bow shape. To determine the ice load parameters (P_{avg}, b and w), it is required to calculate the following ice load characteristics for sub-regions of the bow area; shape coefficient (fa_i), total glancing impact force (F_i), line load (Q_i) and pressure (P_i).

3.3.1.4 In other ice-strengthened areas, the ice load parameters (P_{avg}, b_{NonBow} and w_{NonBow}) are determined independently of the hull shape and based on a fixed load patch aspect ratio, AR = 3.6.

3.3.1.5 Design ice forces calculated according to 3.3.2.1.3 are applicable for bow forms where the buttock angle γ at the stem is positive and less than 80º, and the normal frame angle β' at the centre of the foremost sub-region, as defined in 3.3.2.1.1, is greater than 10º.

3.3.1.6 Design ice forces calculated according to 3.3.2.1.4 are applicable for ships which are assigned the Polar class PC6 or PC7 and have a bow form with vertical sides. This includes bows where the normal frame angles β' at the considered sub-regions, as defined in 3.3.2.1.1, are between 0 and 10º.

3.3.1.7 For ships which are assigned the Polar class PC6 or PC7, and equipped with bulbous bows, the design ice forces on the bow are to be determined according to 3.3.2.1.4. In addition, the design forces are not to be taken less than those given in 3.3.2.1.3, assuming fa = 0,6 and AR = 1.3.

3.3.1.8 For ships with bow forms other than those defined in 3.3.2.1.5 to 3.3.2.1.7, design forces are to be specially considered by the *Register*.

3.3.1.9 Ship structures that are not directly subjected to ice loads may still experience inertial loads of stowed cargo and equipment resulting from ship/ice interaction. These inertial loads, based on accelerations determined by the *Register*, are to be considered in the design of these structures.

3.3.2 Glancing impact load characteristics

The parameters defining the glancing impact load characteristics are reflected in the class factors listed in Table 3.3.2-1 and Table 3.3.2-2.

Table 3.3.2-1 - Class factors to be used in 3.3.2.1.3

Polar class	Crushing failure class factor (CF_C)	Flexural failure class factor (CF_F)	Load patch dimensions class factor (CF_D)	Displacement class factor (CF_{DIS})	Longitudinal strength class factor (CF_L)
PC1	17.69	68.60	2.01	250	7.46
PC2	9.89	46.80	1.75	210	5.46
PC3	6.06	21.17	1.53	180	4.17
PC4	4.50	13.48	1.42	130	3.15
PC5	3.10	9.00	1.31	70	2.50
PC6	2.40	5.49	1.17	40	2.37
PC7	1.80	4.06	1.11	22	1.81

Table 3.3.2-2 - Class factors to be used in 3.3.2.1.4

Polar class	Crushing failure class factor (CF_{CV})	Line load class factor (CF_{QV})	Pressure class factor (CF_{PV})
PC6	3.43	2.82	0.65
PC7	2.60	2.33	0.65

3.3.2.1 Bow area

3.3.2.1.1 In the Bow area, the force (F), line load (Q), pressure (P) and load patch aspect ratio (AR) associated with the glancing impact load scenario are functions of the hull angles measured at the upper ice waterline (UIWL). The influence of the hull angles is captured through calculation of a bow shape coefficient (fa). The hull angles are defined in Fig. 3.3.2.1.1

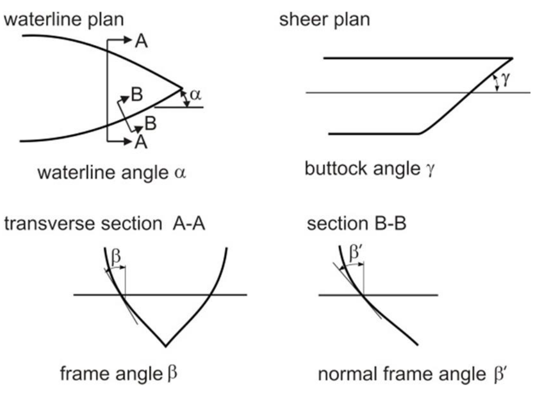


Figure 3.3.2.1.1 - Definition of hull angles

NOTES:

β' = normal frame angle at upper ice waterline, [°]
α = upper ice waterline angle, [°]
γ = buttock angle at upper ice waterline (angle of buttock line measured from horizontal), [°]
$\tan(\beta) = \tan(\alpha)/\tan(\gamma)$
$\tan(\beta') = \tan(\beta)\cdot\cos(\alpha)$

3.3.2.1.2 The waterline length of the bow region is generally to be divided into 4 sub-regions of equal length. The force (F), line load (Q), pressure (P) and load patch aspect ratio (AR) are to be calculated with respect to the mid-length position of each sub-region (each maximum of F, Q and P is to be used in the calculation of the ice load parameters P_{avg}, b and w).

3.3.2.1.3 The Bow area load characteristics for bow forms defined in 3.3.1.5 are determined as follows:

(a) Shape coefficient, fa_i, is to be taken as

$$fa_i = \text{minimum}\ (fa_{i,1}\ ;fa_{i,2}\ ;fa_{i,3})$$

where:

$$fa_{i,1} = (0.097 - 0.68\,(x/L - 0.15)^2)\cdot \alpha_i / (\beta'_i)^{0.5}$$

$$fa_{i,2} = 1.2\cdot CF_F / (\sin(\beta'_i)\cdot CF_C\cdot \Delta^{0.64})$$

$$fa_{i,3} = 0.60$$

(b) Force, F_i:

$$F_i = fa_i\cdot CF_C\cdot \Delta^{0.64}\ \text{, [MN]}$$

(c) Load patch aspect ratio, AR_i:

$$AR_i = 7.46\cdot \sin(\beta'_i) \geq 1.3$$

(d) Line load, Q_i:

$$Q_i = F_i^{\ 0.61}\cdot CF_D / AR_i^{0.35}\ \text{, [MN/m]}$$

(e) Pressure, P_i:

$$P_i = F_i^{0.22}\cdot CF_D^{\ 2}\cdot AR_i^{0.3}\ \text{, [MPa]}$$

where:

i = sub-region considered;
L = ship length as defined in the *Rules for the classification of ships, Part 2 - Hull,*

1.2.3.1, but measured on the upper ice waterline (UIWL), [m];

x = distance from the forward perpendicular (FP) to station under consideration, [m];

α = waterline angle, [º], see Fig. 3.3.2.1.1;

β' = normal frame angle, [º], see Fig. 3.3.2.1.1;

Δ = ship displacement, [kt], not to be taken less than 5 kt;

CF_C = crushing failure class factor from Table 3.3.2-1;

CF_F = flexural failure class factor from Table 3.3.2-1;

CF_D = load patch dimensions class factor from Table 3.3.2-1.

3.3.2.1.4 The Bow area load characteristics for bow forms defined in 3.3.1.6 are determined as follows:

(a) Shape coefficient, fa_i, is to be taken as

$fa_i = \alpha_i / 30$

(b) Force, F:

$F_i = fa_i \cdot CF_{CV} \cdot \Delta^{0.47}$, [MN]

(c) Line load, Q:

$Q_i = F_i^{\ 0.22} \cdot CF_{QV}$, [MN/m]

(d) Pressure, P:

$P_i = F^{0.56} \cdot CF_{PV}$, [MPa]

where

i = sub-region considered

α = waterline angle [º], see Fig. 3.3.2.1.1;

Δ = ship displacement, [kt], not to be taken less than 5 kt;

CF_{CV} = crushing failure class factor from Table 3.3.2-2;

CF_{QV} = line load class factor from Table 3.3.2-2;

CF_{PV} = pressure class factor from Table 3.3.2-2.

3.3.2.2 Hull areas other than the bow

3.3.2.2.1 In the hull areas other than the bow, the force (F_{NonBow}) and line load (Q_{NonBow}) used in the determination of the load patch dimensions (b_{NonBow}, w_{NonBow}) and design pressure (P_{avg}) are determined as follows:

(a) Force, F_{NonBow}:

$$F_{NonBow} = 0.36 \cdot CF_C \cdot DF \text{ , [MN]}$$

(b) Line Load, Q_{NonBow}:

$$Q_{NonBow} = 0.639 \cdot F_{NonBow}^{\ 0.61} \cdot CF_D \text{ , [MN/m]}$$

where:

CF_C = crushing force class factor from Table 3.3.2-1;

DF = ship displacement factor

= $\Delta^{0.64}$, if $\Delta \le CF_{DIS}$

= $CF_{DIS}^{0.64} + 0.10 \cdot (\Delta - CF_{DIS})$, if $\Delta > CF_{DIS}$

Δ = ship displacement, [kt], not to be taken less than 10 kt;

CF_{DIS} = displacement class factor from Table 3.3.2-1;

CF_D = load patch dimensions class factor from 3.3.2-1.

3.3.3 Design load patch

3.3.3.1 In the Bow area, and the Bow intermediate icebelt area for ships with class notation PC6 and PC7, the design load patch has dimensions of width, w_{Bow}, and height, b_{Bow}, defined as follows:

$$w_{Bow} = F_{Bow} / Q_{Bow} \text{ [m]}$$

$$b_{Bow} = Q_{Bow} / P_{Bow} \text{ [m]}$$

where:

F_{Bow} = maximum F_i in the Bow area, [MN];
Q_{Bow} = maximum Q_i in the Bow area, [MN/m];
P_{Bow} = maximum P_i in the Bow area, [MPa].

3.3.3.2 In hull areas other than those covered by 3.3.3.1, the design load patch has dimensions of width, w_{NonBow}, and height, b_{NonBow}, defined as follows:

$$w_{NonBow} = F_{NonBow} / Q_{NonBow} \text{ , [m]}$$

$$b_{NonBow} = w_{NonBow} / 3.6 \text{ , [m]}$$

where:

F_{NonBow} = force as defined in 3.3.2.1 (a), [MN],

Q_{NonBow} = line load as defined in 3.3.2.1 (b), [MN/m].

3.3.4 Pressure within the design load patch

3.3.4.1 The average pressure, P_{avg}, within a design load patch is determined as follows:

$$P_{avg} = F / (b \cdot w) \text{, [MPa]}$$

where:

F = F_{Bow} or F_{NonBow} as appropriate for the hull area under consideration, [MN],

b = b_{Bow} or b_{NonBow} as appropriate for the hull area under consideration, [m],

w = w_{Bow} or w_{NonBow} as appropriate for the hull area under consideration, [m].

3.3.4.2 Areas of higher, concentrated pressure exist within the load patch. In general, smaller areas have higher local pressures. Accordingly, the peak pressure factors listed in Table 3.3.4.2 are used to account for the pressure concentration on localized structural members.

Table 3.3.4.2 - Peak pressure factors

Structural member		**Peak pressure factor (PPF_i)**
Plating	Transversely-framed	$PPF_p = (1.8 - s) \geq 1.2$
	Longitudinally-framed	$PPF_p = (2.2 - 1.2 \cdot s) \geq 1.5$
Frames in transverse framing systems	With load distributing stringers	$PPF_t = (1.6 - s) \geq 1.0$
	With no load distributing stringers	$PPF_t = (1.8 - s) \geq 1.2$
Frames in bottom structures		$PPF_s = 1.0$
Load carrying stringers Side longitudinals Web frames		$PPF_s = 1.0$, if $S_w \geq 0.5 \cdot w$ $PPF_s = 2.0 - 2.0 \cdot S_w / w$, if $S_w < (0.5 \cdot w)$
where: s = frame or longitudinal spacing, [m] S_w = web frame spacing, [m] w = ice load patch width, [m]		

3.3.5 Hull area factors

3.3.5.1 Associated with each hull area is an area factor that reflects the relative magnitude of the load expected in that area. The area factor (*AF*) for each hull area is listed in Table 3.3.5-1.

3.3.5.2 In the event that a structural member spans across the boundary of a hull area, the largest hull area factor is to be used in the scantling determination of the member.

3.3.5.3 Due to their increased manoeuvrability, ships having propulsion arrangements with azimuth thruster(s) or "podded" propellers are to have specially considered Stern icebelt (S_i) and Stern lower (S_l) hull area factors.

3.3.5.4 For ships assigned the additional notation "Ice-breaker", the area factor (*AF*) for each hull area is listed in Table 3.3.5-2.

Table 3.3.5-1 - Hull area factors (*AF*)

Hull area		**Area**	**Polar class**						
			PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**
Bow (B)	All	B	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bow intermediate (BI)	Icebelt	BI_i	0.90	0.85	0.85	0.80	0.80	1.00*	1.00*
	Lower	BI_l	0.70	0.65	0.65	0.60	0.55	0.55	0.50
	Bottom	BI_b	0.55	0.50	0.45	0.40	0.35	0.30	0.25
Midbody (M)	Icebelt	M_i	0.70	0.65	0.55	0.55	0.50	0.45	0.45
	Lower	M_l	0.50	0.45	0.40	0.35	0.30	0.25	0.25
	Bottom	M_b	0.30	0.30	0.25	**	**	**	**
Stern (S)	Icebelt	S_i	0.75	0.70	0.65	0.60	0.50	0.40	0.35
	Lower	S_l	0.45	0.40	0.35	0.30	0.25	0.25	0.25
	Bottom	S_b	0.35	0.30	0.30	0.25	0.15	**	**

Note to Table 3.3.5-1:* See 3.1.3.
** Indicates that strengthening for ice loads is not necessary.

Table 3.3.5-2 - Hull area factors (*AF*) for ships with additional notation "Icebreaker"

Hull area		**Area**	**Polar class**						
			PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**
Bow (B)	All	B	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bow intermediate (BI)	Icebelt	BI_i	0.90	0.85	0.85	0.85	0.85	1.00	1.00
	Lower	BI_l	0.70	0.65	0.65	0.65	0.65	0.65	0.65
	Bottom	BI_b	0.55	0.50	0.45	0.45	0.45	0.45	0.45
Midbody (M)	Icebelt	M_i	0.70	0.65	0.55	0.55	0.55	0.55	0.55
	Lower	M_l	0.50	0.45	0.40	0.40	0.40	0.40	0.40
	Bottom	M_b	0.30	0.30	0.25	0.25	0.25	0.25	0.25
Stern (S)	Icebelt	S_i	0.95	0.90	0.80	0.80	0.80	0.80	0.80
	Lower	S_l	0.55	0.50	0.45	0.45	0.45	0.45	0.45
	Bottom	S_b	0.35	0.30	0.30	0.30	0.30	0.30	0.30

3.4 SHELL PLATE REQUIREMENTS

3.4.1 The required minimum shell plate thickness, t, is given by:

$$t = t_{net} + t_s, \text{ [mm]}$$

where:

t_{net} = plate thickness required to resist ice loads according to 3.4.2, [mm]

t_s = corrosion and abrasion allowance according to 3.7, [mm].

3.4.2 The thickness of shell plating required to resist the design ice load, t_{net}, depends on the orientation of the framing.

In the case of transversely-framed plating ($\Omega \geq$ 70º), including all bottom plating, i.e. plating in hull areas B_{Ib}, M_b and S_b, the net thickness is given by:

$$t_{net} = 500 \cdot s \cdot ((AF \cdot PPF_p \cdot P_{avg}) / R_{eH})^{0.5} / (1 + s / (2 \cdot b)), \text{ [mm]}$$

In the case of longitudinally-framed plating ($\Omega \leq 20$º), when $b \geq s$, the net thickness is given by:

$$t_{net} = 500 \cdot s \cdot ((AF \cdot PPF_p \cdot P_{avg}) / R_{eH})^{0.5} / (1 + s / (2 \cdot l)), \text{ [mm]}$$

In the case of longitudinally-framed plating ($\Omega \leq 20$º), when $b < s$, the net thickness is given by:

$$t_{net} = 500 \cdot s \cdot ((AF \cdot PPF_p \cdot P_{avg}) / R_{eH})^{0.5} \cdot (2 \cdot b/s - (b/s)^2)^{0.5} / (1 + s/(2 \cdot l)), \text{ [mm]}$$

In the case of obliquely-framed plating (70º > Ω > 20º), linear interpolation is to be used.

where:

Ω = smallest angle between the chord of the waterline and the line of the first level framing as illustrated in Fig. 3.4.2, [º].

s = transverse frame spacing in transversely-framed ships or longitudinal frame spacing in longitudinally-framed ships, [m].

AF = hull area factor from Table 3.3.5-1 or Table 3.3.5-2.

PPF_p = peak pressure factor from Table 3.3.4.2.

P_{avg} = average patch pressure as defined in 3.3.4, [MPa].

R_{eH} = minimum upper yield stress of the material, [N/mm²].

B = height of design load patch, [m], where b is to be taken not greater than ($l - s/4$) in the case of determination of the net thickness for transversely framed plating.

l = distance between frame supports, i.e. equal to the frame span as given in 3.5.5, but not reduced for any fitted end brackets, [m]. When a load-distributing stringer is fitted, the length l need not be taken larger than the distance from the stringer to the most distant frame support.

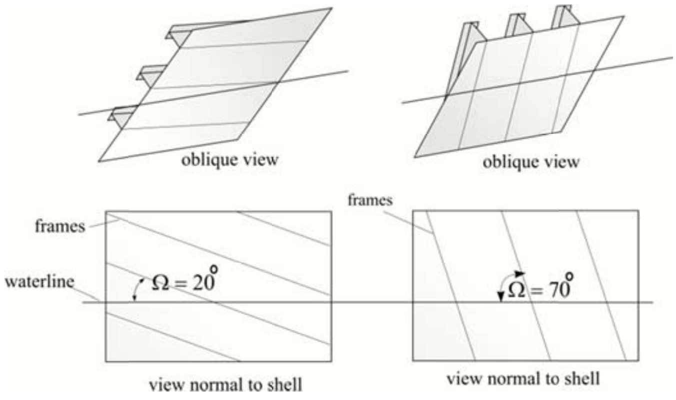


Figure 3.4.2 - Shell framing angle Ω

3.5 FRAMING

3.5.1 General

3.5.1.1 Framing members of Polar class ships are to be designed to withstand the ice loads defined in 3.3.

3.5.1.2 The term “framing member” refers to transverse and longitudinal local frames, load-carrying stringers and web frames in the areas of the hull exposed to ice pressure, see Fig. 3.2.1.1. Where load-distributing stringers have been fitted, the arrangement and scantlings of these are to be in accordance with the requirements of the *Register*.

3.5.1.3 The strength of a framing member is dependent upon the fixity that is provided at its supports. Fixity can be assumed where framing members are either continuous through the support or attached to a supporting section with a connection bracket. In other cases, simple support is to be assumed unless the connection can be demonstrated to provide significant rotational restraint. Fixity is to be ensured at the support of any framing which terminates within an ice-strengthened area.

3.5.1.4 The details of framing member intersection with other framing members, including plated structures, as well as the details for securing the ends of framing members at supporting sections, are to be in accordance with the requirements of the *Register*.

3.5.1.5 The effective span of a framing member is to be determined on the basis of its moulded length. If brackets are fitted, the effective span may be reduced in accordance with the usual practice of the *Register*. Brackets are to be configured to ensure stability in the elastic and post-yield response regions.

3.5.1.6 When calculating the section modulus and shear area of a framing member, net thickness of the web, flange (if fitted) and attached shell plating are to be used. The shear area of a framing member may include that material contained over the full depth of the member, i.e. web area including portion of flange, if fitted, but excluding attached shell plating.

3.5.1.7 The actual net effective shear area, A_w, of a transverse or longitudinal local frame is given by:

$$A_W = h \cdot t_{wn} \cdot \sin \varphi_W / 100 \text{ , [cm}^2\text{]}$$

where:

- h = height of stiffener, [mm], see Fig. 3.5.1.7;
- t_{wn} = net web thickness, [mm];
  = $t_w - t_c$
- t_w = as built web thickness, [mm], see Fig. 3.5.1.7;
- t_c = corrosion deduction, [mm], to be subtracted from the web and flange thickness (as specified by the *Register*, but not less than t_s as required by 3.7.3;
- φ_w = smallest angle between shell plate and stiffener web, measured at the midspan of the stiffener, see Fig. 3.5.1.7. The angle φ_w may be taken as 90° provided the smallest angle is not less than 75°.

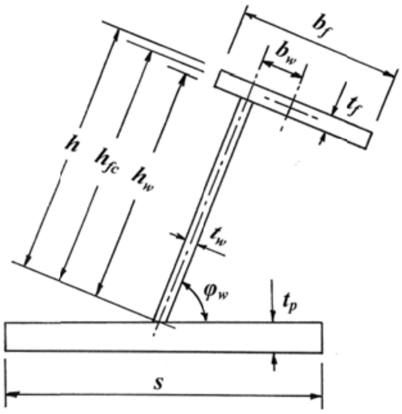


Figure 3.5.1.7 - Stiffener geometry

3.5.1.8 When the cross-sectional area of the attached plate flange exceeds the cross-sectional area of the local frame, the actual net effective plastic section modulus, Z_p, in [cm^3], of a transverse or longitudinal frame is given by:

$$Z_p = A_{pn} \cdot t_{pn}/20 + \frac{h_w^2 \cdot t_{wn} \cdot \sin\varphi_w}{2000} + A_{fn} \cdot \left(h_{fc} \cdot \sin\varphi_w - b_w \cdot \cos\varphi_w\right)/10$$

where:

- h, t_{wn}, t_c, and φ_w as given in 3.5.1.7 and s as given in 3.4.2.
- A_{pn} = net cross-sectional area of the local frame, [cm^2];
- t_{pn} = fitted net shell plate thickness, [mm], (complying with t_{net} as required by 3.4.2);
- h_w = height of local frame web, [mm], see Fig. 3.5.1.7;
- A_{fn} = net cross-sectional area of local frame flange, [cm^2];
- h_{fc} = height of local frame measured to centre of the flange area, [mm], see Fig. 3.5.1.7;
- b_w = distance from mid thickness plane of local frame web to the centre of the flange area, [mm], see Fig. 3.5.1.7.

When the cross-sectional area of the local frame exceeds the cross-sectional area of the attached plate flange, the plastic neutral axis is located a distance z_{na} above the attached shell plate, given by:

$$z_{na} = \left(100 \cdot A_{fn} + h_w \cdot t_{wn} - 1000 \cdot t_{pn} \cdot s\right) / \left(2 \cdot t_{wn}\right) \text{, [mm]}$$

and the net effective plastic section modulus, Z_p, in [cm^3], of a transverse or longitudinal frame is given by:

$$Z_p = t_{pn} \cdot s \cdot \left(z_{na} + t_{pn}/2\right) \cdot \sin\varphi_w + \left(\begin{array}{l} \frac{\left((h_w - z_{na})^2 + z_{na}^2\right) \cdot t_{wn} \cdot \sin\varphi_w}{2000} \\ + A_{fn} \cdot \left((h_{fc} - z_{na}) \cdot \sin\varphi_w - b_w \cdot \cos\varphi_w\right)/10 \end{array}\right)$$

3.5.1.9 In the case of oblique framing arrangement (70° > Ω > 20°, where Ω is defined as given in 3.4.2), linear interpolation is to be used.

3.5.2 Local frames in bottom structures and transverse local frames in side structures

3.5.2.1 The local frames in bottom structures (i.e. hull areas B_{Ib}, M_b and S_b) and transverse local frames in side structures are to be dimensioned such that the combined effects of shear and bending do not exceed the plastic strength of the member. The plastic strength is defined by the magnitude of midspan load that causes the development of a plastic collapse mechanism. For bottom structures the patch load shall be applied with the dimension (b) parallel with the frame direction.

3.5.2.2 The actual net effective shear area of the frame, A_w, as defined in 3.5.1.7, is to comply with the following condition: $A_w \geq A_t$, where:

$$A_t = 100^2 \cdot 0.5 \cdot LL \cdot s \cdot (AF \cdot PPF \cdot P_{avg})/(0.577 \cdot R_{eH}) \text{, [cm}^2\text{]}$$

where:

- LL = length of loaded portion of span,
  = lesser of a and b, [m],
- a = local frame span as defined in 3.5.1.5, [m],
- b = height of design ice load patch as defined in 3.3.3.1 or 3.3.3.2, [m],
- s = spacing of local frame, [m],
- AF = hull area factor from Table 3.3.5-1 or 3.3.5-2,
- PPF = peak pressure factor, PPF_t or PPF_s as appropriate from Table 3.3.4.2,
- P_{avg} = average pressure within load patch as defined in 3.3.4, [MPa],
- R_{eH} = minimum upper yield stress of the material, [N/mm^2].

3.5.2.3 The actual net effective plastic section modulus of the plate/stiffener combination, Z_p, as defined in 3.5.1.8, is to comply with the following condition: $Z_p \geq Z_{pt}$, where Z_{pt} is to be the greater calculated on the basis of two load conditions: a) ice load acting at the midspan of the local frame, and b) the ice load acting near a support. The A_1 parameter defined below reflects these two conditions:

$Z_{pt} = 100^3 \cdot LL \cdot Y \cdot s \cdot (AF \cdot PPF \cdot P_{avg}) \cdot a \cdot A_1 / (4 \cdot R_{eH})$, [cm^3]

where:

AF, *PPF*, P_{avg}, *LL*, *b*, *s*, *a* and *ReH* are as given in 3.5.2.2,

Y = $1 - 0.5 \cdot (LL / a)$,

A_1 = maximum of A_{1A} and A_{1B},

A_{1A} = $1 / (1 + j / 2 + k_w \cdot j / 2 \cdot [(1 - a_1^2)^{0.5} - 1])$,

A_{1B} = $(1 - 1 / (2 \cdot a_1 \cdot Y)) / (0.275 + 1.44 \cdot k_z^{0.7})$,

j = 1 for a local frame with one simple support outside the ice-strengthened areas,
= 2 for a local frame without any simple supports,

a_1 = A_t / A_w,

A_t = minimum shear area of the local frame as given in 3.5.2.2, [cm^2],

A_w = effective net shear area of the local frame (calculated according to 3.5.1.7), [cm^2],

k_w = $1 / (1 + 2 \cdot A_{fn} / A_w)$ with A_{fn} as given in 3.5.1.8,

k_z = z_p / Z_p in general,
= 0.0 when the frame is arranged with end bracket,

z_p = sum of individual plastic section modulii of flange and shell plate as fitted, [cm^3],
= $(b_f \cdot t_{fn}^2 / 4 + b_{eff} \cdot t_{pn}^2 / 4) / 1000$,

b_f = flange breadth, [mm], see Fig. 3.5.1.7,

t_{fn} = net flange thickness, [mm],
= $t_f - t_c$ (t_c as given in 3.5.1.7),

t_f = as-built flange thickness, [mm], see Fig. 3.5.1.7,

t_{pn} = the fitted net shell plate thickness, [mm], (not to be less than t_{net} as given in 3.4),

b_{eff} = effective width of shell plate flange, [mm],
= $500 \cdot s$

Z_p = net effective plastic section modulus of the local frame (calculated according to 3.5.1.8), [cm^3].

3.5.2.4 The scantlings of the local frame are to meet the structural stability requirements of 3.5.5.

3.5.3 Longitudinal local frames in side structures

3.5.3.1 Longitudinal local frames in side structures are to be dimensioned such that the combined effects of shear and bending do not exceed the plastic strength of the member. The plastic strength is defined by the magnitude of midspan load that causes the development of a plastic collapse mechanism.

3.5.3.2 The actual net effective shear area of the frame, A_w, as defined in 3.5.1.7, is to comply with the following condition: $A_w \geq A_L$, where:

$A_L = 100^2 \cdot (AF \cdot PPF_s \cdot P_{avg}) \cdot 0.5 \cdot b_1 \cdot a / (0.577 \cdot R_{eH})$, [cm^2],

where:

AF = Hull Area Factor from Table 3.3.5-1 or 3.3.5-2,

PPF_s = peak pressure factor from Table 3.3.4.2,

P_{avg} = average pressure within load patch as defined in 3.3.4, [MPa],

b_1 = $k_o \cdot b_2$, [m],

k_o = $1 - 0.3 / b'$,

b' = b / s,

b = height of design ice load patch as defined in 3.3.3.1 or 3.3.3.2, [m],

s = spacing of longitudinal frames, [m],

b_2 = $b \cdot (1 - 0.25 \cdot b')$, [m], if $b' < 2$,
= s, [m], if $b' \geq 2$,

A = effective span of longitudinal local frame as given in 3.5.1.5, [m],

R_{eH} = minimum upper yield stress of the material, [N/mm^2].

3.5.3.3 The actual net effective plastic section modulus of the plate/stiffener combination, Z_p, as defined in 3.5.1.8, is to comply with the following condition: $Z_p \geq Z_{pL}$, where:

$Z_{pL} = 100^3 \cdot (AF \cdot PPF_s \cdot P_{avg}) \cdot b_1 \cdot a^2 \cdot A_4 / (8 \cdot R_{eH})$, [cm^3],

where:

AF, PPF_s, P_{avg}, b_1, *a* and R_{eH} are as given in 3.5.3.2,

A_4 = $1 / (2 + k_{wl} \cdot [(1 - a_4^2)^{0.5} - 1])$,

a_4 = A_L / A_w,

A_L = minimum shear area for longitudinal as given in 3.5.3.2, [cm^2],

A_w = net effective shear area of longitudinal (calculated according to 3.5.1.7), [cm^2],

k_{wl} = $1 / (1 + 2 \cdot A_{fn} / A_w)$ with A_{fn} as given in 3.5.1.8.

3.5.3.4 The scantlings of the longitudinals are to meet the structural stability requirements of 3.5.5.

3.5.4 Web frames and load carrying stringers

3.5.4.1 Web frames and load-carrying stringers are to be designed to withstand the ice load patch as defined in 3.3. The load patch is to be applied at locations where the capacity of these members under the combined effects of bending and shear is minimised.

3.5.4.2 Web frames and load-carrying stringers are to be dimensioned such that the combined effects of shear and bending do not exceed the limit state(s) defined by the *Register*. Where the structural configuration is such that members do not form part of a grillage system, the appropriate peak pressure factor (*PPF*) from Table 3.3.4.2 is to be used. Special attention is to be paid to the shear capacity in way of lightening holes and cut-outs in way of intersecting members.

3.5.4.3 For determination of scantlings of load carrying stringers, web frames supporting local frames, or web frames supporting load carrying stringers forming part of a structural grillage system, appropriate methods as outlined in 3.12 are normally to be used.

3.5.4.4 The scantlings of web frames and load-carrying stringers are to meet the structural stability requirements of 3.5.5.

3.5.5 Structural stability

3.5.5.1 To prevent local buckling in the web, the ratio of web height (h_w) to net web thickness (t_{wn}) of any framing member is not to exceed:

For flat bar sections: $h_w / t_{wn} \leq 282/(R_{eH})^{0.5}$

For bulb, tee and angle sections: $h_w / t_{wn} \leq 805/(R_{eH})^{0.5}$

where:

h_w = web height,

t_{wn} = net web thickness,

R_{eH} = minimum upper yield stress of the material, [N/mm^2].

3.5.5.2 Framing members for which it is not practicable to meet the requirements of 3.5.5.1 (e.g. load carrying stringers or deep web frames) are required to have their webs effectively stiffened. The scantlings of the web stiffeners are to ensure the structural stability of the framing member. The minimum net web thickness for these framing members is given by:

$$t_{wn} = 2.63 \cdot 10^{-3} \cdot c_1 \cdot (R_{eH} /(5.34 + 4 \cdot (c_1 / c_2)^2))^{0.5}, \text{ [mm]},$$

where:

c_1 = h_w - 0.8 · h, [mm],

h_w = web height of stringer/web frame, [mm], (see Fig. 3.5.5.2),

h = height of framing member penetrating the member under consideration (0 if no such framing member), [mm], see Fig. 3.5.5.2,

c_2 = spacing between supporting structure oriented perpendicular to the member under consideration, [mm], see Fig. 3.5.5.2,

R_{eH} = minimum upper yield stress of the material, [N/mm^2].

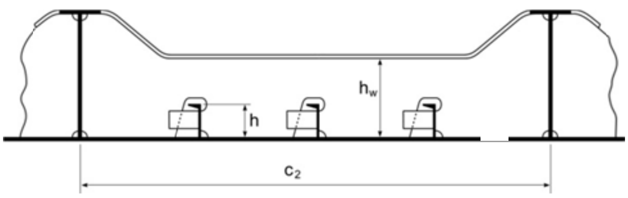


Figure 3.5.5.2 Parameter definition of web stiffening

3.5.5.3 In addition, the following is to be satisfied:

$$t_{wn} \geq 0.35 \cdot t_{pn} \cdot (R_{eH} /235)^{0.5}$$

where:

R_{eH} = minimum upper yield stress of the shell plate in way of the framing member, [N/mm^2],

t_{wn} = net thickness of the web, [mm],

t_{pn} = net thickness of the shell plate in way of the framing member, [mm].

3.5.5.4 To prevent local flange buckling of welded profiles, the following are to be satisfied:

(i) The flange width, b_f, in [mm], is not to be less than five times the net thickness of the web, t_{wn}.

(ii) The flange outstand, b_{out}, in [mm], is to meet the following requirement:

$$b_{out} / t_{fn} \leq 155/(R_{eH})^{0.5}$$

where:

t_{fn} = net thickness of flange, [mm],

R_{eH} = minimum upper yield stress of the material, [N/mm^2].

3.6 PLATED STRUCTURES

3.6.1 Plated structures are those stiffened plate elements in contact with the hull and subject to ice loads. These requirements are applicable to an inboard extent which is the lesser of:

(i) web height of adjacent parallel web frame or stringer; or

(ii) 2.5 times the depth of framing that intersects the plated structure.

3.6.2 The thickness of the plating and the scantlings of attached stiffeners are to be such that the degree of end fixity necessary for the shell framing is ensured.

3.6.3 The stability of the plated structure is to adequately withstand the ice loads defined in 3.3.

3.7 CORROSION / ABRASION ADDITIONS AND STEEL RENEWAL

3.7.1 Effective protection against corrosion and ice-induced abrasion is recommended for all external surfaces of the shell plating for Polar class ships.

3.7.2 The values of corrosion/abrasion additions, t_s, to be used in determining the shell plate thickness are listed in Table 3.7.2.

3.7.3 Polar class ships are to have a minimum corrosion/abrasion addition of t_s = 1.0 mm applied to all internal structures within the ice-strengthened hull areas, including plated members adjacent to the shell, as well as stiffener webs and flanges.

3.7.4 Steel renewal for ice strengthened structures is required when the gauged thickness is less than t_{net} + 0.5 mm.

Table 3.7.2 - Corrosion / abrasion additions for shell plating

Hull area	**t_s [mm]**					
	With effective protection			**Without effective protection**		
	PC1 - PC3	**PC4 & PC5**	**PC6 & PC7**	**PC1 - PC3**	**PC4 & PC5**	**PC6 & PC7**
Bow; Bow Intermediate Icebelt	3.5	2.5	2.0	7.0	5.0	4.0
Bow Intermediate Lower; Midbody & Stern Icebelt	2.5	2.0	2.0	5.0	4.0	3.0
Midbody & Stern Lower; Bottom	2.0	2.0	2.0	4.0	3.0	2.5

3.8 MATERIALS

3.8.1 Steel grades of plating for hull structures are to be not less than those given in Tables 2.1.1 and Table 2.1.4 based on the as-built thickness, the Polar class and the material class of structural members according to 2.1.2.

3.9 LONGITUDINAL STRENGTH

3.9.1 Application

3.8.1.1 A ramming impact on the bow is the design scenario for the evaluation of the longitudinal strength of the hull.

3.9.1.2 Intentional ramming is not considered as a design scenario for ships which are designed with vertical or bulbous bows, see 1.3.2.1.4. Hence the longitudinal strength requirements given in 3.9 is not to be considered for ships with stem angle γ_{stem} equal to or larger than 80º.

3.9.1.3 Ice loads are only to be combined with still water loads. The combined stresses are to be compared against permissible bending and shear stresses at different locations along the ship's length. In addition, sufficient local buckling strength is also to be verified.

3.9.2 Design vertical ice force at the bow

3.9.2.1 The design vertical ice force at the bow, F_{IB}, is to be taken as

$$F_{IB} = \text{minimum } (F_{IB,1}; F_{IB,2}) \text{ [MN]}$$

where:

$F_{IB,1} = 0.534 \cdot K_I^{0.15} \cdot \sin^{0.2}(\gamma_{stem}) \cdot (\Delta \cdot K_h)^{0.5} \cdot CF_L$, [MN],

$F_{IB,2} = 1.20 \cdot CF_F$, [MN],

K_I = indentation parameter = K_f / K_h,

a) for the case of a blunt bow form

$K_f = (2 \cdot C \cdot B^{1-eb} / (1 + e_b))^{0.9} \cdot \tan(\gamma_{stem})^{-0.9 \cdot (1 + eb)}$,

b) for the case of wedge bow form ($\alpha_{stem} < 80º$),

e_b = 1 and the above simplifies to

K_f = $(\tan \alpha_{stem}) / \tan^2(\gamma_{stem}))^{0.9}$,
K_h = $0.01 \cdot A_{wp}$, [MN/m],
CF_L = longitudinal strength class factor from Table 3.1.2.1,

e_b = bow shape exponent which best describes the waterplane (see Fig. 3.9.2.1-1 and 3.9.2.1-2),
= 1.0 for a simple wedge bow form,
= 0.4 to 0.6 for a spoon bow form,
= 0 for a landing craft bow form.

An approximate e_b determined by a simple fit is acceptable.

γ_{stem} = stem angle to be measured between the horizontal axis and the stem tangent at the upper ice waterline, [º], (buttock angle as per Fig. 3.3.2.1.1 measured on the centreline),

α_{stem} = waterline angle measured in way of the stem at the upper ice waterline (UIWL), [º], (see Fig. 3.9.2.1-1),

C = $1 / (2 \cdot (L_B / B)^{eb})$,

B = ship moulded breadth, [m],

L_B = bow length used in the equation
$y = B/2 \cdot (x/L_B)^{eb}$, [m], (see Fig. 3.9.2.1-1 and 3.9.2.1-2),

Δ = ship displacement,[kt], not to be taken less than 10 kt,

A_{wp} = ship waterplane area, [m^2],

CF_F = flexural failure class factor from Table 3.1.2.1.

Where applicable, draught dependent quantities are to be determined at the waterline corresponding to the loading condition under consideration.

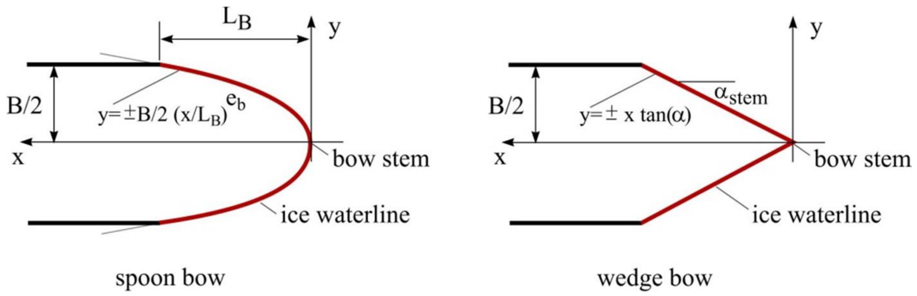


Figure 3.9.2.1-1 - Bow shape definition

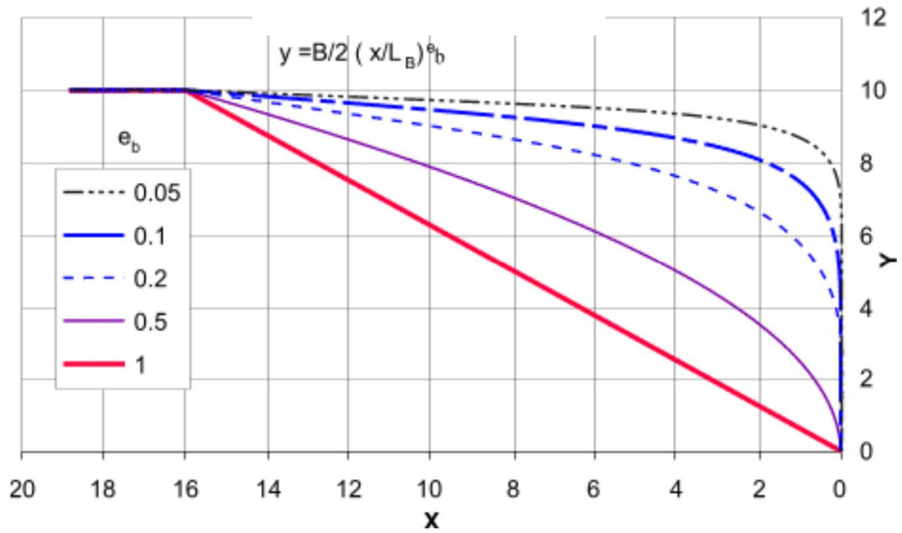


Figure 3.9.2.1-2 - Illustration of e_b effect on the bow shape for B = 20 and L_B =16

3.9.3 Design vertical shear force

3.9.3.1 The design vertical ice shear force, F_I, along the hull girder is to be taken as:

$$F_I = C_f \cdot F_{IB}\ , \text{[MN]}$$

where:

C_f = longitudinal distribution factor to be taken as follows:

(a) Positive shear force

C_f = 0.0 between the aft end of *L* and 0.6*L* from aft,

C_f = 1.0 between 0.9 *L* from aft and the forward end of *L*.

(b) Negative shear force

C_f = 0.0 at the aft end of *L*,

C_f = 0.5 between 0.2 *L* and 0.6*L* from aft,

C_f = 0.0 between 0.8 *L* from aft and the forward end of *L*.

Intermediate values are to be determined by linear interpolation.

3.9.3.2 The applied vertical shear stress, τ_a, is to be determined along the hull girder in a similar manner as in Section 4.6.4.2 of the *Rules for the classification of ships, Part 2 - Hull* by substituting the design vertical ice shear force for the design vertical wave shear force.

3.9.4 Design vertical ice bending moment

3.9.4.1 The design vertical ice bending moment, M_I, along the hull girder is to be taken as:

$$M_I = 0.1 \cdot C_m \cdot L \cdot \sin^{-0.2} \gamma_{stem}) \cdot F_{IB}\ , \text{[MNm]},$$

where:

L = ship length as defined in the *Rules for the classification of ships, Part 2 - Hull*, 1.2.3.1, but measured on the upper ice waterline [UIWL], [m],

γ_{stem} = as given in 3.9.2.1,

F_{IB} = design vertical ice force at the bow, [MN],

C_m = longitudinal distribution factor for design vertical ice bending moment to be taken as follows:

C_m = 0.0 at the aft end of *L*,

C_m = 1.0 between 0.5*L* and 0.7*L* from aft,

C_m = 0.3 at 0.95*L* from aft,

C_m = 0.0 at the forward end of *L*.

Intermediate values are to be determined by linear interpolation.

Where applicable, draught dependent quantities are to be determined at the waterline corresponding to the loading condition under consideration.

3.9.4.2 The applied vertical bending stress, σ_a, is to be determined along the hull girder in a similar manner as in Section 4.6.4.1 of the *Rules for the classification of ships, Part 2 - Hull*, by substituting the design vertical ice bending moment for the design vertical wave bending moment. The ship still water bending moment is to be taken as the maximum sagging moment.

3.9.5 Longitudinal strength criteria

3.9.5.1 The strength criteria provided in Table 3.9.5.1 are to be satisfied. The design stress is not to exceed the permissible stress.

Table 3.9.5.1 - Logitudinal strength

Failure mode	Applied stress	Permissible stress when $R_{eH} / R_m \le 0.7$	Permissible stress when $R_{eH} / R_m > 0.7$
Tension	σ_a	$\eta \cdot \sigma_y$	$\eta \cdot 0.41\ (\sigma_u + \sigma_y)$
Shear	τ_a	$\eta \cdot R_{eH} / (3)^{0.5}$	$\eta \cdot 0.41\ (R_m + R_{eH}) / (3)^{0.5}$
Buckling	σ_a	σ_c for plating and for web plating of stiffeners σ_c / 1.1 for stiffeners	
	τ_a	τ_c	

where:

σ_a = applied vertical bending stress, [N/mm^2],

τ_a = applied vertical shear stress, [N/mm^2],

R_{eH} = minimum upper yield stress of the material, [N/mm^2],

R_m = ultimate tensile strength of material, [N/mm^2],

σ_c = critical buckling stress in compression, according to the *Rules for the classification of ships, Part 2 - Hull*, 4.6, [N/mm^2],

τ_c = critical buckling stress in shear, according to the *Rules for the classification of ships, Part 2 - Hull*, 4.6, [N/mm^2],

η = 0,8,

η = 0.6 for ships which are assigned the additional notation ñIcebreakerò.

3.10 STEM AND STERN FRAMES

3.10.1 The stem and stern frame are to be designed according to the requirements of the *Register*. For PC6/PC7 ships requiring 1AS/1A equivalency, the stem and stern requirements of the Section 8 may need to be additionally considered.

3.11 APPENDAGES

3.11.1 General

3.11.1.1 All appendages are to be designed to withstand forces appropriate for the location of their attachment to the hull structure or their position within a hull area.

3.11.1.2 Bilge keels are normally to be avoided and should preferably be substituted by roll-damping equipment. If bilge keels are fitted, it is required that the connection to the hull is so designed that the risk of damage to the hull, in case the bilge keel is ripped off, is minimized.

3.11.1.3 Stern frames, rudders and propeller nozzles shall be designed according to the *Rules for the classification of ships, Part 3 - Hull Equipment*, Section 2.

3.11.1.4 Load definition and response criteria are to be determined by the *Register*.

3.11.2 Rudders

3.11.2.1 The rudder stock and upper edge of the rudder shall be effectively protected against ice pressure.

3.11.2.2 Rudder stops are to be provided. The design ice force on rudder shall be transmitted to the rudder stops without damage to the steering system.

3.11.2.3 Ice horn shall in general be fitted to protect the rudder in centre position. The ice horn shall extend below BWL. Design forces shall be determined according to the Section 6.5.

3.11.2.4 Ice horns shall be fitted directly abaft each rudder in such a manner that:

- the upper edge of the rudder is protected within two degrees to each side of the mid position when going astern, and
- ice is prevented from wedging between the top of the rudder and the ship's hull.

The ice horn shall extend vertically to, minimum = 1.5 CFD , in [m], below LIWL, where CFD shall be taken as given in Table 3.3.2-1. Alternatively an equivalent arrangement shall be arranged.

3.11.2.5 Exposed seals for rudder stock are assumed to be designed for the given environmental conditions such as:

- ice formation
- specified design temperature.

3.11.3 Ice load on rudder

3.11.3.1 The ice force, F_U, acting on the uppermost part of the rudder, the ice horn included shall be assessed on a case to case basis based on the current practice of the *Register*.

The force F_U shall be divided between rudder and ice horn according to their support position. The force acting on the ice horn, in [kN], may generally be taken as:

$$F_H = \frac{F_U \cdot (X - X_F)}{X_K - X_F}$$

where;

X = distance from leading edge of rudder to point of attack of the force F,
= 0.5 l_r minimum, in [m],
= 0.67 l_r maximum, in [m],

l_r = length of rudder profile (including ice horn), in [m],

X_F = longitudinal distance, in [m], from the leading edge of the rudder to the axis of the rudder stock,

X_K = distance, in [m], from leading edge of rudder to centre of ice horn.

For this loading the stress response of the rudder, the ice horn and support structures for these shall not exceed R_{eH}, where R_{eH} denotes the specified minimum yield stress of the material.

3.11.3.2 The ice force, F_R, acting on the rudder the distance Z_{LIWL} below LIWL shall be assessed on a case to case basis based on the current practice of the *Register*.

The rudder force, F_R, in [kN], gives rise to bending moments in the rudder, the rudder stock and the rudder horn, as applicable. Alternative positions for the ice load area shall be considered in order that the maximum bending moment shall be determined.

3.11.3.3 The bending moment in way of the rudder section in question, in [kNm], is given as:

$$M_B = F_R \cdot h_s$$

where:

h_s = vertical distance from the ice load area position to the rudder section in question, in [m].

The rudder force, F_R, gives rise to a rudder torque, M_{TR}, and a bending moment in the rudder stock, M_B, which both will vary depending on the position of the assumed ice load area, and on the rudder type and arrangement used.

In general the load giving the most severe combination of F_R, M_{TR} and M_B with respect to the structure under consideration shall be applied in a direct calculation of the rudder structure.

The design value of M_{TR} is given by:

M_{TR} = F_R (0.6 l_r ï X_F), in [kNm],
= 0.15 F_R l_r minimum,

X_F = longitudinal distance, in [m], from the leading edge of the rudder to the axis of the rudder stock,

l_r = length of rudder profile, in [m].

3.11.4 Rudder scantlings

3.11.4.1 Scantlings of rudder, rudder stock, rudder horn and rudder stoppers, as applicable, shall be calculated for the force, F, given in 3.11.3.1 acting on the rudder and ice horn, with respect to bending and shear. The nominal von Mises stress shall not exceed R_{eH}, where R_{eH} denotes the specified minimum yield stress of the material, in [N/mm^2].

3.11.4.2 The scantlings of rudders, rudder stocks and shafts, pintles, rudder horns and rudder actuators shall be calculated from the formulae given in the *Rules for the classification of ships, Part 3 - Hull Equipment,* Section 2, inserting the rudder torque M_{TR}, bending moments M_B and rudder force F_R as given in 3.11.3.2.

3.11.4.3 Provided an effective torque relief arrangement is installed for the steering gear, and provided effective ice stoppers are fitted, the design rudder torque need not be taken greater than:

$M_{TR} = M_{TRO},$

M_{TRO} = steering gear relief torque, in [kNm].

3.11.4.4 For rudder plating the ice load thickness shall be calculated as given in 3.4 for the stern area or lower stern area as applicable.

3.11.5 Ice loads on propeller nozzles

3.11.5.1 The transverse ice force, *FN*, shall be calculated on a case by case basis based on the current practice of the *Register*.

3.11.5.2 The longitudinal ice force, F_L, acting on the nozzle shall be assessed on a case to case basis based on the current practice of the *Register*.

For the determination of F_L, the following two alternative ice load areas, *A*, shall be considered:

- an area positioned at the lower edge of the nozzle with width equal to 0.65 *D* and height equal to the height of the nozzle profile, in [m],
- an area on both sides of the nozzle at the propeller shaft level, with transverse width equal to the height of the nozzle profile, in [m], and with height equal to 0.35 *D*. Both symmetric and asymmetric loading shall be checked.

D = nozzle diameter, in [m].

3.11.6 Propeller nozzle scantlings

3.11.6.1 The scantlings of the propeller nozzle and its supports in the hull shall be calculated for the ice loads given in 3.11.5. The nominal von Mises stress shall not exceed R_{eH}, where R_{eH} denotes the specified minimum yield stress of the material, in [N/mm^2].

For nozzle plating the ice load thickness shall be taken as given in 3.4 using the design ice pressure as given for the stern area, lower stern area as applicable.

3.12 LOCAL DETAILS

3.12.1 For the purpose of transferring ice-induced loads to supporting structure (bending moments and shear forces), local design details are to comply with the requirements of the *Register*.

3.12.2 The loads carried by a member in way of cutouts are not to cause instability. Where necessary, the structure is to be stiffened.

3.13 DIRECT CALCULATIONS

3.13.1 Direct calculations are not to be utilised as an alternative to the analytical procedures prescribed for the shell plating and local frame requirements given in 3.4, 3.5.2, and 3.5.3.

3.13.2 Direct calculations are to be used for load carrying stringers and web frames forming part of a grillage system.

3.13.3 Where direct calculation is used to check the strength of structural systems, the load patch specified in 3.3 is to be applied, without being combined with any other loads. The load patch is to be applied at locations where the capacity of these members under the combined effects of bending and shear is minimised. Special attention is to be paid to the shear capacity in way of lightening holes and cutouts in way of intersecting members.

3.13.4 The strength evaluation of web frames and stringers may be performed based on linear or non-linear analysis. Recognized structural idealisation and calculation methods are to be applied, but the detailed requirements are to be specified by the *Register*. In the strength evaluation, the guidance given in 3.13.5 and 3.13.6 may generally be considered.

3.13.5 If the structure is evaluated based on linear calculation methods, the following are to be considered:

(1) Web plates and flange elements in compression and shear to fulfil relevant buckling criteria as specified by the *Register;*

(2) Nominal shear stresses in member web plates to be less than $R_{eH}/\sqrt{3}$;

(3) Nominal von Mieses stresses in member flanges to be less than 1.15 R_{eH}.

3.13.6 If the structure is evaluated based on non-linear calculation methods, the following are to be considered:

(1) The analysis is to reliably capture buckling and plastic deformation of the structure;

(2) The acceptance criteria are to ensure a suitable margin against fracture and major buckling and yielding causing significant loss of stiffness;

(3) Permanent lateral and out-of plane deformation of considered member are to be minor relative to the relevant structural dimensions.

(4) Detailed acceptance criteria to be decided by the *Register*.

3.14 WELDING

3.14.1 All welding within ice-strengthened areas is to be of the double continuous type.

3.14.2 Continuity of strength is to be ensured at all structural connections.

3.15 METHOD FOR DETERMINING THE EQUIVALENCY

3.15.1 For the purpose of Section 3 and Section 6 of these Rules, ñother standards offering an equivalent level of safety are to comply with the provisions of 3.15.2 to 3.15.7 below. The methodology is consistent with guidance developed by the Organization [1)] while allowing for the use of a simplified approach.

3.15.2 Other standards offering an equivalent level of safety are to be determined by as stated below:

.1 The basic approach for considering equivalency for categories A and B ships can be the same for both new and existing ships.

.2 For ice classes under category C, additional information on comparisons of strengthening levels is available for the guidance [2)].

.3 The responsibility for generating the equivalency request and supporting information required is to rest with the owner/operator.

.4 Review/approval of any equivalency request is to be undertaken by the *Register*.

.5 If there is not full and direct compliance, then an equivalent level of risk are to be as deemed appropriate by the *Register*.

.6 An increase in the probability of an event can be balanced by a reduction in its consequences. Alternatively, a reduction in probability could potentially allow acceptance of more serious consequences. Using a hull area example, a local shortfall in strength level or material grade could be accepted if the internal compartment is a void space, for which local damage will not put the overall safety of the ship at risk or lead to any release of pollutants.

3.15.3 The scope of a simplified equivalency assessment, referring to 3.15.5.1 to 3.15.5.3 below, is expected to be limited to materials selection, structural strength of the hull and propulsion machinery.

3.15.4 For existing ships, service experience can assist in risk assessment. As an example, for an existing ship with a record of polar ice operations a shortfall in the extent of the ice belt (hull areas) may be acceptable if there is no record of damage to the deficient area; i.e. a ship that would generally meet PC5 requirements but in limited areas is only PC7 could still be considered as a category A, PC5 ship. In all such cases, the ship s documentation is to make clear the nature and scope of any deficiencies.

3.15.5 The assessment procedure for equivalency

.1 select the target Polar class for equivalency;

.2 compare materials used in the design with minimum requirements of the Polar class; identify any shortfalls; and

.3 compare strength levels of hull and machinery components design with requirements of the Polar class; quantify levels of compliance.

3.15.6 Where gaps in compliance are identified in steps 3.15.5.1 to 3.15.5.3 above, additional steps are to be necessary to demonstrate equivalency, as outlined below:

.4 identify any risk mitigation measures incorporated in the design of the ship;

.5 where applicable, provide documentation of service experience of existing ships, in conditions relevant to the target ice class for equivalency; and

.6 undertake an assessment, taking into account information from steps 3.15.5.1 to 3.15.5.3, as applicable, and on the principles outlined in paragraphs 3.15.2 to 3.15.5 above.

3.15.7 Documentation provided with an application for equivalency is to identify each stage that has been undertaken, and sufficient supporting information to validate assessments.

3.15.8 Where a ship in categories A or B is provided with an equivalency for ice class by its flag state, this should be noted in its Polar ship certificate.

NOTES:

1) Refer to the Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments (MSC.1/Circ.1455).

2) Refer to the annex to HELCOM Recommendation 25/7, Safety of Winter Navigation in the Baltic Sea Area, available at www.helcom.fi

4 SUBDIVISION AND STABILITY

4.1 GOAL

The goal of this Section is to ensure adequate subdivision and stability in both intact and damaged conditions of Polar class ships.

4.2 FUNCTIONAL REQUIREMENTS

In order to achieve the goal set out in 4.1 above, the following functional requirements are embodied in the regulations of this Section:

4.2.1 Ships are to have sufficient stability in intact conditions when subject to ice accretion; and

4.2.2 Ships of category A and B, constructed on or after 1 January 2017, are to have sufficient residual stability to sustain ice-related damages.

4.2.3 The applicable requirements of the *Rules for the classification of ships, Part 4 - Stability* and the *Rules for the classification of ships, Part 5 - Subdivision* are also to be met.

4.3 REGULATIONS

4.3.1 Stability in intact conditions

In order to comply with the functional requirement of 4.2.1above, the following apply.

4.3.1.1 For ships operating in areas and during periods where ice accretion is likely to occur, the following icing allowance is to be made in the stability calculations:

.1 30 kg/m^2 on exposed weather decks and gangways;

.2 7,5 kg/m^2 for the projected lateral area of each side of the ship above the water plane; and the projected lateral area of discontinuous surfaces of rail, sundry booms, spars (except masts) and rigging of ships having no sails and the projected lateral area of other small objects is to be computed by increasing the total projected area of continuous surfaces by 5% and the static moments of this area by 10%.

4.3.1.2 Ships operating in areas and during periods where ice accretion is likely to occur are to be:

.1 designed to minimize the accretion of ice; and

.2 equipped with such means for removing ice as the *Register* may require; for example, electrical and pneumatic devices, and/or special tools such as axes or wooden clubs for removing ice from bulwarks, rails and erections.

4.3.1.3 Information on the icing allowance included in the stability calculations is to be given in the PWOM.

4.3.1.4 Ice accretion is to be monitored and appropriate measures taken to ensure that the ice accretion does not exceed the values given in the PWOM.

4.3.2 Stability in damaged conditions

In order to comply with the functional requirements of 4.2.2 above, ships of categories A and B, constructed on or after 1 January 2017, are to be able to withstand flooding resulting from hull penetration due to ice impact, of which the damage extent is to be in accordance with the 4.3.2.1 to 4.3.2.3 below. The residual stability following ice damage is to be such that the factor s_i, as defined in 2.7.2 and 2.7.3 of the *Rules for the classification of ships, Part 5 - Subdivision*, is equal to one for all loading conditions used to calculate the attained subdivision index *A* as defined in 2.5 of the said Rules. However, for cargo ships that comply with subdivision and damage stability regulations in another instrument (see SOLAS Reg. II-1/4.1), the residual stability criteria of that instrument is to be met for each loading condition.

4.3.2.1 The longitudinal extent is 0,045 times the upper ice waterline length if centred forward of the maximum breadth on the upper ice waterline, and 0,015 times the upper ice waterline length otherwise, and are to be assumed at any longitudinal position along the ship s length;

4.3.2.2 The transverse penetration extent is 760 mm, measured normal to the shell over the full extent of the damage; and

4.3.3.3 The vertical extent is the lesser of 0,2 times the upper ice waterline draught or the longitudinal extent, and is to be assumed at any vertical position between the keel and 1,2 times the upper ice waterline draught.

5 WATERTIGHT AND WEATHERTIGHT INTEGRITY

5.1 GOAL

The goal of this Section is to provide measures to maintain watertight and weathertight integrity.

5.2 FUNCTIONAL REQUIREMENTS

In order to achieve the goal set out in 5.1 above, all closing appliances and doors relevant to watertight and weathertight integrity of the ship is to be operable.

5.3 REGULATIONS

5.3.1 General

In order to comply with the functional requirements of 5.2 above, the following apply:

5.3.1.1 For ships operating in areas and during periods where ice accretion is likely to occur, means are to be provided to remove or prevent ice and snow accretion around hatches and doors.

5.3.1.2 In addition to 5.3.1.1 above, for ships intended to operate in low air temperature (see 1.4 of Section 1 of these Rules) the following apply:

.1 if the hatches or doors are hydraulically operated, means are to be provided to prevent freezing or excessive viscosity of liquids; and

.2 watertight and weathertight doors, hatches and closing devices which are not within an habitable environment and require access while at sea are to be designed to be operated by personnel wearing heavy winter clothing including thick mittens.

6 MACHINERY INSTALLATIONS

6.1 GOAL

The goal of this Section is to ensure that, machinery installations are capable of delivering the required functionality necessary for safe operation of ships.

6.1.2 Functional requirements

In order to achieve the goal set out in 6.1.1, the provisions of 6.1.2.1, 6.1.2.2 and 6.1.2.3 are to be complied with.

6.1.2.1 Machinery installations are to provide functionality under the anticipated environmental conditions, taking into account the provisions of .1 to .5 below:

.1 Ice accretion and/or snow accumulation;
.2 Ice ingestion from seawater;
.3 Freezing and increased viscosity of liquids;
.4 Seawater intake temperature; and
.5 Snow ingestion.

6.1.2.2 In addition to 6.1.2.1 above, for ships intended to operate in low air temperatures (see also 6.1.3.2 below) the provisions of .1 and .2 below are to be complied with.

.1 Machinery installations are to provide functionality under the anticipated environmental conditions, also taking into account the .1 and .2 below:
  .1 cold and dense inlet air; and
  .2 loss of performance of battery or other stored energy device.
.2 Materials used are to be suitable for operation at the ships polar service temperature.

6.1.2.3 In addition to 6.1.2.1 and 6.1.2.2 above, for ships ice strengthened in accordance with Section 3 of these Rules, machinery installations are to provide functionality under the anticipated environmental conditions, taking into account loads imposed directly by ice interaction.

6.1.3 Regulations

6.1.3.1 General

In order to comply with the functional requirement of 6.1.2.1, taking into account the anticipated environmental conditions, the provisions of .1 to .3 below are to apply.

.1 Machinery installations and associated equipment are to be protected against the effect of ice accretion and/or snow accumulation, ice ingestion from sea water, freezing and increased viscosity of liquids, seawater intake temperature and snow ingestion.
.2 Working liquids are to be maintained in a viscosity range that ensures operation of the machinery.
.3 Seawater supplies for machinery systems are to be designed to prevent ingestion of ice are to be in accordance with IMO MSC/Circ.504.

6.1.3.2 Ships intended to operate in low air temperatures

In addition to 6.1.3.1, for ships intended to operate in low air temperatures (see 1.4 of Section 1 of these Rules), the provisions of .1 to .3 below are to apply:

.1 In order to comply with 6.1.2.2, exposed machinery and electrical installation and appliances are to function at the polar service temperature;
.2 In order to comply with 6.1.2.2.1, means are to be provided to ensure that combustion air for internal combustion engines driving essential machinery is maintained at a temperature in compliance with the criteria provided by the engine manufacturer; and
.3 In order to comply with 6.1.2.2.2 materials of exposed machinery and foundations are to be either of the following .1 or .2:
  .1 Those complying the requirements specified in Section 2 of these Rules applicable to materials of machinery installations and approved by the *Register*; or
  .2 Those complying with other standards offering an equivalent level of safety based on the polar service temperature and complying with 1.8 of Section 1 of these Rules.

6.1.3.3 Ice strengthened ships

In addition to 6.1.3.1 and 6.1.3.2, for ships ice strengthened in accordance with Section 3 of these Rules, in order to comply with 6.1.2.3, the provisions of .1 to .3 below are to apply.

.1 Scantlings of propeller blades, propulsion line, steering equipment and other appendages of category A ships are to be either of the following .1 or .2:
  .1 Those complying with the requirements of this Section applicable to scantlings of propeller blades, propulsion line, steering equipment and other appendages and approved by the *Register*; or
  .2 Those complying with other standards offering an equivalent level of safety complying with 1.8 of Section 1 of these Rules.
.2 Scantlings of propeller blades, propulsion line, steering equipment and other appendages of category B ships are to be either of the following .1 or .2 below:
  .1 Those complying with the requirements specified in these Rules applicable to scantlings of propeller blades, propulsion line, steering equipment and other appendages and approved by the *Register*; or

.2 Those complying with other standards offering an equivalent level of safety and approved by the Flag State Administration.

.3 Scantlings of propeller blades, propulsion line, steering equipment and other appendages of ice-strengthened category C ships are to be approved by the Administration or the *Register* taking into account acceptable standards adequate with the ice types and concentration encountered in the area of operation.

6.2 DRAWINGS AND PARTICULARS TO BE SUBMITTED

6.2.1 Details of the environmental conditions and the required ice class for the machinery, if different from shipôs ice class.

6.2.2 Detailed drawings of the main propulsion machinery. Description of the main propulsion, steering, emergency and essential auxiliaries are to include operational limitations. Information on essential main propulsion load control functions.

6.2.3 Description detailing how main, emergency and auxiliary systems are located and protected to prevent problems from freezing, ice and snow and evidence of their capability to operate in intended environmental conditions.

6.2.4 Calculations and documentation indicating compliance with the requirements of this chapter.

6.3 SYSTEM DESIGN

6.3.1 Machinery and supporting auxiliary systems shall be designed, constructed and maintained to comply with the requirements of ñperiodically unmanned machinery spacesò with respect to fire safety. Any automation plant (i.e. control, alarm, safety and indication systems) for essential systems installed is to be maintained to the same standard.

6.3.2 Systems, subject to damage by freezing, shall be drainable.

6.3.3 Single screw vessels classed PC1 to PC5 inclusive shall have means provided to ensure sufficient vessel operation in the case of propeller damage including CP-mechanism.

6.4 MATERIALS

6.4.1 Materials exposed to sea water

6.4.1.1 Materials exposed to sea water, such as propeller blades, propeller hub and blade bolts shall have an elongation not less than 15% on a test piece the length of which is five times the diameter.

6.4.1.2 Charpy V impact test shall be carried out for other than bronze and austhenitic steel materials. Test pieces taken from the propeller castings shall be representative of the thickest section of the blade. An average impact energy value of 20 J taken from three Charpy V tests is to be obtained at minus 10 ºC.

6.4.2 Materials exposed to sea water temperature

Materials exposed to sea water temperature shall be of steel or other approved ductile material. An average impact energy value of 20 J taken from three tests is to be obtained at minus 10 ºC.

6.4.3 Material exposed to low air temperature

Materials of essential components exposed to low air temperature shall be of steel or other approved ductile material. An average impact energy value of 20 J taken from three Charpy V tests is to be obtained at 10 ºC below the lowest design temperature.

6.5 ICE INTERACTION LOAD

6.5.1 Propeller ice interaction

6.5.1.1 These Rules cover open and ducted type propellers situated at the stern of a vessel having controllable pitch or fixed pitch blades. Ice loads on bow propellers and pulling type propellers shall receive special consideration. The given loads are expected, single occurrence, maximum values for the whole ships service life for normal operational conditions. These loads do not cover off-design operational conditions, for example when a stopped propeller is dragged through ice. These Rules apply also for azimuthing (geared and podded) thrusters considering loads due to propeller ice interaction. However, ice loads due to ice impacts on the body of azimuthing thrusters are not covered by these Rules.

6.5.1.2 The loads given in Section of these Rules are total loads (unless otherwise stated) during ice interaction and are to be applied separately (unless otherwise stated) and are intended for component strength calculations only. The different loads given here are to be applied separately:

F_b is a force bending a propeller blade backwards when the propeller mills an ice block while rotating ahead.

F_f is a force bending a propeller blade forwards when a propeller interacts with an ice block while rotating ahead.

6.5.2 Ice class factors

The Table 6.5.2 below lists the design ice thickness and ice strength index to be used for estimation of the estimation of the propeller ice loads.

Table 6.5.2

Ice class	H_{ice}, [m]	S_{ice}	S_{quice}
PC1	4,0	1,2	1,15
PC2	3,5	1,1	1,15
PC3	3,0	1,1	1,15
PC4	2,5	1,1	1,15
PC5	2,0	1,1	1,15
PC6	1,75	1	1
PC7	1,5	1	1

where:

H_{ice} = Ice thickness for machinery strength design,

S_{ice} = Ice strength index for blade ice force,
S_{quice} = Ice strength index for blade ice torque.

6.5.3 Design ice loads for open propeller

6.5.3.1 Maximum backward blade force, F_b

when $D < D_{limit}$,

$$F_b = 27 \cdot S_{ice} \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z}\right]^{0.3} \cdot D^2 \text{, [kN]}$$

when $D \geq D_{limit}$,

$$F_b = 23 \cdot S_{ice} \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z}\right]^{0.3} [H_{ice}]^{1.4} \cdot D \text{, [kN]}$$

where:

$$D_{limit} = 0.85 \cdot [H_{ice}]^{1.4} \text{, [m]}$$

n is the nominal rotational speed at MCR in the free running open water condition for CP-propellers and 85% of the nominal rotational speed (at MCR free running condition) for a FP-propeller (regardless driving engine type) [rps].

F_b is to be applied as a uniform pressure distribution to an area on the back (suction) side of the blade for the following load cases:

a) Load case 1: from 0.6R to the tip and from the blade leading edge to a value of 0.2 chord length.
b) Load case 2: a load equal to 50% of the F_b is to be applied on the propeller tip area outside of 0.9R.
c) Load case 5: for reversible propellers a load equal to 60% of the F_b is to be applied from 0.6R to the tip and from the blade trailing edge to a value of 0.2 chord length.

See load cases 1, 2 and 5 in Table 6.5.3.

6.5.3.2 Maximum forward blade force F_f for open propellers

when $D < D_{limit}$,

$$F_f = 250 \cdot \left[\frac{EAR}{Z}\right] \cdot D^2 \text{, [kN],}$$

when $D \geq D_{limit}$,

$$F_f = 500 \cdot \left[\frac{1}{1-\frac{d}{D}}\right] \cdot H_{ice} \cdot \left[\frac{EAR}{Z}\right] \cdot D \text{, [kN],}$$

where:

$$D_{limit} = \left[\frac{2}{1-\frac{d}{D}}\right] H_{ice} \text{, [m].}$$

where:

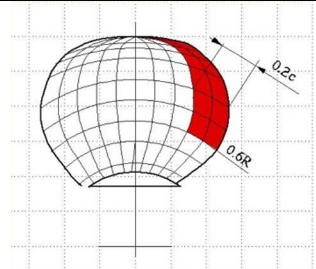
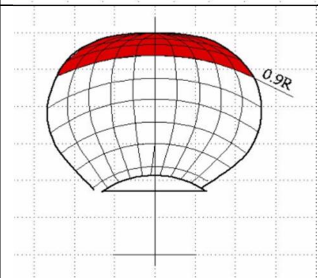
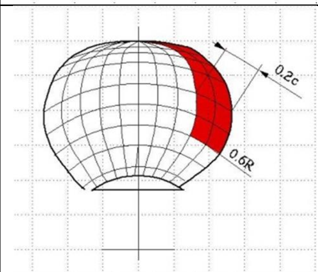
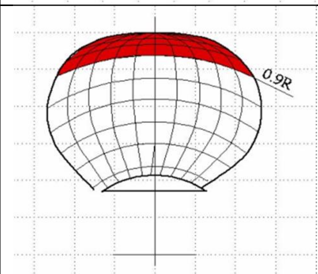
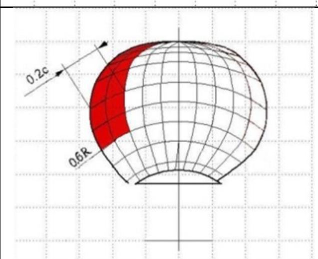
d = propeller hub diameter, [m],
D = propeller diameter, [m],
EAR = expanded blade area ratio
Z = number of propeller blades

F_f is to be applied as a uniform pressure distribution to an area on the face (pressure) side of the blade for the following loads cases:

a) Load case 3: from 0.6R to the tip and from the blade leading edge to a value of 0.2 chord length.
b) Load case 4: a load equal to 50% of the F_f is to be applied on the propeller tip area outside of 0.9R.
c) Load case 5: for reversible propellers a load equal to 60% F_f is to be applied from 0.6R to the tip and from the blade trailing edge to a value of 0.2 chord length.

See load cases 3, 4 and 5 in Table 6.5.3.

Table 6.5.3 - Loaded areas and load case definition for open propellers

	Force	Loaded area	Right-handed propeller blade seen from behind
Load case 1	F_b	Uniform pressure applied on the back of the blade (suction side) to an area from 0.6*R* to the tip and from the leading edge to 0.2 times the chord length.	
Load case 2	50% of F_b	Uniform pressure applied on the back of the blade (suction side) on the propeller tip area outside 0.9*R* radius.	
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6*R* to the tip and from the leading edge to 0.2 times the chord length.	
Load case 4	50% of F_f	Uniform pressure applied on propeller face (pressure side) on the propeller tip area outside 0.9*R* radius.	
Load case 5	60% of F_f or 60% of F_b, whichever is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0.6*R* to the tip and from the trailing edge to 0.2 times the chord length	

6.5.3.3 Maximum blade spindle torque, Q_{smax}

Spindle torque Q_{smax} around the spindle axis of the blade fitting shall be calculated both for the load cases described in 6.5.4.1 and 6.5.4.2 for F_b and F_f. If these spindle torque values are less than the default value given below, the default minimum value shall be used.

Default value:

$$Q_{s\max} = 0{,}25 \cdot F \cdot c_{0{,}7}\text{, [kNm]},$$

where:

$c_{0.7}$ = length of the blade chord at 0.7R radius [m]

F is either F_b or F_f which ever has the greater absolute value.

6.5.3.4 Maximum propeller ice torque applied to the propeller

When D < D_{limit}

Q_{max} = 105·(1 ï d/D)·S_{qice}·$(P_{0.7}/D)^{0,16}$·$(t_{0.7}/D)^{0,6}$·$(nD)^{0,17}$·D^3, [kNm],

When D ÓD_{limit}

Q_{max} = 202·(1ï d/D)·S_{qice}·$H_{ice}^{1,1}$·$(P_{0.7}/D)^{0,16}$·$(t_{0.7}/D)^{0,6}$· $(nD)^{0,17}$ ·$D^{1,9}$, [kNm],

where:

D_{limit} = 1.81 H_{ice}

S_{qice} = Ice strength index for blade ice torque

$P_{0.7}$ = propeller pitch at 0.7 R [m]

$t_{0.7}$ = max. thickness at 0.7 radius

n = the rotational propeller speed, [rps], at bollard condition. If not known, n is to be taken as follows in Table 6.5.3.4:

Table 6.5.3.4

Propeller type	*n*
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	0,85 n_n

Where n_n is the nominal rotational speed at MCR, free running condition.

For CP propellers, propeller pitch, $P_{0.7}$ shall correspond to MCR in bollard condition. If not known, $P_{0.7}$ is to be taken as $P_{0.7n}$, where $P_{0.7n}$ is propeller pitch at is to free running condition.

6.5.3.5 Maximum propeller ice thrust applied to the shaft

$T_f = 1.1 \cdot F_f$, [kN],

$T_b = 1.1 \cdot F_b$, [kN],

6.5.4 Design ice loads for ducted propeller

6.5.4.1 Maximum backward blade force, F_b for ducted propellers

when $D < D_{limit}$

$$F_b = -9.5 \cdot S_{ice} \cdot \left[\frac{EAR}{Z}\right]^{0.3} \cdot [n \cdot D]^{0.7} \cdot D^2\text{, [kN]}$$

when $D \geq D_{limit}$,

$$F_b = -66 \cdot S_{ice} \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z}\right]^{0.3} \cdot [H_{ice}]^{1.4} \cdot D^{0.6}\text{, [kN]}$$

where:

D_{limit} = 4ÄH_{ice}, [m],

n shall be taken as in 6.5.3.1

F_b is to be applied as a uniform pressure distribution to an area on the back side for the following load cases (see Table 6.5.4.4):

a) Load case 1: On the back of the blade from 0.6R to the tip and from the blade leading edge to a value of 0.2 chord length.

b) Load case 5: For reversible rotation propellers a load equal to 60% of F_b is applied on the blade face from 0.6R to the tip and from the blade trailing edge to a value of 0.2 chord length.

6.5.4.2 Maximum forward blade force, F_f for ducted propellers

when D ÒD_{limit}

$$F_f = 250 \cdot \left[\frac{EAR}{Z}\right] \cdot D^2\text{, [kN]},$$

when D > D_{limit}

$$F_f = 500 \cdot \left[\frac{EAR}{Z}\right] \cdot D \cdot \frac{1}{\left(1 - \frac{d}{D}\right)} \cdot H_{ice}\text{, [kN]}$$

F_f is to be applied as a uniform pressure distribution to an area on the face (pressure) side for the following load case (see Table 6.5.4.4):

a) Load case 3: On the blade face from 0.6R to the tip and from the blade leading edge to a value of 0.5 chord length.

b) Load case 5: A load equal to 60% F_f is to be applied from 0.6R to the tip and from the blade leading edge to a value of 0.2 chord length.

6.5.4.3 Maximum propeller ice torque applied to the propeller

Q_{max} is the maximum torque on a propeller due to ice-propeller interaction.

when $D < D_{limit}$,

Q_{max} = 74·(1ï d/D)·$(P_{0.7}/D)^{0,16}$·$(t_{0.7}/D)^{0,6}$·$(nD)^{0,17}$· S_{qice}·D^3, [kNm].

when D ÓD_{limit}

Q_{max} = 141·(1ï d/D)·$(P_{0.7}/D)^{0,16}$·$(t_{0.7}/D)^{0,6}$·$(nD)^{0,17}$·S_{qice}·$D^{1,9}$· $H_{ice}^{1,1}$, [kNm].

where:

D_{limit} = 1.81 H_{ice},

S_{qice} = Ice strength index for blade ice torque,

$P_{0.7}$ = propeller pitch at 0.7 R, [m],

$t_{0.7}$ = max thickness at 0.7 radius,

n = the rotational propeller speed, [rps], at bollard condition. If not known, n is to be taken as follows in Table 6.5.4.3:

Table 6.5.4.3

Propeller type	n
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	0,85 n_n

Where n_n is the nominal rotational speed at MCR, free running condition.

For CP propellers, propeller pitch, $P_{0.7}$ shall correspond to MCR in bollard condition. If not known, $P_{0.7}$ is to be taken as $P_{0.7n}$, where $P_{0.7n}$ is propeller pitch at is to free running condition.

6.5.4.4 Maximum blade spindle torque for CP mechanism design, Q_{smax}

Spindle torque Q_{smax} around the spindle axis of the blade fitting shall be calculated for the load cases described in 6.5.1. If these spindle torque values are less than the default value given below, the default value shall be used.

$$Q_{s\max} = 0{,}25 \cdot F \cdot c_{0,7}\text{, [kNm],}$$

where:

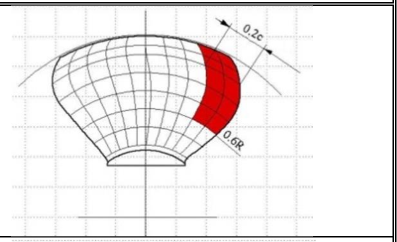
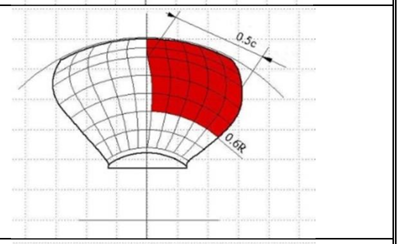
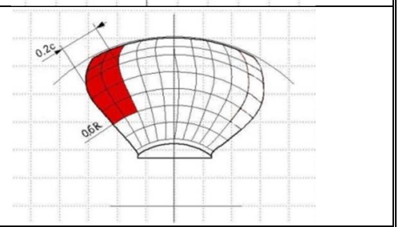
$c_{0.7}$ = length of the blade chord at 0.7R radius [m]

F = either F_b or F_f which ever has the greater absolute value.

6.5.4.5 Maximum propeller ice thrust applied to the shaft at the location of the propeller

$T_f = 1.1 \cdot F_f$, [kN],
$T_b = 1.1 \cdot F_b$, [kN].

Table 6.5.4.4 - Loaded areas and load case definition for ducted propellers

	Force	Loaded area	Right handed propeller blade seen from behind
Load case 1	F_b	Uniform pressure applied on the back of the blade (suction side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length.	
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6R to the tip and from the leading edge to 0.5 times the chord length.	
Load case 5	60% of F_f or 60% of F_b, whichever is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0.6R to the tip and from the trailing edge to 0.2 times the chord length.	

6.5.5 Design loads on propulsion lLine

6.5.5.1 Torque

The propeller ice torque excitation for shaft line dynamic analysis shall be described by a sequence of blade impacts which are of half sine shape and occur at the blade. The torque due to a single blade ice impact as a function of the propeller rotation angle is then

$Q(\varphi)=C_q \cdot Q_{max} \cdot sin(\varphi(180/\alpha_i))$, for $\varphi=0$é α_i

$Q(\varphi)=0$, for $\varphi=\alpha_i$é .360

where C_q and α_i parameters is to be taken according to Table 6.5.5.1.

Table 6.5.5.1

Torque excitation	Propeller ice interaction	C_q	α_i
Case 1	Single ice block	0,5	45
Case 2	Single ice block	0,75	90
Case 3	Single ice block	1,0	135
Case 4	Two ice block with 45º phase in rotation angle	0,5	45

The total ice torque is obtained by summing the torque of single blades taking into account the phase shift 360º./Z. The number of propeller revolutions during a milling sequence shall be obtained with the formula:

$N_Q = 2 \cdot H_{ice}$

The number of impacts is $Z \cdot N_Q$

Milling torque sequence duration is not valid for pulling bow propellers, which are subject to special consideration.

The response torque at any shaft component shall be analyzed considering excitation torque $Q(\varphi)$ at the propeller, actual engine torque Q_e and mass elastic system.

Q_e = actual maximum engine torque at considered speed

Design torque along propeller shaft line: The design torque (Q_r) of the shaft component shall be determined by means of torsional vibration analysis of the propulsion line. Calculations have to be carried out for all excitation cases given above and the response has to be applied on top of the mean hydrodynamic torque in bollard condition at considered propeller rotational speed.

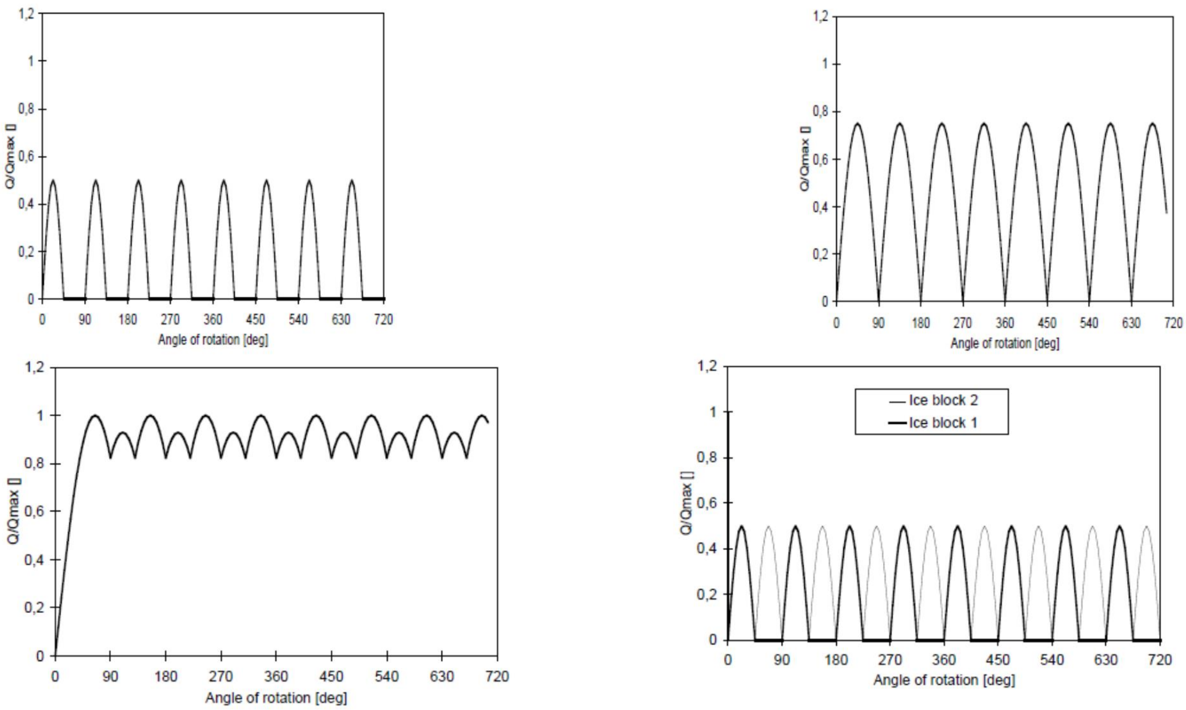


Figure 1 - The shape of the propeller ice torque excitation for 45, 90, 135º single blade impact sequences and 45º double blade impact sequence(two ice pieces) on a four bladed propeller

6.5.5.2 Maximum response thrust

Maximum thrust along the propeller shaft line is to be calculated with the formulae below. The factors 2.2 and 1.5 take into account the dynamic magnification due to axial vibration. Alternatively the propeller thrust magnification factor may be calculated by dynamic analysis.

Maximum Shaft Thrust Forwards: $T_r = T_n + 2.2 \cdot T_f$, [kN],

Maximum Shaft Thrust Backwards: $T_r = 1.5 \cdot T_b$, [kN].

T_n = propeller bollard thrust, [kN],

T_f = maximum forward propeller ice thrust, [kN].

If hydrodynamic bollard thrust, T_n, is not known, T_n is to be taken according to Table 6.5.5.2.

Table 6.5.5.2

Propeller type	T_n
CP propellers (open)	1,25·T
CP propellers (ducted)	1,1·T
FP propellers driven by turbine or electric motor	T
FP propellers driven by diesel engine (open)	0,85·T
FP propellers driven by diesel engine (ducted)	0,75·T

where T is nominal propeller trust at MCR at free running open water conditions.

6.5.5.3 Blade failure load for both open and nozzle propeller

The force is acting at 0.8R in the weakest direction of the blade and at a spindle arm of 2/3 of the distance of axis of blade rotation of leading and trailing edge whichever is the greatest.

The blade failure load is:

$$F_{ex} = \frac{0.3 \cdot c \cdot t^{2} \cdot \sigma_{ref1}}{0.8 \cdot D - 2 \cdot r} \cdot 10^3 \text{, [kN]},$$

where:

$$\sigma_{ref1} = 0.6 \cdot \sigma_{0.2} + 0.4 \cdot \sigma_u \text{, [N/mm}^2\text{]}.$$

σ_u (minimum ultimate tensile strength to be specified on the drawing) and $\sigma_{0.2}$ (minimum yield or 0.2% proof strength to be specified on the drawing) are representative values for the blade material

c, *t* and *r* are respectively the actual chord length, maximum thickness and radius of the cylindrical root section of the blade, which is the weakest section outside the root fillet located typically at the termination of the fillet into the blade profile.

6.6 DESIGN

6.6.1 Design principle

The strength of the propulsion line shall be designed:

a) for maximum loads in 6.5;
b) such that the plastic bending of a propeller blade shall not cause damages in other propulsion line components;
c) with sufficient fatigue strength.

6.6.2 Azimuthing main propulsors

In addition to the above requirements special consideration shall be given to the loading cases which are extraordinary for propulsion units when compared with conventional propellers. Estimation of the loading cases must reflect the operational realities of the ship and the thrusters. In this respect, for example, the loads caused by impacts of ice blocks on the propeller hub of a pulling propeller must be considered. Also loads due to thrusters operating in an oblique angle to the flow must be considered. The steering mechanism, the fitting of the unit and the body of the thruster shall be designed to withstand the loss of a blade without damage. The plastic bending of a blade shall be considered in the propeller blade position, which causes the maximum load on the studied component.

Azimuth thrusters shall also be designed for estimated loads due to thruster body/ice interaction as per Section 3, 3.11.

6.6.3 Blade design

6.6.3.1 Maximum blade stresses

Blade stresses are to be calculated using the backward and forward loads given in Section 6.5.3 and 6.5.4. The stresses shall be calculated with recognized and well documented FE-analysis or other acceptable alternative method. The stresses on the blade shall not exceed the allowable stresses ůall for the blade material given below.

$$\sigma_{calc} < \sigma_{all}$$

where:

$$\sigma_{all} = \frac{\sigma_{ref}}{1{,}5}$$

σ_{ref} = reference stress, defined as:

$\sigma_{ref} = 0{,}7 \cdot \sigma_u$ or

$\sigma_{ref} = 0{,}6 \cdot \sigma_{0{,}2} + 0{,}4 \cdot \sigma_u$, whichever is less.

where σ_u (ultimate tensile strength for blade material) and $\sigma_{0,2}$ (0,2% proof stress for blade material) are representative values for the blade material.

6.6.3.2 Blade edge thickness

The blade edge thickness ted and tip thickness ttip are to be greater than tedge given by the following formula:

$$t_{edge} \geq x \cdot S \cdot S_{ice} \cdot \sqrt{\frac{3 \cdot p_{ice}}{\sigma_{ref}}}$$

where:

x	=	distance from the blade edge measured along the cylindrical sections from the edge and shall be 2.5% of chord length, however not to be taken greater than 45 mm. In the tip area (above 0.975R radius) x shall be taken as 2.5% of 0.975R section length and is to be measured perpendicularly to the edge, however not to be taken greater than 45 mm.
S	=	safety factor
	=	2.5 for trailing edges
	=	3.5 for leading edges
	=	5 for tip
S_{ice}	=	according to 6.5.2
p_{ice}	=	ice pressure; 16 N/mm^2 for leading edge and tip thickness
σ_{ref}	=	reference stress according 6.6.3.1.

The requirement for edge thickness has to be applied for leading edge and in case of reversible rotation open propellers also for trailing edge. Tip thickness refers to the maximum measured thickness in the tip area above 0.975*R* radius. The edge thickness in the area between position of maximum tip thickness and edge thickness at 0.975 radius has to be interpolated between edge and tip thickness value and smoothly distributed.

6.6.4 Prime movers

6.6.4.1 The Main engine is to be capable of being started and running the propeller with the CP in full pitch.

6.6.4.2 Provisions shall be made for heating arrangements to ensure ready starting of the cold emergency power units at an ambient temperature applicable to the Polar class of the ship.

6.6.4.3 Emergency power units shall be equipped with starting devices with a stored energy capability of at least three consecutive starts at the design temperature. The source of stored energy shall be protected to preclude critical depletion by the automatic starting system, unless a second independent means of starting is provided. A second source of energy shall be provided for an additional three starts within 30 min., unless manual starting can be demonstrated to be effective.

6.7 MACHINERY FASTENING LOADING ACCELERATIONS

6.7.1 Essential equipment and main propulsion machinery supports shall be suitable for the accelerations as indicated in as follows. Accelerations are to be considered acting independently.

6.7.2 Longitudinal impact accelerations, a_l

Maximum longitudinal impact acceleration at any point along the hull girder:

$$a_l = \frac{F_{IB}}{\Delta} \cdot \left[1{,}1 \cdot \tan(\gamma + \phi) + 7 \cdot \frac{H}{L} \right], \text{ [m/s}^2\text{].}$$

6.7.3 Vertical acceleration, a_v

Combined vertical impact acceleration at any point along the hull girder:

$$a_v = 2{,}5 \cdot F_{IB} \cdot \frac{F_X}{\Delta_{UI}}, \quad \text{[m/s}^2\text{].}$$

F_X = 1.3 at FP
= 0.2 at midships
= 0.4 at AP
= 1.3 at AP for vessels conducting ice breaking astern

Intermediate values to be interpolated linearly.

6.7.4 Transverse impact acceleration, a_t

Combined transverse impact acceleration at any point along hull girder:

$$a_t = 3 \cdot \frac{F_X}{\Delta}, \text{ [m/s}^2\text{].}$$

F_X = 1.5 at FP
= 0.25 at midships
= 0.5 at AP
= 1.5 at AP for vessels conducting ice breaking astern

Intermediate values to be interpolated linearly.

where:

ϕ = maximum friction angle between steel and ice, normally taken as 10°, [°],
γ = bow stem angle at waterline, [°],
Δ = displacement,
L = length between perpendiculars, [m],
H = distance, in meters, from the waterline to the point being considered, [m],
F_{IB} = vertical impact force, defined in Section 3, 3.9 Longitudinal strength
F_i = total force normal to shell plating in the bow area due to oblique ice impact, defined in Section 3, 3.3.

6.8 AUXILIARY SYSTEMS

6.8.1 Machinery shall be protected from the harmful effects of ingestion or accumulation of ice or snow. Where continuous operation is necessary, means should be provided to purge the system of accumulated ice or snow.

6.8.2 Means should be provided to prevent damage due to freezing, to tanks containing liquids.

6.8.3 Vent pipes, intake and discharge pipes and associated systems shall be designed to prevent blockage due to freezing or ice and snow accumulation.

6.9 SEA INLETS AND COOLING WATER SYSTEMS

6.9.1 Cooling water systems for machinery that are essential for the propulsion and safety of the vessel, including sea chests inlets, shall be designed for the environmental conditions applicable to the ice class.

6.9.2 At least two sea chests are to be arranged as ice boxes for class PC1 to PC5 inclusive where. The calculated volume for each of the ice boxes shall be at least 1m3 for every 750 kW of the total installed power. For PC6 and PC7 there shall be at least one ice box located preferably near centerline.

6.9.3 Ice boxes are to be designed for an effective separation of ice and venting of air.

6.9.4 Sea inlet valves are to be secured directly to the ice boxes. The valve shall be a full bore type.

6.9.5 Ice boxes and sea bays are to have vent pipes and are to have shut off valves connected direct to the shell.

6.9.6 Means are to be provided to prevent freezing of sea bays, ice boxes, ship side valves and fittings above the load waterline.

6.9.7 Efficient means are to be provided to re-circulate cooling seawater to the ice box. Total sectional area of the circulating pipes is not to be less than the area of the cooling water discharge pipe.

6.9.8 Detachable gratings or manholes are to be provided for ice boxes. Manholes are to be located above the deepest load line. Access is to be provided to the ice box from above.

6.9.9 Openings in ship sides for ice boxes are to be fitted with gratings, or holes or slots in shell plates. The net area through these openings is to be not less than 5 times the area of the inlet pipe. The diameter of holes and width of slot in shell plating is to be not less than 20 mm. Gratings of the ice boxes are to be provided with a means of clearing. Clearing pipes are to be provided with screw-down type non return valves.

6.10 BALLAST TANKS

6.10.1 Efficient means are to be provided to prevent freezing in fore and after peak tanks and wing tanks located above the water line and where otherwise found necessary.

6.11 VENTILATION SYSTEM

6.11.1 The air intakes for machinery and accommodation ventilation are to be located on both sides of the ship.

6.11.2 Accommodation and ventilation air intakes shall be provided with means of heating.

6.11.3 The temperature of inlet air provided to machinery from the air intakes shall be suitable for the safe operation of the machinery.

6.12 ALTERNATIVE DESIGN

6.12.1 As an alternative a comprehensive design study may be submitted and may be requested to be validated by an agreed test programme.

7 FIRE SAFETY AND PROTECTION

7.1 GOAL

The goal of this Section is to ensure that fire safety systems and appliances are effective and operable, and that means of escape remain available so that persons on board can safely and swiftly escape to the lifeboat and liferaft embarkation deck under the expected environmental conditions.

7.2 FUNCTIONAL REQUIREMENTS

In order to achieve the goal set out in 7.1, the provisions in 7.2.1 to 7.2.5 are to be complied with:

7.2.1 All components of fire safety systems and appliances if installed in exposed positions are to be protected from ice accretion and snow accumulation;

7.2.2 Local equipment and machinery controls are to be arranged so as to avoid freezing, snow accumulation and ice accretion and their location to remain accessible at all time;

7.2.3 The design of fire safety systems and appliances are to take into consideration the need for persons to wear bulky and cumbersome cold weather gear, where appropriate;

7.2.4 Means are to be provided to remove or prevent ice and snow accretion from accesses;

7.2.5 Extinguishing media are to be suitable for intended operation.

7.3 REGULATIONS

7.3.1 Ships intended to operate in low air temperature

In addition to provisions in 7.2, for ships intended to operate in low air temperature, the provisions in 7.3.1.1 and 7.3.1.2 are to be complied with:

7.3.1.1 All components of fire safety systems and appliances are to be designed to ensure availability and effectiveness under the polar service temperature; and

7.3.1.2 Materials used in exposed fire safety systems are to be suitable for operation at the polar service temperature.

7.3.2 Fire safety systems and appliances installed in exposed positions

In order to comply with the requirements of 7.2.1, the 7.3.2.1 and 7.3.2.2 are to apply:

7.3.2.1 Isolating and pressure/vacuum valves in exposed locations are to be protected from ice accretion and remain accessible at all time; and

7.3.2.2 All two-way portable radio communication equipment is to be operable at the polar service temperature.

7.3.3 Local equipment and machinery controls

In order to comply with the requirements of 7.2.2, the provisions of 7.3.3.1 to 7.3.3.4 are to be complied with:

7.3.3.1 Fire pumps including emergency fire pumps, water mist and water spray pumps are to be located in compartments maintained above freezing;

7.3.3.2 The fire main is to be arranged so that exposed sections can be isolated and means of draining of exposed sections are to be provided. Fire hoses and nozzles need not be connected to the fire main at all times, and may be stored in protected locations near the hydrants;

7.3.3.3 Firefighter s outfits are to be stored in warm locations on the ship;

7.3.3.4 Where fixed water-based firefighting systems are located in a space separate from the main fire pumps and use their own independent sea suction, this sea suction is to be also capable of being cleared of ice accumulation.

7.3.4 Ships intended to operate in low air temperatures

In addition to 7.3.2 and 7.3.3, for ships intended to operate in low air temperature, the provisions in 7.3.4.1 and 7.3.4.2 are to apply:

7.3.4.1 In order to comply with the requirements of 7.3.1.1, portable and semi-portable extinguishers are to be located in positions protected from freezing temperatures, as far as practical. Locations subject to freezing are to be provided with extinguishers capable of operation under the polar service temperature.

7.3.4.2 In order to comply with the functional requirements of 7.3.3.2, materials of exposed fire safety systems are to be acceptable to the *Register*.

8 ICE CLASS SHIPS

8.1 GENERAL

8.1.1 The requirements of this Section are related to ships intended for navigation in first year ice conditions primarily in the Northern Baltic irrespective of whether assistance from ice breakers is anticipated.

8.1.2 Requirements stated in this Section are in accordance with the "*Finnish-Swedish' Ice Class Rules 2017*".

The relationship between ice class notation in accordance with the "*Finnish-Swedish Ice Class Rules*" and ice class notation of the *Register* is given in Section 1.3.3.

Special requirements for ice class 1D relating to the hull and machinery are given in Section 8.13.8.

8.2 MAXIMUM AND MINIMUM DRAUGHT

8.2.1 Upper and lower ice waterline

8.2.1.1 The upper ice waterline (UIWL) shall be the envelope of the highest points of the waterlines at which the ship is intended to operate in ice. The line may be a broken line.

8.2.1.2 The lower ice waterline (LIWL) shall be the envelope of the lowest points of the waterlines at which the ship is intended to operate in ice. The line may be a broken line.

8.2.2 Maximum and minimum draught fore and aft

8.2.2.1 The maximum and minimum ice class draughts at fore and aft perpendiculars shall be determined in accordance with the upper and lower ice waterlines and the draught of the ship at fore and aft perpendiculars, when ice conditions require the ship to be ice-strengthened, shall always be between the upper and lower ice waterlines.

8.2.2.2 Restrictions on draughts when operating in ice shall be documented and kept on board readily available to the master. The maximum and minimum ice class draughts fore, amidships and aft shall be indicated in the Class certificate. If the summer load line in fresh water is anywhere located at a higher level than the UIWL, the ship's sides are to be provided with a warning triangle and with an ice class draught mark at the maximum permissible ice class draught amidships, see 8.2.3.

8.2.2.3 The draught and trim, limited by the UIWL, are not to be exceeded when the ship is navigating in ice. The salinity of the sea water along the intended route is to be taken into account when loading the ship.

8.2.2.4 The ship shall always be loaded down at least to the draught of LIWL when navigating in ice. Any ballast tank, situated above the LIWL and needed to load down the ship to this water line, shall be equipped with devices to prevent the water from freezing. In determining the LIWL, regard shall be paid to the need for ensuring a reasonable degree of ice-going capability in ballast. The highest point of the propeller shall be submerged and if possible at a depth of at least h_0 below the water surface in all loading conditions.

8.2.2.5 The forward draught shall be at least:

$$d_{min} = h_o\,(2{,}0 + 0{,}00025 \cdot \Delta)\,, \quad [\text{m}],$$

but need not exceed:

$$d_{min} = 4 \cdot h_o\,, \ [\text{m}],$$

Δ = displacement of the ship, in [t], determined from the waterline on the UIWL (see section 8.2.1). Where multiple waterlines are used for determining the UIWL, the displacement must be determined from the waterline corresponding to the greatest displacement;

h_o = the level ice thickness, according to Section 8.4.1.

8.2.3 Ice class draught marking

8.2.3.1 Subject to Section 8.2.2.2, the ship's sides are to be provided with a warning triangle and with a draught mark at the maximum permissible ice class draught amidships (see Fig. 8.2.3.1). The purpose of the warning triangle is to provide information on the draught limitation of the vessel when it is sailing in ice for masters of icebreakers and for inspection personnel in ports.

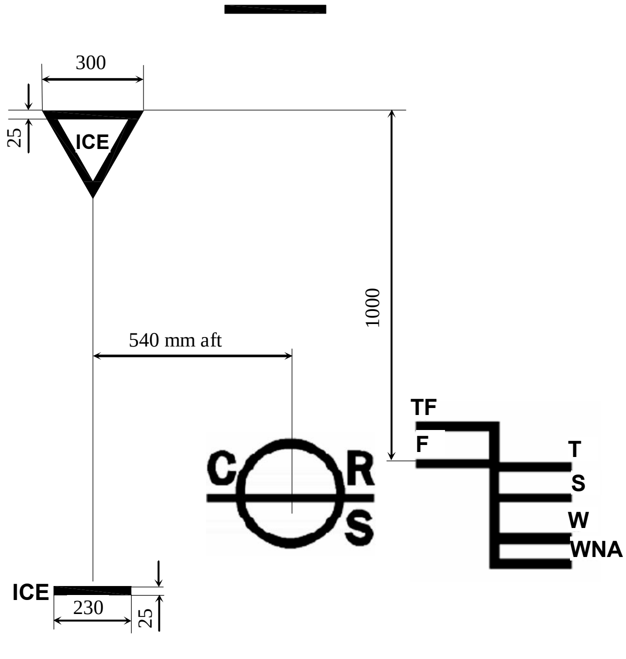


Figure 8.2.3.1 - Ice class draught marking

NOTES to Fig. 8.2.3.1:

1. The upper edge of the warning triangle is to be located vertically above the ñICEò mark, 1000 mm higher than the summer load line in fresh water but in no case higher than the deck line. The sides of the triangle are to be 300 mm in length.
2. The ice class draught mark is to be located 540 mm abaft the centre of the load line ring or 540 mm abaft the vertical line of the timber load line mark, if applicable.
3. The marks and figures are to be cut out of 5 - 8 mm plate and then welded to the ship's side. The marks and figures are to be painted in a red or yellow reflecting colour in order to make the marks and figures plainly visible even in ice conditions.
4. The dimensions of all letters are to be the same as those used in the load line mark.

8.3 HULL STRUCTURAL DESIGN

8.3.1 General

8.3.1.1 The method for determining the hull scantlings is based on certain assumptions concerning the nature of the ice load on the structure. These assumptions are from full scale observations made in the northern Baltic.

It has thus been observed that the local ice pressure on small areas can reach rather high values. This pressure may be well in excess of the normal uniaxial crushing strength of sea ice. This is explained by the fact that the stress field is in fact multiaxial.

Furthermore, it has been observed that the ice pressure on a frame can be higher than on the shell plating at the midspacing between frames. This is due to the different flexural stiffness of frames and shell plating. The load distribution is assumed to be as shown in Fig. 8.3.1.1.

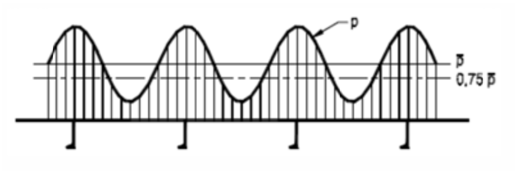


Figure 8.3.1.1 - Ice load distribution on a ship's side

8.3.1.2 The formulae and values given in this Section may be substituted by direct calculation methods if they are deemed by the *Register* to be invalid or inapplicable for a given structural arrangement or detail.

Otherwise, direct analysis is not to be used as an alternative to the analytical procedures prescribed by the explicit requirements in 8.5 to 8.7.

Direct analyses are to be carried out using the load patch defined in 8.4 (p, h and l_a). The pressure to be used is $1.8{\cdot}p$, where p is determined according to 8.4.2. The load patch is to be applied at locations where the capacity of the structure under the combined effects of bending and shear are minimized. In particular, the structure is to be checked with the load centred on the UIWL, $0.5{\cdot}h_0$ below the LIWL, and several vertical locations in between. Several horizontal locations are also to be checked, especially the locations centred at the mid-span or mid-spacing. Furthermore, if the load length l_a cannot be determined directly from the arrangement of the structure, several values of l_a shall be checked using corresponding values for c_a.

The acceptance criterion for designs is that the combined stresses from bending and shear, using the von Mises yield criterion, are lower than the yield strength R_{eH}. When the direct calculation is performed using beam theory, the allowable shear stress is not to be greater than $0.9 \cdot \tau_y$, where $\tau_y = R_{eH} / \sqrt{3}$.

If scantlings derived from these regulations are less than those required by the *Register* for a ship that has not been ice strengthened ship, the latter shall be used.

8.3.1.3 The frame spacings and spans defined in the following text are normally (in accordance with the *Rules for the classification of ships, Part 2 - Hull,* Section 2) assumed to be measured along the plate and perpendicular to the axis of the stiffener for plates, along the flange for members with a flange, and along the free edge for flat bar stiffeners. For curved members the span (or spacing) is defined as the chord length between span (or spacing) points. The span points are defined by the intersection between the flange or upper edge

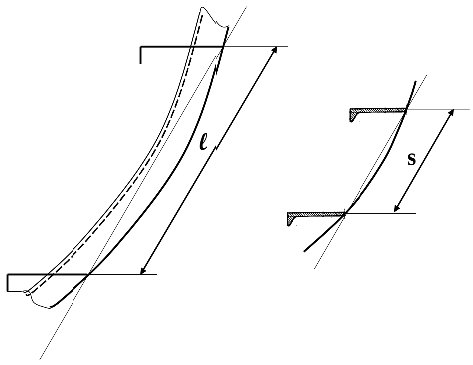


Figure 8.3.1.3 - Definition of the frame span (left) and frame spacing (right) for curved members

8.3.1.4 The effective breadth of the attached plate to be used for calculating the combined section modulus of the stiffener, stringer and web frame and attached plate must be given the value which the appropriate Rules of the *Register* require. The effective breadth shall in no case be more than what is stated in the appropriate Rules of the *Register* for the ship in question.

8.3.1.4 The requirements for the section modulus and shear area of the frames, stringers and web frames in 8.6, 8.7 and 8.8 are in accordance with the effective member cross section. For cases where the member is not normal to the plating, the section properties are to be calculated in accordance with the appropriate Rules of the *Register* for the ship in question.

8.3.2 Hull regions

For the purpose of this Section, the ship's hull is divided into regions as follows (see also Fig. 8.3.2):

8.3.2.1 Bow region

The region from the stem to a line parallel to and $0.04{\cdot}L$ aft of the forward borderline of the part of the hull where the waterlines run parallel to the centerline. For ice classes 1AS and 1A, the overlap over the borderline need not exceed 6 meters, for ice classes 1B and 1C this overlap need not exceed 5 meters and for ice class 1D this overlap need not exceed 2 meter.

8.3.2.2 Midbody region

The region from the aft boundary of the Bow region to a line parallel to and $0.04{\cdot}L$ aft of the aft borderline of the part of the hull where the waterlines run parallel to the centerline. For ice classes 1AS and 1A the overlap over the borderline need not exceed 6 meters, for ice classes 1B and 1C this overlap need not exceed 5 meters and for ice class 1D this overlap need not exceed 2 meter.

8.3.2.3 Stern region

The region from the aft boundary of the mid-body region to the stern.

L shall be taken as the ship's rule length as defined in the *Rules for the classification of ships, Part 2 - Hull*, 1.2.3.1.

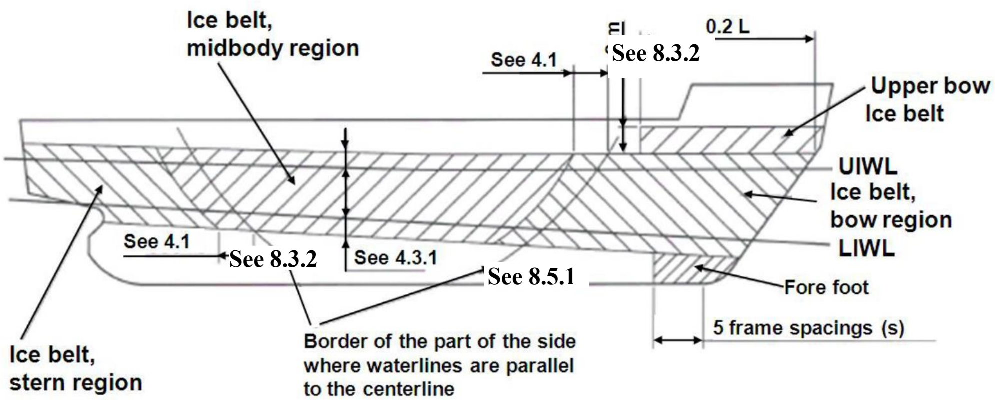


Figure 8.3.2 - Ice strengthened regions of the hull

8.4 ICE LOAD

8.4.1 Height of load area

An ice strengthened ships is assumed to operate in open sea conditions corresponding to a level ice thickness not exceeding h_o. The design ice load height *h* of the area actually under ice pressure at any particular point of time is, however, assumed to be only a fraction of the ice thickness. The values for h_o and *h* are given in Table 8.4.1.

Table 8.4.1

Ice class	h_o [m]	*h* [m]
1AS	1,0	0,35
1A	0,8	0,30
1B	0,6	0,25
1C	0,4	0,22
1D	0,4	0,22

8.4.2 Ice pressure

The design ice pressure is to be determined according to the following formula:

$$p = C_d \cdot C_p \cdot C_a \cdot p_o, \text{ in [N/mm}^2\text{]},$$

where:

C_d is a factor which takes account of the influence of the size and engine output of the ship. The value of this factor is a maximum of c_d = 1. It is calculated by the formula:

$$C_d = \frac{a \cdot k + b}{1000};$$

$k = \frac{\sqrt{\Delta \cdot P}}{1000}$, for the ice class notations 1AS, 1A, 1B and 1C;

$k = \frac{\sqrt{\Delta \cdot 740}}{1000}$, for the ice class notation 1D;

a,b = the values are given in Table 8.4.2-1:

Δ = displacement of the ship at maximum ice class draught, [t], see 8.2.2;

P = actual continuous engine output of the ship available when sailing in ice, [kW], see 8.12.1. If additional power sources are available for propulsion power (e.g. shaft motors) in addition to the power of the main engine(s), they shall also be included in the total engine output used as the basis for hull scant-ling calculations. The engine output used for the calculation of the hull scantlings shall be clearly stated on the shell expansion drawing.

C_p = factor that reflects the magnitude of the load expected in the hull area in question relative to the bow area.

The value of c_p is given in Table 8.4.2-2;

c_a = factor which takes account of the probability that the full length of the area under consideration will be under pressure at the same time. It is calculated using the formula:

$$c_a = \sqrt{\frac{l_0}{l_a}}, \text{ max 1,0; min 0,35;}$$

l_0 = 0,6 m.

l_a = effective length, [m], according to Table 8.4.2-3;

p_o = 5,6 N/mm^2 (nominal ice pressure).

Table 8.4.2-1

Region	Bow		Midbody and Stern	
k	$k \le 12$	$k > 12$	$k \le 12$	$k > 12$
a	30	6	8	2
b	230	518	214	286

Table 8.4.2-2

Ice class	Region		
	Bow	Midbody	Stern
1AS	1,0	1,0	0,75
1A	1,0	0,85	0,65
1B	1,0	0,7	0,45
1C	1,0	0,5	0,25
1D	0,3	-	-

Table 8.4.2-3

Structure	Type of framing	l_a [m]
Shell	transverse	frame spacing
	longitudinal	1,7 x frame spacing
Frames	transverse	frame spacing
	longitudinal	span of frame
Ice stringer		span of stringer
Web frame		2 x web frame spacing

8.5 SHELL PLATING

8.5.1 Vertical extension of ice strengthening for plating (ice belt)

8.5.1.1 The vertical extension of the ice belt shall be as given in Table 8.5.1.1, see also Fig. 8.3.2.

Table 8.5.1.1

Ice Class	Hull region	Above UIWL	Below LIWL
1AS	Bow	0,6 m	1,20 m
	Midbody		
	Stern		1,0 m
1A	Bow	0,5 m	0,9 m
	Midbody		0,75 m
	Stern		
1B, 1C, 1D	Bow	0,4 m	0,7 m
	Midbody		0,6 m
	Stern		

In addition, the following areas shall be strengthened:

8.5.1.2 Fore foot

For ice class 1AS, the shell plating below the ice belt from the stem to a position five main frame spacing abaft of the point where the bow profile departs from the keel line shall be ice-strengthened in the same way as the bow region.

8.5.1.3 Upper bow ice belt

For ice classes 1AS and IA on ships with an open water service speed equal to or exceeding 18 knots, the shell plate from the upper limit of the ice belt to 2 m above it and from the stem to a position at least 0.2 *L* abaft of the forward perpendicula, shall be ice-strengthened in the same way as the midbody region. A similar strengthening of the bow region is also advisable for a ship with a lower service speed when, on the basis of the model tests, for example, it is evident that the ship will have a high bow wave.

Sidescuttles shall not be situated in the ice belt. If the weather deck in any part of the ship is situated below the upper limit of the ice belt (e.g. in way of the well of a raised quarter decker), the bulwark shall be provided with at least the same strength as is required for the shell in the ice belt. The strength of the construction of the freeing ports shall meet the same requirements.

8.5.2 Plate thickness in the ice belt

8.5.2.1 The thickness of the shell plating is to be determined by the following formulae:

a) transverse framing:

$$t = 667 \cdot s \cdot \sqrt{\frac{f_1 \cdot p_{PL}}{R_{eH}}} + t_k \text{, [mm];}$$

b) longitudinal framing:

$$t = 667 \cdot s \sqrt{\frac{p}{f_2 \cdot R_{eH}}} + t_k \text{, [mm],}$$

where:

p_{PL} = 0.75 *p*, where *p* is given in 8.4.2;

f_1 = $1{,}3 - \dfrac{4{,}2}{(1{,}8 + h/s)^2}$;

f_{1max} = 1,0

f_2 = $0{,}6 + \dfrac{0{,}4}{h/s}$, for $h/s \le 1$;

f_2 = 1,4 ï 0,4 (*h*/*s*), for $1 \le h/s \le 1{,}8$;

t_k = the increment for abrasion and corrosion, in [mm]. Normally t_k shall be 2 mm. If a special surface coating, by experience, shown by experience to be capable of withstanding abrasion by ice, is applied and maintained, lower values may be approved, see 8.5.2.2.

s = frame spacing, in [m];

R_{eH} = minimum nominal upper yield stress for hull structural steel according to the *Rules for the classification of ships, Part 2 - Hull*, Section 1.4.2.1;

h = design ice load height, in [m], according to 8.4.1.

8.5.2.2 The corrosion allowance is to be taken as 2 mm. A 1 mm reduction in corrosion allowance can be considered if a recognized abrasion resistant coating is applied. Recognition of an abrasion resistant ice coating is generally based on satisfactory service experience and laboratory tests. As the actual performance of a coating cannot be accurately assessed in laboratory, service experience is particularly important to the assessment of such products. Manufacturers should therefore submit sufficient dry docking reports of ships to which the coating has previously been applied and which have operated in ice conditions, in addition to laboratory test results. The laboratory tests should be carried using a recognised coating system as a reference.

The surface preparation and coating application are as important as selecting the correct coating and should strictly follow the manufacturerǿs instruction. In general, the steel surfaces should be abrasive blasted to Sa2½ (ISO 8501-1) or Sa3, with a surface roughness of at least 75 εm. If a repair painting is applied, similar requirements are to be followed ï and the old coating should be roughened and the salinity (chloride contamination level) of the surfaces should be checked and must be less than 5 εg/cm^2.

When considering the laboratory testing, the following testing procedure could be followed:

- Resistance to abrasion (Taber abraser test),
- Impact resistance,
- Adhesion strength,
- Extensibility (flexibility) e.g. according to ASTM D4145.

In addition, the following corrosion tests could be considered:

- Cyclic corrosion test or salt spray test,
- Water immersion test,
- Cathodic disbondment test.

The test results should be compared with those from a product already recognised by the *Register*. A measure of an abrasion resistance is given by the Taber abrasion test (ASTM D4060) where the rate of abrasion has been 160 mg/1000 rounds using a 1kg weight and CS17 disks.

The acceptance of 1mm corrosion allowance is subject to adequate documentation submitted to the *Register*.

8.6 FRAMES

8.6.1 Vertical extension of ice strengthening for framing

8.6.1.1 The vertical extension of the ice strengthening of framing shall be at least as given in Table 8.6.1.1.

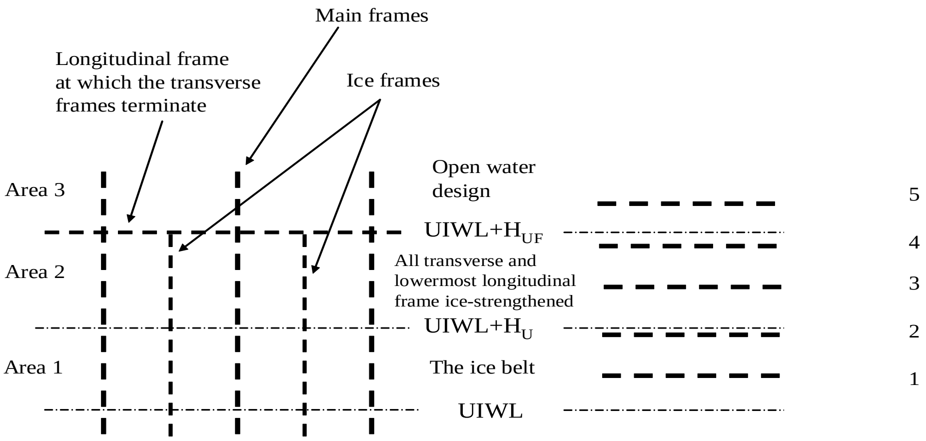
Where an upper bow ice belt is required (see 8.5.1), the ice-strengthened part of the framing shall be extended at least to the top of this ice belt.

Where the ice-strengthening would go beyond a deck, the top or bottom plating of a tank or tank top by no more than 250 mm, it can be terminated at that deck, top or bottom plating of the tank or tank top.

Table 8.6.1.1

Ice class	Hull region	Above UIWL	Below LIWL
1AS	Bow	1.2 m	Down to tank top or below top of the floors
	Midbody		2.0 m
	Stern		1.6 m
1A, 1B, 1C	Bow	1.0 m	1.6 m
	Midbody		1.3 m
	Stern		1.0 m
1D		1.0 m	1.0 m

8.6.1.2 It is assumed that only the ice belt area (Area 1 in Fig. 8.6.1.2), as defined in paragraph 8.5.1, will be directly exposed to the ice contact and pressure. For this reason, the vertical extension of the ice strengthening of the longitudinal frames should be extended up to and including the next frame up from the upper edge of the ice belt (frame 3 in Fig. 8.6.1.2). Additionally the frame spacing of the longitudinal frames just above and below the edge of the ice belt should be the same as the frame spacing in the ice belt (spacing between frames 2 and 3 should be the same as between frames 1 and 2 in Fig. 8.6.1.2). If, however, the first frame in the area above the ice belt (frame 3 in area 2 in Fig. 8.6.1.2) is closer than about $s/2$ to the edge of the ice belt, then the same frame spacing as in the ice belt should be used above the edge of the ice belt, i.e. in the spacing between frames 3 and 4 (where s is frame spacing in the ice belt).



Transverse framing Longitudinal framing

Figure 8.6.1.2 - The different ice strengthening areas at and above the UIWL. The distances H_U and H_{UF} are specified in tables 8.5.1.1 and 8.6.1.1, respectively (columns 'above UIWL'); these distances vary depending on the ice class

8.6.2 Transverse frames

8.6.2.1 Section modulus and shear area

The section modulus of a main, 'tweendeck or intermediate transverse frame is to be determined according to the following formula:

$$W = \frac{p \cdot s \cdot h \cdot l}{m_t \cdot R_{eH}} \cdot 10^6, \quad [cm^3],$$

and the effective shear area is calculated from:

$$A = \frac{\sqrt{3} \cdot f_3 \cdot s \cdot p \cdot h}{2 \cdot R_{eH}} 10^4, \quad [cm^2],$$

where:

p = ice pressure as given in 8.4.2, [N/mm^2];
s = frame spacing, [m];
l = span of the frame, [m];
h = height of load area as given in 8.4.1, [m].

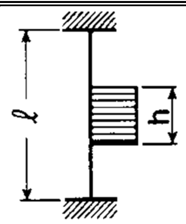
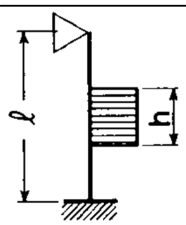
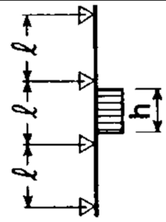
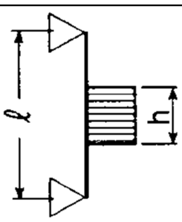
$$m_t = \frac{7 \cdot m_o}{7 - 5 \cdot h / l};$$

f_3 = factor which takes into account the maximum shear force versus the load location and shear stress distribution, defined as f_3 = 1.2.

R_{eH} = minimum upper yield stress for hull structural steel according to the *Rules for the classification of ships, Part 2 - Hull*, Section 1.4.2.1;

m_o = coefficient taking into account the boundary conditions. The values of m_0 are given in Table 8.6.2.1.

Table 8.6.2.1

Boundary condition	m_o	**Example**
	7	Frames in a bulk carrier with top wing tanks
	6	Frames extending from the tank top to the main deck of a single-decked vessel
	5,7	Continuous frames between several decks or stringers
	5	Frames extending between two decks only.

The boundary conditions referred to in Table 8.6.2.1 are those for the main and intermediate frames. Load is applied at mid span.

Where less than 15% of the span, l, of the frame is situated within the ice-strengthening zone for frames as defined in 8.6.1, ordinary frame scantlings may be used.

8.6.2.2 Upper end of transverse framing

The upper end of the strengthened part of a main frame and of an intermediate ice frame shall be attached to a deck, top or bottom plating of a tank or an ice stringer (Section 8.7).

Where a frame terminates above a deck or a stringer which is situated at or above the upper limit of the ice belt (Section 8.5.1), the part above the deck or stringer may have the scantlings required by the *Register* for an non ice-strengthened ship and the upper end of an intermediate frame may be connected to the adjacent frames by a horizontal member having the same scantlings as the main frame.

8.6.2.2 Lower end of transverse framing

The lower end of the strengthened part of a main frame and of an intermediate ice frame shall be attached to a deck, top or bottom plating of a tank or an ice stringer (Section 8.7).

Where an intermediate frame terminates below a deck, top or bottom plating of a tank or ice stringer which is situated at or below the lower limit of the ice belt (Section 8.5.1), the lower end may be connected to the adjacent main frames by a horizontal member of the same scantlings as the main frames. Note that the main frames below the lower edge of ice belt must be ice strengthened, see 8.6.1.

8.6.3 Longitudinal frames

8.6.3.1 The following requirements are intended for longitudinal frames with all end conditions.

8.6.3.2 The section modulus of a longitudinal frame shall be calculated using the following formula:

$$W = \frac{f_4 \cdot p \cdot h \cdot l^2}{m \cdot R_{eH}} \cdot 10^6, \qquad [\text{cm}^3],$$

and the effective shear area shall be calculated using the formula:

$$A = \frac{\sqrt{3} \cdot f_4 \cdot f_5 \cdot p \cdot h \cdot l}{2 \cdot R_{eH}} 10^4, \quad [\text{cm}^2],$$

In calculating the actual shear area of the frames, the shear area of the brackets is not to be taken into account.

where:

p = ice pressure as given in 8.4.2, [N/mm^2];

l = total span of frame, [m];

h = height of load area as given in 8.4.1, [m];.

f_4 = a factor which takes account of the load distribution over adjacent frames:

$f_4 = (1 - 0.2\, h/s)$;

f_5 = factor which takes into account of the maximum shear force versus the load location and shear stress distribution, defined as f_5 = 2.16;

R_{eH} = minimum upper yield stress for hull structural steel according to the *Rules for the classification of ships, Part 2 - Hull*, Section 1.4.2.1;

m = boundary condition factor; m = 13.3 for a continuous beam with brackets; where the boundary conditions deviate significantly from those of a continuous beam with brackets, e.g. in an end field, a smaller boundary condition factor may be required.

8.6.4 General on framing

8.6.4.1 The attachment of frames to supporting structures

Within the ice-strengthened area, all frames shall be effectively attached to all of the supporting structures. A longitudinal frame shall be attached by brackets to all the supporting web frames and bulkheads. When a transversal frame terminates at a stringer or deck, a bracket or similar construction is to be fitted. When a frame is running through the supporting structure, both sides of the web plate of the frame are to be connected to the structure (by direct welding, collar plate or lug). When a bracket is installed, it has to have at least the same thickness as the web plate of the frame and the edge has to be appropriately stiffened against buckling.

8.6.4.2 Support of frames against instability, in particular tripping

The frames shall be attached to the shell by double continuous weld. No scalloping is allowed (except when crossing shell plate butts).

The web thickness of the frames shall be at least the maximum of the following:

$$t = \frac{h_w \sqrt{R_{eH}}}{C}, \ [\text{mm}],$$

= half of the net thickness of the shell plating, $t - t_c$. For the purpose of calculating the web thickness of frames, the required thickness of the shell plating is to be calculated according to 8.5.2 using the yield strength R_{eH} of the frames;

= 9 mm.

where:

h_w = the web height, [m];

C = 805 for profiles;

C = 282 for flat bars.

Where there is a deck, top or bottom plating of a tank or bulkhead in lieu of a frame, the plate thickness of it shall be as above, to a depth corresponding to the height of the adjacent frames. In such a case, the material properties of the deck, top or bottom plating of the tank, tank top or bulkhead and the frame height h_w of the adjacent frames shall be used in the calculations, and the constant C shall be 805.

Asymmetrical frames and frames which are not at right angles to the shell (web less than 90 degrees to the shell) shall be supported against tripping by brackets, intercoastals, stringers or similar, at a distance not exceeding 1,3 m. For frames with spans greater than 4 m, the extent of antitripping supports has to be applied to all regions and for all ice classes. For frames with spans less than or equal to 4 m, the extent of antitripping supports must be applied to all regions for ice class 1AS, to the bow and midbody regions for ice class 1A, and to the bow region for ice classes 1B and 1C. Direct calculation methods may be applied to demonstrate the equivalent level of support provided by alternative arrangements.

8.6.4.3 Inclined or unsymmetric frame profiles

Section 8.6.4.2 refers to the need for supporting frames that are 'not normal' or 'unsymmetrical' against tripping, but defines neither 'normal' nor 'symmetric'. For design purposes, the frame inclination as well as the combined effects of frame inclination and asymmetry on the principal axis of the frame, are to be separately evaluated. Accordingly, if neither the angle of frame inclination or the principal axis of the frame (without attached plating) deviates more than 15° from normal to the plating, support against tripping is required.

8.7 ICE STRINGERS

8.7.1 Stringers within the ice belt

The section modulus and the shear area of a stringer are to be calculated using the following formulae:

a) section modulus:

$$W = \frac{f_6 \cdot f_7 \cdot p \cdot h \cdot l^2}{m \cdot R_{eH}} \cdot 10^6, \quad [\text{cm}^3];$$

b) shear area:

$$A = \frac{\sqrt{3} \cdot f_6 \cdot f_7 \cdot f_8 \cdot p \cdot h \cdot l}{2 \cdot R_{eH}} \cdot 10^4, \ [\text{cm}^2],$$

where:

- m = boundary condition factor as defined in 8.6.3,
- p = ice pressure as given in 8.4.2, [N/mm^2];
- h = height of load area as given in 8.4.1, [m];
- $p \cdot h$ = is not to be taken as less than 0,15;
- f_6 = factor which takes account of the distribution of load over the transverse frames; to be taken as 0,9;
- f_7 = safety factor of stringers; to be taken as 1,8;
- f_8 = factor that takes into account the maximum shear force versus load location and the shear stress distribution;
- f_8 = 1,2;
- l = unsupported span of stringer, in [m].
- R_{eH} = minimum upper yield stress for hull structural steel according to the *Rules for the classification of ships, Part 2 - Hull*, Section 1.4.2.1;

8.7.2 Stringers outside the ice belt

The section modulus and the shear area of stringer situated outside the ice belt but supporting ice-strengthened frames are to be calculated according to the following formulae:

a) Section modulus:

$$W = \frac{f_9 \cdot f_{10} \cdot p \cdot h \cdot l^2}{m \cdot R_{eH}} (1 - h_s/l_s) \cdot 10^6, \ [\text{cm}^3];$$

b) Effective shear area:

$$A = \frac{\sqrt{3} \cdot f_9 \cdot f_{10} \cdot f_{11} \cdot p \cdot h \cdot l}{2 \cdot R_{eH}} (1 - h_s/l_s) \cdot 10^4, \ [\text{cm}^2],$$

where:

- f_9 = factor which takes account of the distribution of load to the transverse frames; to be taken as 0,80;
- f_{10} = safety factor of stringers; to be taken as 1,8;
- f_{11} = factor that takes into account the maximum shear force versus load location and the shear stress distribution; to be taken as 1,2;
- m = boundary condition factor as defined in 8.6.3,
- p = ice pressure as given in 8.4.2, [N/mm^2];
- h = height of load area as given in 8.4.1, [m];
- $p \cdot h$ = is not to be taken as less than 0,15;
- h_s = distance to the ice belt, in [m];
- l_s = distance to the adjacent ice stirnger, in [m];
- l = span of stringer, in [m].
- R_{eH} = minimum upper yield stress for hull structural steel according to the *Rules for the classification of ships, Part 2 - Hull*, Section 1.4.2.1.

8.7.3 Deck strips

8.7.3.1 Narrow deck strips abreast of hatches and serving as ice stringers are to comply with the section modulus and shear area requirements in 8.7.1 and 8.7.2 respectively. In the case of very long hatches the product $p \cdot h$ may be taken as less than 0,15 but in no case less than 0,10.

8.7.3.2 Regard is to be paid to the deflection of the ship's sides due to ice pressure with respect to very long hatch openings (more than B/2) when designing weatherdeck hatch covers and their fittings.

8.8 WEB FRAMES

8.8.1 Ice load

The ice load transferred to a web frame from an ice stringer or from longitudinal framing is to be calculated according to the following formula:

$$P = f_{12} \cdot p \cdot h \cdot S \cdot 10^3 \quad , \quad [\text{kN}],$$

where:

- p = ice pressure as given in 8.4.2, [N/mm^2], in calculating c_a, however, l_a is to be 2·S.
- h = height of load area as given in 8.4.1, [m];
- $p \cdot h$ = is not to be taken less than 0,15;
- f_{12} = safety factor of stringers; to be taken as 1,8;
- S = web frame spacing, in [m].

In case the supported stringer is outside the ice belt, the load P may be multiplied by $(1-h_s/l_s)$, where h_s and l_s shall be taken as defined in 8.7.2.

8.8.2 Section modulus and shear area

The section modulus and effective shear area of web frames are to be calculated by the following formulae:

a) Section modulus:

$$W = \frac{M}{R_{eH}} \sqrt{\frac{1}{1-(\gamma A / A_a)^2}} \cdot 10^6, \quad [\text{cm}^3];$$

b) Effective shear area:

$$A = \frac{\sqrt{3} \cdot \alpha \cdot f_{13} \cdot F}{R_{eH}} \cdot 10^4, \qquad [\text{cm}^2],$$

where:

M = maximum calculated bending moment under the ice load P; this is to be taken as $M = 0{,}193 \cdot P \cdot l$;

F = maximum calculated shear force under the ice load P, as given in 8.8.1;

A = required shear area;

A_a = actual cross sectional area of the web frame, $A_a = A_f + A_w$;

A_f = actual cross-sectional area of the free flange;

A_w = actual effective cross-sectional area of the web plate;

f_{13} = factor that takes into account the shear force distribution, $f_{13} = 1{,}1$.

Factors γ and α can be obtained from the Table 8.8.2.

8.8.3 Instead of using the formulae above for the section modulus and shear area of web frames, a direct stress calculation may be performed to determine these values.

In each case, the point of application of the concentrated load should be chosen in relation to the arrangement of stringers and longitudinal frames so as to obtain the maximum shear and bending moments. The allowable stresses are as follows:

Shear stress: $\tau = \dfrac{\sigma_y}{\sqrt{3}}$

Bending stress: $\sigma_b = \sigma_y$

Equivalent stress: $\sigma_e = \sqrt{\sigma_b^2 + 3\tau^2} = \sigma_y$

Table 8.8.2

$\frac{A_f}{A_w}$	0,00	0,20	0,40	0,60	0,80	1,00	1,20	1,40	1,60	1,80	2,00
α	1,50	1,23	1,16	1,11	1,09	1,07	1,06	1,05	1,05	1,04	1,04
γ	0,00	0,44	0,62	0,71	0,76	0,80	0,83	0,85	0,87	0,88	0,89

A_f = cross sectional area of free flange
A_w = actual effective cross sectional area of web plate

8.9 STEM

8.9.1 The stem may be made of rolled, cast or forged steel or of shaped steel plates, see Fig. 8.9.1

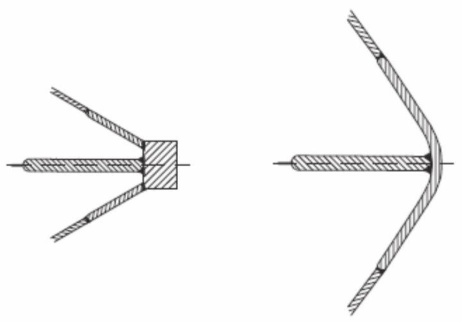


Figure 8.9.1

8.9.2 The plate thickness of a shaped plate stem and, in the case of a blunt bow, any part of the shell where ŬÓ30° and ɣ Ó75°, see Fig. 8.12.2.1 for angle definition, is to be calculated according to the formulae in 8.5.2, assuming that:

s = spacing of elements supporting the plate, [m];

$p_{PL} = p$, [N/mm^2], (see Section 8.5.2);

l_a = spacing of vertical supporting elements, [m].

The stem and the part of a blunt bow defined above shall be supported by floors or brackets spaced not more than 0.6 m apart and having a thickness of at least half the plate thickness. The reinforcement of the stem shall extend from the keel to a point 0.75 m above UIWL or, if an upper bow ice belt is required (8.5.1), to the upper limit of this.

8.10 STERN

8.10.1 The introduction of new propulsion arrangements with azimuthing thrusters, which provide an improved manoeuvrability, will result in increased ice loading of the stern region and the stern area. This fact should be considered in the design of the aft/stern structure.

8.10.2 In order to avoid very high loads on propeller blade tips, the minimum distance between propeller(s) and hull (including stern frame) should not be less than h_0 (see 8.4.1).

8.10.3 On twin and triple screw ships the ice strengthening of the shell and framing shall be extended to the double bottom for 1.5 metres forward and aft of the side propellers.

8.10.4 The shafting and stern tubes of side propellers shall normally be enclosed within plated bossings. If detached struts are used, due consideration shall be taken of their design, strength and attachments to the hull.

8.11 RUDDER AND STEERING ARRANGEMENTS

8.11.1 The scantlings of rudder post, rudder stock, pintles, steering engine etc. as well as the capability of the steering engine shall be determined according to the *Rules for the classification of ships, Part 3 - Hull Equipment*, Section 2. The maximum service speed of the ship to be used in these calculations shall, however, not be taken as less than stated below:

1AS	20 knots
1A	18 knots
1B	16 knots
1C, 1D	14 knots

If the actual maximum service speed of the ship is higher, that speed shall be used.

8.11.2 The local scantlings of rudders are to be determined assuming that the whole rudder belongs to the ice belt. Furthermore, the rudder plating and frames are to be designed using the ice pressure p for the plating and frames in the midbody region.

8.11.3 For ice classes 1A and 1AS, the rudder (rudder stock and the upper part of the rudder) shall be protected from direct contact with intact ice by an ice knife that extends below the LIWL, if practicable (or equivalent means). Special consideration shall be given to the design of the rudder and the ice knife for ships with flap-type rudders.

8.11.4 When going astern, level ice will be broken by the stern and the ice floes forced under the ship. The function of the ice knife is to push the ice floes that are approaching the rudder downwards, so that the rudder is not subject to head-on impacts with ice floes and large forces that deviate the rudder out the amidships position occur less frequently. Attention should be paid to the strength and proper shape of the ice knife with regard to its function. A properly shaped ice knife is shown in Fig. 8.11.4: the lowest part of the ice knife should be below water for all draughts.

However, if the ship is not intended to go astern in ice at some draughts, a smaller ice knife could be used. An ice knife is recommended for all ships with an ice class 1AS or 1A.

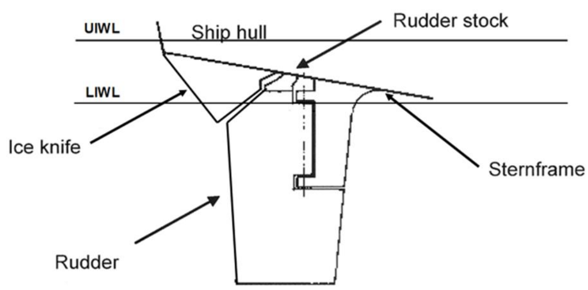


Figure 8.11.4 - An example of an adequate ice knife design

If the vessel has a flap-type rudder, special attention should be given to the design of the rudder in combination with the ice knife, as the flap mechanism is more vulnerable to ice forces.

8.11.5 For ice classes 1A and 1AS, due regard shall be paid to the large loads that arise when the rudder is forced out of the midship position while going astern in ice or into ice ridges. Suitable arrangement such as rudder stoppers shall be installed to absorb these loads.

8.11.6 Relief valves for hydraulic pressure in rudder turning mechanism(s) shall be installed. The components of the steering gear (e.g. rudder stock, rudder coupling, rudder horn etc.) shall be dimensioned to withstand loads causing yield stresses within the required diameter of the rudder stock.

8.11.7 When going astern, a large turning moment will be applied to the rudder, especially if it is allowed to deviate from the amidships position. In order to avoid a situation where the rudder is forced sideways, the operators should pay attention to keeping the rudder amidships when going astern. At the same time, rudder stoppers should be installed in order to avoid excessive movement of the rudder(s).

8.11.8 When the rudder is turned sideways, a great deal of pressure will act on the rudder turning mechanism. The relief valves for hydraulic pressure in the turning mechanism must therefore be effective. The components of the steering gear shall be dimensioned to withstand loads corresponding to the required diameter of the rudder stock.

8.12 ENGINE OUTPUT

8.12.1 Definition of engine output

The engine output P is the maximum output the propulsion machinery can continuously deliver to the propeller(s). If the output of the machinery is restricted by technical means or by any regulations applicable to the ship, P shall be taken as the restricted output. If additional power sources are available for propulsion power (e.g. shaft motors), in addition to the power of the main engine(s), they shall also be included in the total engine output.

8.12.2 Required engine output for ice classes 1AS, 1A, 1B and 1C

The engine output shall not be less than that determined by the formula below and in no case less than 1000 kW for ice class 1A, 1B and 1C, and not less than 2800 kW for 1AS.

8.12.2.1 Definitions

The dimensions of the ship and some other parameters are defined below (see also Fig. 8.12.2.1):

L_{PAR} = length of the parallel midship body, [m];

L_{pp} = length of the ship between perpendiculars, [m];

L_{BOW} = length of the bow, [m];

B = maximum breadth of the ship, [m];

d = maximum and minimum ice class draughts amidships according to 8.2.2, [m];

A_{wf} = area of the waterplane of the bow, [m^2];

φ_1 = rake of the stem at the centreline, [°];

φ_2 = rake of the bow at B/4, [°];

α = angle of the waterline at B/4, [°]

Ψ = flare angle, [°], calculated as Ψ=arctan(tanφ/sinα) using angles α and φ at each location. For this Section, the flare angle is calculated using ű = ű$_2$.

D_P = diameter of the propeller, [m];

H_M = thickness of the brash ice in mid channel, [m];

H_F = thickness of the brash ice layer displaced by the bow, [m].

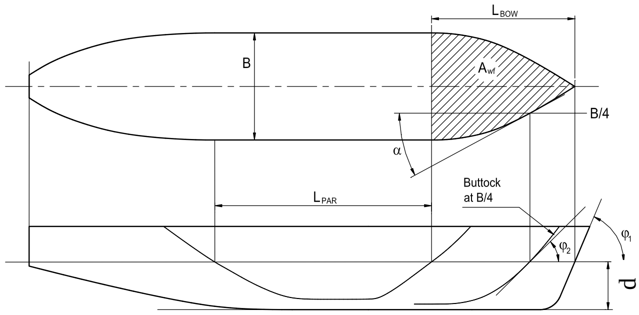


Figure 8.12.2.1 - Determination of the geometric quantities of the hull. If the ship has a bulbous bow, then φ_1=90°

8.12.2.2 New ships

To qualify for ice class 1AS, 1A, 1B or 1C, a ship the keel of which is laid or which is at a similar stage of construction on or after 1 September 2003 shall comply with the following requirements regarding its engine output. The engine output requirement shall be calculated for two draughts by formula 8.12.1. Draughts to be used are the maximum draught amidships referred to as UIWL and the minimum draught referred to as LIWL, as defined in Section 8.2.2. In the calculations, the ship's parameters which depend on the draught are to be determined at the appropriate draught, but L and B are to be determined only at the UIWL. The engine output shall not be less than the greater of these two outputs.

The engine output P_{min}, in [kW], shall not be less than that determined by the following formula:

$$P_{\min} = K_e \cdot \frac{(R_{CH}/1000)^{3/2}}{D_P}, \text{ [kW]},$$

where Ke shall be taken according to Table 8.12.2.2-1:

Table 8.12.2.2-1

Number of propellers	CP propeller or electric or hydraulic propulsion machinery	FP propeller
1 propeller	2,03	2,26
2 propeller	1,44	1,60
3 propeller	1,18	1,31

These K_e values apply for conventional propulsion systems. Other methods may be used for determining the required power for advanced propulsion systems (see 8.12.2.5).

R_{CH} is the ice resistance, in [N], of the ship in a channel with brash ice and a consolidated surface layer:

$$R_{CH}=C_1+C_2+C_3\cdot C_\mu\cdot(H_F+H_M)^2\cdot(B+C_\psi\cdot H_F)+C_4\cdot L_{PAR}\cdot H_F^2+C_5\cdot\left(\frac{L\cdot d}{B^2}\right)^3\cdot\frac{A_{wf}}{L}$$

where:

$C_\mu = 0{,}15\cdot\cos\varphi_2+\sin\psi\cdot\sin\alpha$;

C_μ is to be taken equal or larger than 0,45.

$C_\psi = 0{,}047\cdot\psi-2{,}115$ and C_Ψ=0 if $\psi\le 45^o$

$H_F = 0{,}26+(H_M\cdot B)^{0,5}$

H_M = 1.0 m for ice classes 1A and 1AS

= 0.8 m for ice class 1B

= 0.6 m for ice class 1C

C_1 and C_2 take into account a consolidated upper layer of the brash ice. C_1=0 and C_2=0 for ice classes 1A, 1B and 1C.

For ice class 1AS:

$$C_1 = f_1\cdot\frac{B\cdot L_{PAR}}{2\cdot\frac{d}{B}+1}+(1+0{,}021\cdot\varphi_1)\cdot(f_2\cdot B+f_3\cdot L_{BOW}+f_4\cdot B\cdot L_{BOW})$$

$$C_2=(1+0{,}063\cdot\varphi_1)\cdot(g_1+g_2\cdot B)+g_3\cdot(1+1{,}2\cdot\frac{d}{B})\cdot\frac{B^2}{\sqrt{L}}$$

For a ship with a bulbous bow, φ_1 shall be taken as 90°.

Coefficients f_1-f_4 and g_1-g_3 for the determination of C_1 and C_2 are given in the Table 8.12.2.2-2:

Table 8.12.2.2-2

$f_1 = 23$ N/m^2	$g_1 = 1530$ N
$f_2 = 45{,}8$ N/m^2	$g_2 = 170$ N/m
$f_3 = 14{,}7$ N/m^2	$g_3 = 400$ N/m^{1,5}
$f_4 = 29$ N/m^2	

$C_3 = 845$ kg/(m^{2}s^2)

$C_4 = 42$ kg/(m^{2}s^2)

$C_5 = 825$ kg/s^2

$$\psi=\arctan(\frac{\tan\varphi_2}{\sin\alpha})$$

If the value of the term $\left(\frac{L\cdot d}{B^2}\right)^3$ is less than 5, the value 5 shall be used and if the value of the term is more than 20, the value 20 shall be used.

The range of validity of the formulae for powering requirements in this Section is presented in Table 8.12.2.2-3. When calculating the parameter D_P/d, d shall be measured at UIWL.

If the shipôs parameter values are beyond the ranges defined in Table 8.12.2.2-3, other methods for determining R_{CH} shall be used as defined in 8.12.2.5.

Table 8.12.2.2-3 - The range of parameters used for validation of the powering requirement

Parameter		Minimum	Maximum
α	(°)	15	55
φ_1	(°)	25	90
φ_2	(°)	10	90
L	(m)	65	250
B	(m)	11	40
d	(m)	4	15
L_{BOW}/L		0,15	0,4
L_{PAR}/L		0,25	0,75
D_P/d		0,45	0,75
$A_{wf}/(L\cdot B)$		0,09	0,27

8.12.2.3 Existing ships of ice class 1B or 1C

In order to retain ice class 1B or 1C a ship, the keel of which has been laid or which has been at a similar stage of construction before 1 September 2003, the engine output shall not be less than that determined by the formula below and in no case less than 740 kW for the ice classes 1B and 1C.

$$P=f_1\cdot f_2\cdot f_3\cdot(f_4\cdot\Delta+P_0)\ ,\ [\text{kW}],$$

where:

$f_1 = 1{,}0$ for a fixed pitch propeller,

=0,9 for a controllable pitch propeller,

$f_2=\phi_1/200+0{,}675$, but not more than 1,1.

where:

φ_1 = the rake of the stem at the centreline, [°].

The product $f_1\cdot f_2$ shall not be taken less than 0,85.

$f_2 = 1{,}1$ for a bulbous bow

$f_3 = 1{,}2\cdot B/\Delta^{1/3}$, but not less than 1,0.

f_4 and P_0 shall be taken according to Table 8.12.2.3.

Δ = displacement, [t], of the ship on the maximum ice class draught according to 8.2.2. It need not be taken as greater than 80 000 t.

Table 8.12.2.3

Ice class	1B	1C	1B	1C
Displacement	Δ<30000		Δ>30000	
f_4	0,22	0,18	0,13	0,11
P_0	370	0	3070	2100

8.12.2.4 Existing ships of ice class 1AS or 1A

In order to retain ice class 1AS or 1A a ship, the keel of which has been laid or which has been at a similar stage of construction before 1 September 2003, shall comply with the requirements in Section 8.12.2.2 above not later than 1 January in the year when twenty years have elapsed since the year the ship was delivered.

If the ship does not comply with the requirements in Section 8.12.2.2 on the date given above, the highest lower ice class for which the engine output is sufficient can be confirmed for the ship.

When, for an existing ship, values for some of the hull form parameters required for the calculation method in Section 8.12.2.2 are difficult to obtain, the following alternative formulae can be used:

$$R_{CH} = C_1 + C_2 + C_3\left(H_F + H_M\right)^2 (B + 0{,}658 H_F) + C_4 L H_F^2 + C_5\left(\frac{L \cdot d}{B^2}\right)^3 \frac{B}{4}$$

where for ice class 1A, C_1 and C_2 shall be taken as zero.

For ice class 1AS, ship without a bulb, C_1 and C_2 shall be calculated as follows:

$$C_1 = f_1 \cdot \frac{B \cdot L}{2 \cdot \frac{d}{B} + 1} + 1{,}84 \cdot (f_2 \cdot B + f_3 \cdot L + f_4 \cdot B \cdot L)$$

$$C_2 = 3{,}52 \cdot (g_1 + g_2 B) + g_3 \cdot (1 + 1{,}2\frac{d}{B}) \frac{B^2}{\sqrt{L}}$$

For ice class 1AS, ship with a bulb, C_1 and C_2 shall be calculated as follows:

$$C_1 = f_1 \cdot \frac{B \cdot L}{2 \cdot \frac{d}{B} + 1} + 2{,}89 \cdot (f_2 \cdot B + f_3 \cdot L + f_4 \cdot B \cdot L)$$

$$C_2 = 6{,}67 \cdot (g_1 + g_2 \cdot B) + g_3 \cdot (1 + 1{,}2 \cdot \frac{d}{B}) \cdot \frac{B^2}{\sqrt{L}}$$

where:

values of the coefficients f_1-f_4 and g_1-g_3 for the determination of C_1 and C_2 are given in the Table 8.12.2.4:

Table 8.12.2.4

$f_1 = 10{,}3$ N/m^2	$g_1 = 1530$ N
$f_2 = 45{,}8$ N/m^2	$g_2 = 170$ N/m
$f_3 = 2{,}94$ N/m^2	$g_3 = 400$ N/m^{1,5}
$f_4 = 5{,}8$ N/m^2	

$C_3 = 460$ kg/(m^{2}s^2)

$C_4 = 18{,}7$ kg/(m^{2}s^2)

$C_5 = 825$ kg/s^2

If the value of the term $\left(\frac{L \cdot d}{B^2}\right)^3$ is less than 5, the value 5 shall be used and if the value of the term is more than 20, the value 20 shall be used.

8.12.2.5 Other methods of determining K_e or R_{CH}

For an individual ship, in lieu of the K_e or R_{CH} values defined in 8.12.2.2 and 8.12.2.3, the use of K_e or R_{CH} values based on more precise calculations or values based on model tests may be approved. Such an approval will be given on the understanding that it can be revoked if experience of the shipĝs performance provides grounds for this in practice.

The design requirement for ice classes is a minimum speed of 5 knots in the following brash ice channels (see Table 8.12.2.5):

Table 8.12.2.5

Ice class	H_M
1AS	1.0 m and a 0.1 m thick consolidated layer of ice
1A	1.0 m
1B	0.8 m
1C	0.6 m

8.13 PROPULSION MACHINERY

8.13.1 Scope

These regulations apply to propulsion machinery covering open and ducted-type propellers with controllable pitch or fixed pitch design for the ice classes 1AS, 1A, 1B and 1C. The given loads are the expected ice loads for the entire shipĝs service life under normal operational conditions, including loads resulting from the changing rotational direction of FP propellers.

However, these loads do not cover off-design operational conditions, for example when a stopped propeller is dragged through ice. However, the load models of the regulations do not include propeller/ice interaction loads when ice enters the propeller of a turned azimuthing thruster from the side (radially).

The regulations also apply to azimuthing and fixed thrusters for main propulsion, taking consideration of loads resulting from propeller/ice interaction and loads on the thruster body/ice interaction. The given azimuthing thruster body loads are the expected ice loads for the shipĝs service life under normal operational conditions. The local strength of the thruster body shall be sufficient to withstand local ice pressure when the thruster body is designed for extreme loads.

The thruster global vibrations caused by blade order excitation on the propeller may cause significant vibratory loads.

8.13.2 Definitions

Table 8.13.2-1 List of symbols

Symbol	Unit	Definition
c	[m]	chord length of blade section
$c_{0.7}$	[m]	chord length of blade section at 0.7*R* propeller radius,
CP		controllable pitch
D	[m]	propeller diameter
d	[m]	external diameter of propeller hub (at propeller plane)
D_{limit}	[m]	limit value for propeller diameter
EAR		expanded blade area ratio
F_b	[kN]	maximum backward blade force for the shipộs service life
F_{ex}	[kN]	ultimate blade load resulting from blade loss through plastic bending
F_f	[kN]	maximum forward blade force for the shipộs service life
Fice	[kN]	ice load
$(F_{ice})_{max}$	[kN]	maximum ice load for the shipộs service life
FP		fixed pitch,
h_0	[m]	depth of the propeller centreline from lower ice waterline
H_{ice}	[m]	thickness of maximum design ice block entering to propeller
I_e	[kgm^2]	equivalent mass moment of inertia of all parts on the engine side of component under consideration
I_t	[kgm^2]	equivalent mass moment of inertia of the whole propulsion system
k		shape parameter for Weibull distribution
LIWL	[m]	lower ice waterline
m		slope for SN curve in log/log scale
M_{BL}	[kNm]	blade bending moment
MCR		maximum continuous rating
n	[rev./s]	propeller rotational speed
n_n	[rev./s]	nominal propeller rotational speed at MCR in free running condition
N_{class}		reference number of impacts per nominal propeller rotational speed per ice class
N_{ice}		total number of ice loads on propeller blade for the shipộs service life
N_R		reference number of load for equivalent fatigue stress (10^8 cycles)
N_Q		number of propeller revolutions during a milling sequence
$P_{0.7}$	[m]	propeller pitch at 0.7*R* radius
$P_{0.7n}$	[m]	propeller pitch at 0.7*R* radius at MCR in free running condition
$P_{0.7b}$	[m]	propeller pitch at 0.7*R* radius at MCR in bollard condition
Q	[kNm]	torque
Q_{emax}	[kNm]	maximum engine torque
Q_{max}	[kNm]	maximum torque on the propeller resulting from propeller/ice interaction
Q_{max}^{n}	[kNm]	maximum torque on the propeller resulting from propeller-ice interaction reduced to the rotational speed in question
Q_{motor}	[kNm]	electric motor peak torque
Q_n	[kNm]	nominal torque at MCR in free running condition
Q_r	[kNm]	response torque along the propeller shaft line
Q_{peak}	[kNm]	maximum of the response torque Q_R
Q_{smax}	[kNm]	maximum spindle torque of the blade for the shipộs service life
Q_{sex}	[kNm]	maximum spindle torque due to blade failure caused by plastic bending

Symbol	Unit	Definition
Q_{vib}	[kNm]	vibratory torque at considered component, taken from frequency domain open water torque vibration calculation (TVC)
R	[m]	propeller radius
r	[m]	blade section radius
T	[kN]	propeller thrust
T_b	[kN]	maximum backward propeller ice thrust for the shipôs service life
T^f	[kN]	maximum forward propeller ice thrust for the shipôs service life
T_n	[kN]	propeller thrust at MCR in free running condition
T_r	[kN]	maximum response thrust along the shaft line
t	[m]	maximum blade section thickness
Z		number of propeller blades
α_i	[°]	duration of propeller blade/ice interaction expressed in rotation angle
α_1	[°]	phase angle of propeller ice torque for blade order excitation component
α_2	[°]	phase angle of propeller ice torque for twice the blade order excitation component
$\gamma_{\varepsilon 1}$		the reduction factor for fatigue; scatter effect
$\gamma_{\varepsilon 2}$		the reduction factor for fatigue; test specimen size effect
γ_v		the reduction factor for fatigue; variable amplitude loading effect
γ_m		the reduction factor for fatigue; mean stress effect
ρ		a reduction factor for fatigue correlating the maximum stress amplitude to the equivalent fatigue stress for 10^8 stress cycles
$\sigma_{0.2}$	[N/mm^2]	proof yield strength (at 0,2% offset) of blade material
σ_{exp}	[N/mm^2]	mean fatigue strength of blade material at 10^8 cycles to failure in sea water
σ_{fat}	[N/mm^2]	equivalent fatigue ice load stress amplitude for 10^8 stress cycles
σ_{fl}	[N/mm^2]	characteristic fatigue strength for blade material
σ_{ref1}	[N/mm^2]	reference stress σ_{ref1} =0,6 $\sigma_{0.2}$+0,4 σ_u
σ_{ref2}	[N/mm^2]	reference stress:σ_{ref2} = 0,7 σ_u or σ_{ref2} =0,6 $\sigma_{0.2}$+0,4 σ_u, whichever is less
σ_{st}	[N/mm^2]	maximum stress resulting from F_b or F_f
σ_u	[N/mm^2]	ultimate tensile strength of blade material
$(\sigma_{ice})_{bmax}$	[N/mm^2]	principal stress caused by the maximum backward propeller ice load
$(\sigma_{ice})_{fmax}$	[N/mm^2]	principal stress caused by the maximum forward propeller ice load
$(\sigma_{ice})_{max}$	[N/mm^2]	maximum ice load stress amplitude

Table 8.13.2-2 Definitions of loads

	Definition	Use of the load in design process
F_b	The maximum lifetime backward force on a propeller blade resulting from propeller/ice interaction, including hydrodynamic loads on that blade. The direction of the force is perpendicular to 0.7R chord line. See Fig. 8.13.2.	Design force for strength calculation of the propeller blade.
F_f	The maximum lifetime forward force on a propeller blade resulting from propeller/ice interaction, including hydro-dynamic loads on that blade. The direction of the force is perpendicular to 0.7R chord line.	Design force for calculation of strength of the propeller blade.
Q_{smax}	The maximum lifetime spindle torque on a propeller blade resulting from propeller/ice interaction, including hydro-dynamic loads on that blade.	In designing the propeller strength, the spindle torque is automatically taken into account because the propeller load is acting on the blade as distributed pressure on the leading edge or tip area.

	Definition	Use of the load in design process
T_b	The maximum lifetime thrust on propeller (all blades) resulting from propeller/ice interaction. The direction of the thrust is the propeller shaft direction and the force is opposite to the hydrodynamic thrust.	Is used for estimation of the response thrust *Tr*. *Tb* can be used as an estimate of excitation for axial vibration calculations. However, axial vibration calculations are not required in the Rules.
T_f	The maximum lifetime thrust on propeller (all blades) resulting from propeller/ice interaction. The direction of the thrust is the propeller shaft direction acting in the direction of hydrodynamic thrust.	Is used for estimation of the response thrust *Tr*. *Tf* can be used as an estimate of excitation for axial vibration calculations. However, axial vibration calculations are not required in the Rules.
Q_{max}	The maximum ice-induced torque resulting from propeller/ice interaction on one propeller blade, including hydrodynamic loads on that blade.	Is used for estimation of the response torque (*Qr*) along the propulsion shaft line and as excitation for torsional vibration calculations.
F_{ex}	Ultimate blade load resulting from blade loss through plastic bending. The force that is needed to cause total failure of the blade so that plastic hinge is caused to the root area. The force is acting on 0.8*R*. Spindle arm is to be taken as 2/3 of the distance between the axis of blade rotation and leading/trailing edge (whichever is the greater) at the 0.8*R* radius.	Blade failure load is used to dimension the blade bolts, pitch control mechanism, propeller shaft, propeller shaft bearing and trust bearing. The objective is to guarantee that total propeller blade failure should not cause damage to other components.
Q_r	Maximum response torque along the propeller shaft line, taking into account the dynamic behaviour of the shaft line for ice excitation (torsional vibration) and hydrodynamic mean torque on propeller.	Design torque for propeller shaft line components.
T_r	Maximum response thrust along shaft line, taking into account the dynamic behaviour of the shaft line for ice excitation (axial vibration) and hydrodynamic mean thrust on propeller.	Design thrust for propeller shaft line components.
F_{ti}	Maximum response force caused by ice block impacts on the thruster body or the propeller hub.	Design load for thruster body and slewing bearings.
F_{tr}	Maximum response force on the thruster body caused by ice ridge/thruster body interaction.	Design load for thruster body and slewing bearings.

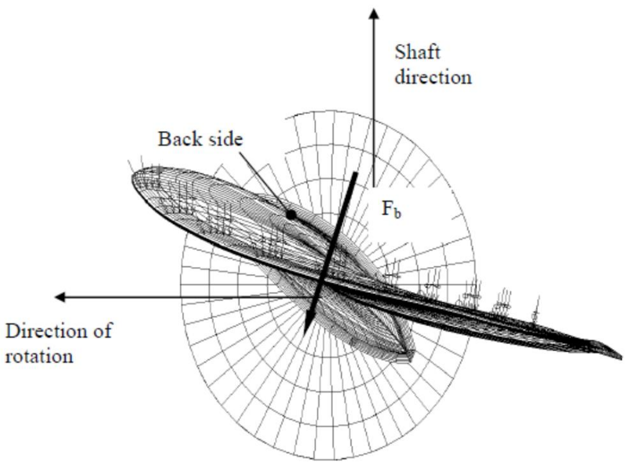


Figure 8.13.2 - Direction of the resultant backward blade force taken perpendicular to the chord line at radius 0.7*R*. The ice contact pressure at the leading edge is indicated with small arrows.

8.13.3 Design ice conditions

In estimating the ice loads of the propeller for ice classes, different types of operation as given in Table 8.13.3-1 were taken into account. For the estimation of design ice loads, a maximum ice block size is determined. The maximum design ice block entering the propeller is a rectangular ice block with the dimensions $H_{ice} \cdot 2H_{ice} \cdot 3H_{ice}$. The thickness of the ice block (H_{ice}) is given in Table 8.13.3-2.

Table 8.13.3-1 Types of operation for different ice classes

Ice class	Operation of the ship
1AS	Operation in ice channels and in level ice. The ship may proceed by ramming.
1A, 1B, 1C	Operation in ice channels

Table 8.13.3-2 Thickness of design ice block

	1AS	1A	1B	1C
Thickness of the design maximum ice block entering the propeller (H_{ice})	1,75 m	1,5m	1,2m	1,0m

8.13.4 Materials

8.13.4.1 Materials exposed to sea water

Materials of components exposed to sea water, such as propeller blades, propeller hubs, and thruster body, shall have an elongation of not less than 15% on a test specimen, the gauge length of which is five times the diameter. A Charpy V impact test shall be carried out for materials other than bronze and austhenitic steel. An average impact energy value of 20 J taken from three tests is to be obtained at minus 10 ºC. For nodular cast iron, average impact energy of 10 J at minus 10 ºC is required accordingly.

8.13.4.2 Materials exposed to sea water temperature

Materials exposed to sea water temperature shall be of steel or other ductile material. An average impact energy value of 20 J taken from three tests is to be obtained at minus 10 ºC. This requirement applies to the propeller shaft, blade bolts, CP mechanisms, shaft bolts, strut-pod connecting bolts etc. It does not apply to surface hardened components, such as bearings and gear teeth. The nodular cast iron of a ferrite structure type may be used for relevant parts other than bolts. The average impact energy for nodular cast iron shall be a minimum of 10 J at minus 10 ºC.

8.13.5 Design loads

The given loads are intended for component strength calculations only and are total loads including ice-induced loads and hydrodynamic loads during propeller/ice interaction. The presented maximum loads are based on a worst case scenario that occurs once during the service life of the ship. Thus, the load level for a higher number of loads is lower.

The values of the parameters in the formulae given in this section are provided in the units shown in the Table 8.13.2-1.

If the highest point of the propeller is not at a depth of at least h_i below the water surface when the ship is in ballast condition, the propulsion system shall be designed according to ice class 1A for ice classes 1B and 1C.

8.13.5.1 Design loads on propeller blades

F_b is the maximum force experienced during the lifetime of the ship that bends a propeller blade backwards when the propeller mills an ice block while rotating ahead. F_f is the maximum force experienced during the lifetime of the ship that bends a propeller blade forwards when the propeller mills an ice block while rotating ahead. F_b and F_f originate from different propeller/ice interaction phenomena, and do not occur simultaneously. Hence, they are to be applied to one blade separately.

13.5.1.1 Maximum backward blade force F_b for open propellers

when D ÒD_{limit}:

$$F_b = 27(n \cdot D)^{0.7}\left(\frac{EAR}{Z}\right)^{0.3} \cdot D^2 \text{ , [kN]}$$

when $D > D_{limit}$:

$$F_b = 23(n \cdot D)^{0.7}\left(\frac{EAR}{Z}\right)^{0.3} \cdot D \cdot H_{ice}^{\ 1.4} \text{ , [kN]}$$

where:

$$D_{limit} = 0.85 \cdot H_{ice}^{\ 1.4} \text{ [m]}$$

n is the nominal rotational speed (at MCR in the free running condition) of a CP-propellers and 85% of the nominal rotational speed (at MCR free running condition) of a FP propeller.

8.13.5.1.2 Maximum forward blade force F_f for open propellers

when D ÒD_{limit}:

$$F_f = 250 \cdot \left(\frac{EAR}{Z}\right) \cdot D^2 \text{ ,[kN}$$

when $D > D_{limit}$:

$$F_f = 500 \cdot \left(\frac{EAR}{Z}\right) \cdot D \cdot \left(\frac{1}{1-d/D}\right) \cdot H_{ice} \text{ , [kN],}$$

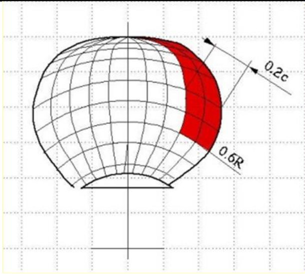
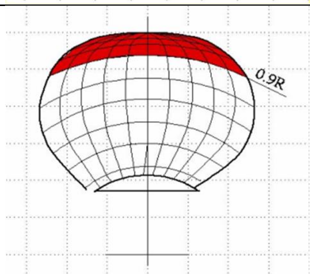
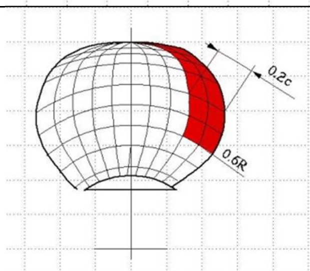
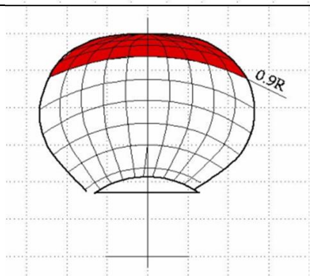
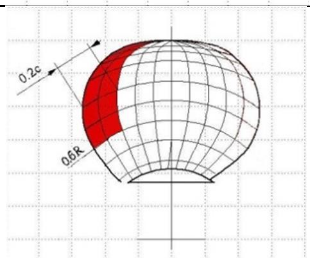
where:

$$D_{limit} = \left(\frac{2}{1-d/D}\right) \cdot H_{ice} \text{ , [m].}$$

8.13.5.1.3 Loaded area on the blade for open propellers

Load cases 1-4 have to be covered, as given in Table 8.13.5.1.3 below, for CP and FP propellers. In order to obtain blade ice loads for a reversing propeller, load case 5 also has to be covered for FP propellers.

Table 8.13.5.1.3 - Load cases for open propellers

	Force	Loaded area	Right-handed propeller blade seen from behind
Load case 1	F_b	Uniform pressure applied on the back of the blade (suction side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length.	
Load case 2	50% of F_b	Uniform pressure applied on the back of the blade (suction side) on the propeller tip area outside 0.9R radius.	
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length.	
Load case 4	50% of F_f	Uniform pressure applied on propeller face (pressure side) on the propeller tip area outside 0.9R radius.	
Load case 5	60% of F_f or F_b, whichever is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0.6R to the tip and from the trailing edge to 0.2 times the chord length	

8.13.5.1.4 Maximum backward blade force F_b for ducted propellers

when $D \leq D_{limit}$

$$F_b = 9.5 \cdot (n \cdot D)^{0.7} \left(\frac{EAR}{Z}\right)^{0.3} \cdot D^2 \text{, [kN],}$$

when $D > D_{limit}$:

$$F_b = 66 \cdot (n \cdot D)^{0.7} \cdot \left(\frac{EAR}{Z}\right)^{0.3} \cdot D^{0.6} \cdot H_{ice}^{1.4} \text{, [kN],}$$

where:

$D_{limit} = 4 \cdot H_{ice}$, [m].

n is the nominal rotational speed (at MCR in free running condition) for a CP propeller and 85% of the nominal rotational speed (at MCR in free running condition) for an FP propeller.

8.13.5.1.5 Maximum forward blade force F_f for ducted propellers

when $D \leq D_{limit}$

$$F_f = 250 \cdot \left(\frac{EAR}{Z}\right) \cdot D^2, \text{ [kN]},$$

when $D > D_{limit}$

$$F_f = 500 \cdot \left(\frac{EAR}{Z}\right) \cdot D \cdot \left(\frac{1}{1-d/D}\right) \cdot H_{ice}, \text{ [kN]}.$$

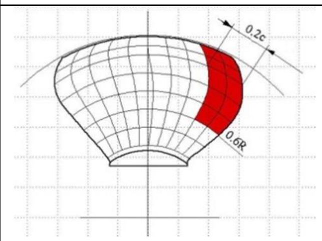
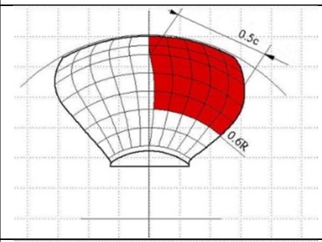
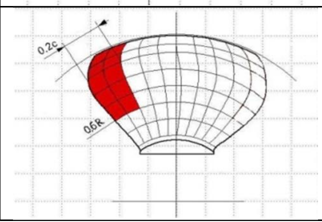
where:

$$D_{limit} = \left(\frac{2}{1-d/D}\right) \cdot H_{ice} \text{ [m]}$$

8.13.5.1.6 Loaded area on the blade for open propellers

Load cases 1 and 3 have to be covered, as given in Table 8.13.5.1.6 for all propellers, and an additional load case (load case 5) for an FP propeller, to cover ice loads when the propeller is reversed.

Table 8.13.5.1.6 - Load cases for ducted propellers

	Force	Loaded area	Right handed propeller blade seen from behind
Load case 1	F_b	Uniform pressure applied on the blade back (suction side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length.	
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6R to the tip and from the leading edge to 0.5 times the chord length.	
Load case 5	60% of F_f or F_b, whichever is greater	Uniform pressure applied on the face (pressure side) to an area from 0.6R to the tip and from blade the trailing edge to 0.2 times the chord length.	

8.13.5.1.7 Maximum blade spindle torque Q_{smax} for open and ducted propellers

The spindle torque Q_{smax} around the axis of the blade fitting shall be determined both for the maximum backward blade force F_b and forward blade force F_f, which are applied as in Table 8.13.5.1.3 and Table 8.13.5.1.6. The larger of the obtained torques is used as the dimensioning torque. If the above method gives a value which is less than the default value given by the formula below, the default value shall be used.

Default value: $Q_{smax} = 0{,}25 \cdot F \cdot c_{0,7}$, [kNm],

where $c_{0.7}$ *is* length of the blade section at 0.7R radius and F is either F_b or F_f whichever has the greater absolute value.

8.13.5.1.8 Load distributions for blade loads

The Weibull-type distribution (probability that F_{ice} exceeds $(F_{ice})_{max}$), as given in Fig. 8.13.5.1.8, is used for the fatigue design of the blade.

$$P\left(\frac{F_{ice}}{(F_{ice})_{max}} \geq \frac{F}{(F_{ice})_{max}}\right) = e^{\left(-\left(\frac{F}{(F_{ice})_{max}}\right)^k \cdot \ln(N_{ice})\right)}$$

where k is the shape parameter of the spectrum, N_{ice} is the number of load cycles in the spectrum, and F_{ice} is the random variable for ice loads on the blade, $0 \leq F_{ice} \leq (F_{ice})_{max}$. The shape parameter k=0.75 shall be used for the ice force distribution of an open propeller and the shape parameter k=1.0 for that of a ducted propeller blade.

8.13.5.1.8 Load distributions for blade loads

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$$P\left(\frac{F_{ice}}{(F_{ice})_{\max}} \geq \frac{F}{(F_{ice})_{\max}}\right) = e^{\left(-\left(\frac{F}{(F_{ice})_{\max}}\right)^{k} \cdot \ln(N_{ice})\right)}$$

where k is the shape parameter of the spectrum, N_{ice} is the number of load cycles in the spectrum, and F_{ice} is the random variable for ice loads on the blade, $0 \leq F_{ice} \leq (F_{ice})_{\max}$. The shape parameter k=0.75 shall be used for the ice force distribution of an open propeller and the shape parameter k=1.0 for that of a ducted propeller blade.

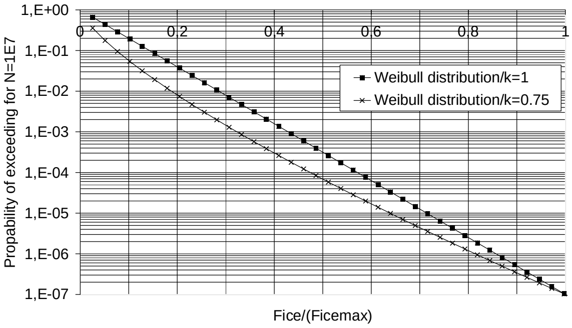


Figure 8.13.5.1.8 - The Weibull-type distribution (probability that F_{ice} exceeds $(F_{ice})_{max}$) used for fatigue design

8.13.5.1.9 Number of ice loads

The number of load cycles per propeller blade in the load spectrum shall be determined according to the formula:

$$N_{ice} = k_1 \cdot k_2 \cdot k_3 \cdot N_{class} \cdot n_n$$

where:

- values for N_{class} are given in the Table 8.13.5.1.9-1:

Table 8.13.5.1.9-1

Class	1AS	1A	1B	1C
Impact in life/n_n	9Ã0^6	6Ã0^6	3,4Ã0^6	2,1Ã0^6

- values of the propeller location factor k_1 are given in the Table 8.13.5.1.9-2::

Table 8.13.5.1.9-2

	Centre propeller Bow first operation	Wing propeller Bow first operation	Pulling propeller (wing and centre) Bow propeller or Stern first operation
k_1	1	2	3

- the submersion factor k_2 is determined from the equation:

k_2=0,8 ï f, when f<0,

k_2=0,8 ï 0,4Ã, when $0 \leq f \leq 1$,

k_2=0,6 ï 0,2Ã, when $1 < f \leq 2{,}5$,

k_2=0,1, when $f > 2{,}5$.

where the immersion function f is:

$$f = \frac{h_o - H_{ice}}{D/2} - 1$$

where h_o is the depth of the propeller centerline at the lower ice waterline (LIWL) of the ship.

- the values of the propulsion machinery type factor k_3 are given in the Table 8.13.5.1.9-3:

Table 8.13.5.1.9-3

Type	Fixed	Azimuthing
k_3	1	1,2

For components that are subject to loads resulting from propeller/ice interaction with all the propeller blades, the number of load cycles (N_{ice}) is to be multiplied by the number of propeller blades (Z).

8.13.5.2 Axial design loads for open and ducted propellers

8.13.5.2.1 Maximum ice thrust on propeller T_f and T_b for open and ducted propellers

The maximum forward and backward ice thrusts are:

$T_f = 1{,}1 \cdot F_f$, [kN],

$T_b = 1{,}1 \cdot F_b$, [kN].

8.13.5.2.2 Design thrust along the propulsion shaft line for open and ducted propellers

The design thrust along the propeller shaft line is to be calculated with the formulae below. The greater value of the forward and backward direction loads shall be taken as the design load for both directions. The factors 2.2 and 1.5 take into account the dynamic magnification resulting from axial vibration.

In forward direction:

$T_r = T_n + 2{,}2 \cdot T_f$, [kN].

In backward direction:

$T_r = 1{,}5 \cdot T_b$, [kN].

If hydrodynamic bollard thrust, T, is not known, it is to be taken as given in the following Table 8.13.5.2.2:

Table 8.13.5.2.2

Propeller type	T
CP propellers (open)	$1{,}25 \cdot T_n$
CP propellers (ducted)	$1{,}1 \cdot T_n$
FP propellers driven by turbine or electric motor	T_n
FP propellers driven by diesel engine (open)	$0{,}85 \cdot T_n$
FP propellers driven by diesel engine (ducted)	$0{,}75 \cdot T_n$

Where T_n is the nominal propeller trust at MCR in the free running open water conditions.

8.13.5.3 Torsional design load

8.13.5.3.1 Design ice torque on propeller Q_{max} for open propellers

Q_{max} is the maximum torque on a propeller resulting from ice/propeller interaction during the service life of the ship.

when $D \leq D_{limit}$:

$$Q_{max} = 10{,}9 \cdot (1 - \frac{d}{D}) \cdot \left(\frac{P_{0,7}}{D}\right)^{0,16} \cdot (n \cdot D)^{0,17} \cdot D^3, \quad \text{[kNm]},$$

when $D > D_{limit}$:

$$Q_{max} = 20{,}7 \cdot (1 - \frac{d}{D}) \cdot \left(\frac{P_{0,7}}{D}\right)^{0,16} \cdot (n \cdot D)^{0,17} \cdot D^{1,9} \cdot H_{ice}^{1,1}, \quad \text{[kNm]}$$

where:

D_{limit} = 1,81 H_{ice}

n = rotational propeller speed in bollard condition. If unknown, n is to be taken as given in the Table 8.13.5.3.1:

Table 8.13.5.3.1

Propeller type	Rotational speed, *n*
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	0,85 n_n

n_n = nominal rotational speed at MCR, in the free running open water condition.

For CP propellers, the propeller pitch, $P_{0.7}$ shall correspond to MCR in bollard condition. If not known, $P_{0.7}$ is to be taken as $0.7 \cdot P_{0.7n}$, where $P_{0.7n}$ is propeller pitch at MCR in free running condition.

8.13.5.3.2 Design ice torque on propeller Q_{max} for ducted propellers

Q_{max} is the maximum torque on a propeller during the service life of the ship resulting from ice/propeller interaction.

when $D \leq D_{limit}$:

$$Q_{max} = 7{,}7 \cdot (1 - \frac{d}{D}) \cdot \left(\frac{P_{0,7}}{D}\right)^{0,16} \cdot (n \cdot D)^{0,17} \cdot D^3, \quad \text{[kNm]}$$

when $D > D_{limit}$:

$$Q_{max} = 14{,}6 \cdot (1 - \frac{d}{D}) \cdot \left(\frac{P_{0,7}}{D}\right)^{0,16} \cdot (n \cdot D)^{0,17} \cdot D^{1,9} \cdot H_{ice}^{1,1}, \quad \text{[kNm]}$$

where:

D_{limit} = 1.81 H_{ice}

n = rotational propeller speed in bollard condition. If not known, n is to be taken according to Table in 8.13.5.3.1.

For CP propellers, the propeller pitch, $P_{0.7}$ shall correspond to MCR in bollard condition. If not known, $P_{0.7}$ shall have a value equal to $0{,}7 \cdot P_{0.7n}$, where $P_{0.7n}$ is propeller pitch at MCR in free running condition.

8.13.5.3.3 Design torque for non-resonant shaft lines

If there is no relevant first blade order torsional resonance in the operational speed range or in the range 20% above and 20% below the maximum operating speed (bollard condition), the following estimation of the maximum torque can be used.

- directly coupled two stroke diesel engines without flexible coupling:

$$Q_{peak} = Q_{emax} + Q_{vib} + Q_{max} \cdot I_e / I_t, \text{ [kNm]},$$

- and other plants:

$$Q_{peak} = Q_{emax} + Q_{max} \cdot I_e / I_t, \text{ [kNm]},$$

where:

Ie = equivalent mass moment of inertia of all parts on the engine side of the component under consideration and

It = equivalent mass moment of inertia of the whole propulsion system.

All the torques and the inertia moments shall be reduced to the rotation speed of the component being examined.

If the maximum torque, Q_{emax}, is unknown, it shall be accorded the value given in Table 8.13.5.3.3.

where:

Q_{motor} = electric motor peak torque.

Table 8.13.5.3.3

Propeller type	Q_{emax}
Propellers driven by electric motor	Q_{motor}
CP propellers not driven by electric motor	Q_n
FP propellers driven by turbine	Q_n
FP propellers driven by diesel engine	$0{,}75 \cdot Q_n$

8.13.5.3.4 Design torque for shaft line having resonances

If there is first blade order torsional resonance in the operational speed range or in the range 20% above and 20% below the maximum operating speed (bollard condition), the design torque (Q_{peak}) of the shaft component shall be determined by means of torsional vibration analysis of the propulsion line. There are two alternative ways of performing the dynamic analysis.

1. time domain calculation for estimated milling sequence excitation,
2. frequency domain calculation for blade orders sinusoidal excitation.

The frequency domain analysis is generally considered conservative compared to the time domain simulation, provided that there is a first blade order resonance in the considered speed range.

8.13.5.3.4.1 Time domain calculation of torsional response

Time domain calculations shall be calculated for the MCR condition, MCR bollard conditions and for blade order resonant rotational speeds so that the resonant vibration responses can be obtained.

The load sequence given in this Section, for a case where a propeller is milling an ice block, shall be used for the strength evaluation of the propulsion line. The given load sequence is not intended for propulsion system stalling analyses.

The following load cases are intended to reflect the operational loads on the propulsion system, when the propeller interacts with ice, and the respective reaction of the complete system. The ice impact and system response causes loads in the individual shaft line components. The ice torque Q_{max} may be taken as a constant value in the complete speed range. When considera-tions at specific shaft speeds are performed, a relevant Q_{max} may be calculated using the rele-vant speed according to Section 8.13.5.3.

Diesel engine plants without an elastic coupling shall be calculated at the least favourable phase angle for ice versus engine excitation, when calculated in the time domain. The engine firing pulses shall be included in the calculations and their standard steady state harmonics can be used.

If there is a blade order resonance just above the MCR speed, calculations shall cover rotation-al speeds up to 105% of the MCR speed.

The propeller ice torque excitation for shaft line transient dynamic analysis in the time domain is defined as a sequence of blade impacts which are of half sine shape. The excitation frequen-cy shall follow the propeller rotational speed during the ice interaction sequence. The torque due to a single blade ice impact as a function of the propeller rotation angle is then defined using the formula:

$Q(\varphi) = C_q \cdot Q_{\max} \cdot \sin\left(\varphi\left(\frac{180}{\alpha_i}\right)\right)$, [kNm], when φ rotates from 0 to α_i plus integer revolutions,

$Q(\varphi) = 0$, when φ rotates from α_i to 360 plus integer revolutions,

where:

φ = rotation angle from when the first impact occurs and parameters C_q and α_i are given in Table 8.13.5.3.4.1,

α_i = duration of propeller blade/ice interaction expressed in terms of the propeller rotation angle. See Figure 8.13.5.3.4.1-1.

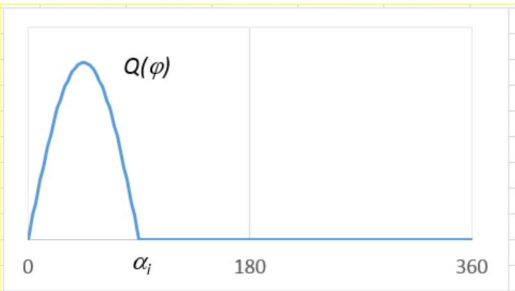


Figure 8.13.5.3.4.1-1 Schematic ice torque due to a single blade ice impact as a function of propeller rotation angle

Table 8.13.5.3.4.1 Ice impact magnification and duration factors for different blade numbers

Torque excitation	Propller/ice interaction	C_q	α_i, [°]			
			Z=3	Z=4	Z=5	Z=6
Excitation case 1	Single ice block	0,75	90	90	72	60
Excitation case 2	Two ice blocks (phase shift 360/(2·Z) °)	1,0	135	135	135	135
Excitation case 3	Single ice block	0,5	45	45	36	30
Excitation case 4	Single ice block	0,5	45	45	36	30

The total ice torque is obtained by summing the torque of single blades, while taking account of the phase shift 360 °/Z, see Fig. 8.13.5.3.4.1-2 At the beginning and end of the milling se-quence (within the calculated duration) linear ramp functions shall be used to increase C_q to its maximum value within one propeller revolution and vice versa to decrease it to zero (see the examples of different Z numbers in Fig. 8.13.5.3.4.1-2).

The number of propeller revolutions during a milling sequence shall be obtained from the for-mula:

$$N_q = 2 \cdot H_{ice}$$

The number of impacts is $Z \cdot N_Q$ for blade order excitation. An illustration of all excitation cases for different numbers of blades is given in Fig. 8.13.5.3.4.1-2.

A dynamic simulation must be performed for all excitation cases at the operational rotational speed range. For a fixed pitch propeller propulsion plant, a dynamic simulation must also cover the bollard pull condition with a corresponding rotational speed assuming the maximum possible output of the engine.

If a speed drop occurs until the main engine is at a standstill, this indicates that the engine may not be sufficiently powered for the intended service task. For the consideration of loads, the maximum occurring torque during the speed drop process must be used.

For the time domain calculation, the simulated response torque typically includes the engine mean torque and the propeller mean torque. If this is not the case, the response torques must be obtained using the formula:

$$Q_{peak} = Q_{e\max} + Q_{rtd}$$

where:

Q_{rtd} = maximum simulated torque obtained from the time domain analysis.

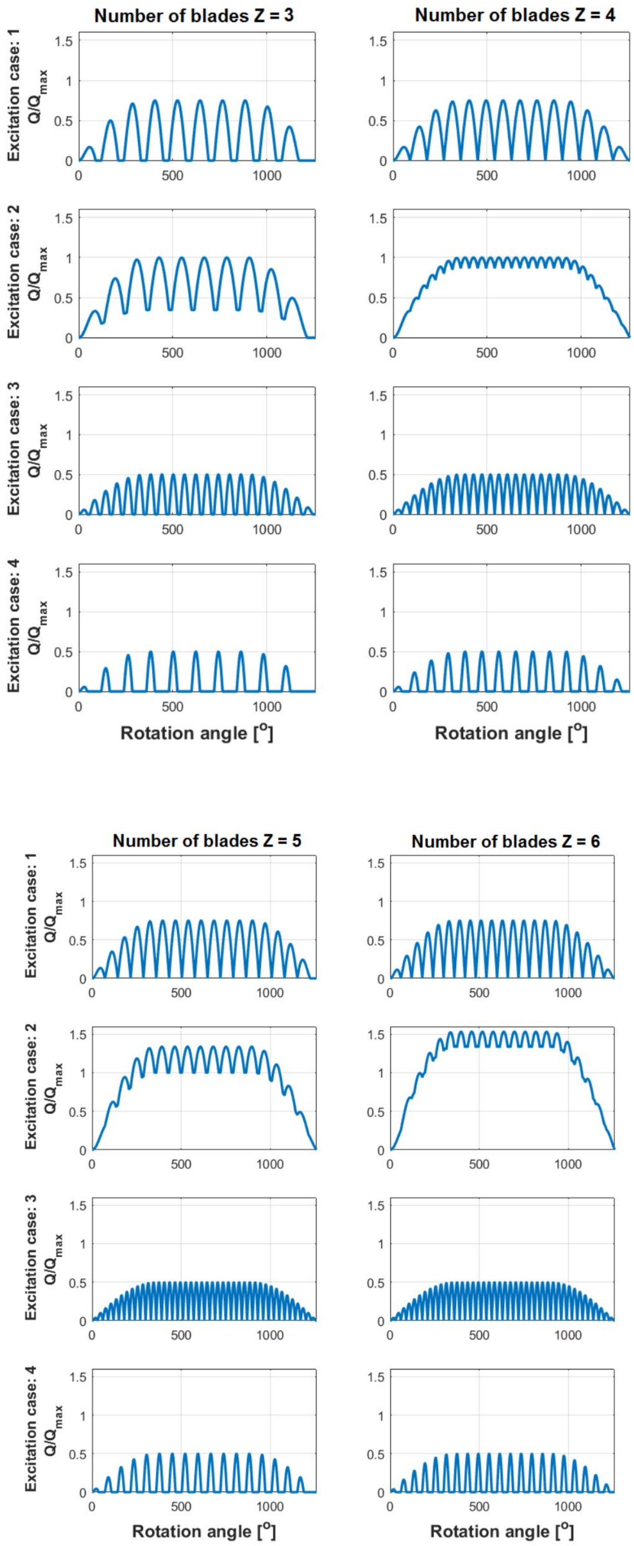


Figure 8.13.5.3.4.1-2 The shape of the propeller ice torque excitation sequences for propellers with 3, 4, 5 or 6 blades

8.13.5.3.4.2 Frequency domain calculation of torsional response

For frequency domain calculations, blade order and twice-the-blade-order excitation may be used. The amplitudes for the blade order and twice-the-blade-order sinusoidal excitation have been derived based on the assumption that the time domain half sine impact sequences were continuous, and the Fourier series components for blade order and twice-the-blade-order components have been derived. The propeller ice torque is then:

$$Q_F(\varphi) = Q_{\max}\left(C_{q0} + C_{q1}\sin\left(ZE_0\varphi + \alpha_1\right) + C_{q2}\sin\left(2ZE_0\varphi + \alpha_2\right)\right)$$
, [kNm]

where:

C_{q0} = mean torque parameter,

C_{q1} = first blade order excitation parameter,

C_{q2} = second blade order excitation parameter,

α_1, α_2 = phase angles of the excitation component,

φ = angle of rotation,

E_0 = number of ice blocks in contact.

The values of the parameters are given in Table 8.13.5.3.4.2.

The design torque for the frequency domain excitation case must be obtained using the formula:

$$Q_{peak} = Q_{e\max} + Q_{vib} + \left(Q^{n}_{\max} \cdot C_{q0}\right) \cdot {}^{I_e}\!/_{I_t} + Q_{rf1} + Q_{rf2}$$, [kNm],

where:

[illegible] = maximum propeller ice torque at the operation speed in consideration

C_{q0} = mean static torque coefficient from Table 8.13.5.3.4.2

Q_{rf1} = blade order torsional response from the frequency domain analysis

Q_{rf2} = second order blade torsional response from the frequency domain analysis

If the prime mover maximum torque, Q_{emax}, is not known, it shall be taken as given in Table 8.13.5.3.3. All the torque values have to be scaled to the shaft revolutions for the component in question.

Table 8.13.5.3.4.2 Coefficient values for frequency domain excitation calculation

Torque excitation	C_{q0}	C_{q1}	α_1	C_{q2}	α_2	E_0
Z=3						
Excitation case 1	0,375	0,36	-90	0	0	1
Excitation case 2	0,7	0,33	-90	0,05	-45	1
Excitation case 3	0,25	0,25	-90	0	0	2
Excitation case 4	0,2	0,25	0	0,05	-90	1
Z=4						
Excitation case 1	0,45	0,36	-90	0,06	-90	1
Excitation case 2	0,9375	0	-90	0,0625	-90	1
Excitation case 3	0.25	0.25	-90	0	0	2
Excitation case 4	0,2	0,25	0	0,05	-90	1
Z=5						
Excitation case 1	0,45	0,36	-90	0,06	-90	1
Excitation case 2	1,19	0,17	-90	0,02	-90	1
Excitation case 3	0,3	0,25	-90	0,048	-90	2
Excitation case 4	0,2	0,25	0	0,05	-90	1
Z=6						
Excitation case 1	0,45	0,36	-90	0,05	-90	1
Excitation case 2	1,435	0,1	-90	0	0	1
Excitation case 3	0,3	0,25	-90	0,048	-90	2
Excitation case 4	0,2	0,25	0	0,05	-90	1

8.13.5.3.4.3 Guidance for torsional vibration calculation

The aim of time domain torsional vibration simulations is to estimate the extreme torsional load for the shipôs lifespan. The simulation model can be taken from the normal lumped mass elastic torsional vibration model, including damping. For a time domain analysis, the model should include the ice excitation at the propeller, other relevant excitations and the mean torques provided by the prime mover and hydrodynamic mean torque in the propeller. The calculations should cover variation of phase between the ice excitation and prime mover excitation. This is extremely relevant to propulsion lines with directly driven combustion engines. Time domain calculations shall be calculated for the MCR condition, MCR bollard conditions and for resonant speed, so that the resonant vibration responses can be obtained.

For frequency domain calculations, the load should be estimated as a Fourier component anal-ysis of the continuous sequence of half sine load sequences. First and second order blade components should be used for excitation.

The calculation should cover the entire relevant rpm range and the simulation of responses at torsional vibration resonances.

8.13.5.4 Blade failure load

8.13.5.4.1 Bending force, F_{ex}

The ultimate load resulting from blade failure as a result of plastic bending around the blade root shall be calculated from the formula below, or alternatively by means of an appropriate stress analysis, reflecting the non-linear plastic material behaviour of the actual blade. In such a case, the blade failure area may be outside the root section. The ultimate load is assumed to be acting on the blade at the 0,8*R* radius in the weakest direction of the blade.

A blade is regarded as having failed if the tip is bent into an offset position by more than 10% of propeller diameter *D*.

$$F_{ex} = \frac{300 \cdot c \cdot t^2 \cdot \sigma_{ref1}}{0{,}8 \cdot D - 2 \cdot r}, \quad [\text{kN}]$$

where:

$$\sigma_{ref1} = 0{,}6 \cdot \sigma_{0,2} + 0{,}4 \cdot \sigma_u$$

σ_u = (minimum ultimate tensile strength to be specified on the drawing),

$\sigma_{0,2}$ = (minimum yield or 0,2% proof strength to be specified on the drawing) are representative values for the blade material,

c, t and r = respectively, the actual chord length, maximum thickness and radius of the cylindrical root section of the blade, which is the weakest section outside the root fillet typically located at the point where the fillet terminates at the blade profile.

8.13.5.4.2 Spindle torquee, Q_{sex}

The maximum spindle torque due to a blade failure load acting at 0,8*R* shall be determined. The force that causes blade failure typically reduces when moving from the propeller centre towards the leading and trailing edges. At a certain distance from the blade centre of rotation, the maximum spindle torque will occur. This maximum spindle torque shall be defined by an appropriate stress analysis or using the equation given below.

$$Q_{sex} = \max\,(C_{LE0.8};\, 0{,}8C_{TE0.8})C_{spex}F_{ex} \quad , \; [\text{kNm}]$$

where:

$$C_{spex} = C_{sp}C_{fex} = 0{,}7\left(1 - \left(\frac{4EAR}{Z}\right)^3\right)$$

C_{sp} = non-dimensional parameter taking account of the spindle arm

C_{fex} = non-dimensional parameter taking account of the reduction of the blade failure force at the location of the maximum spindle torque.

If C_{spex} is below 0,3, a value of 0,3 shall to be used for C_{spex}.

$C_{LE0.8}$= leading edge portion of the chord length at 0,8R

$C_{TE0.8}$= trailing edge portion of the chord length at 0,8R.

Fig. 8.13.5.4.2 illustrates the spindle torque values due to blade failure loads across the entire chord length.

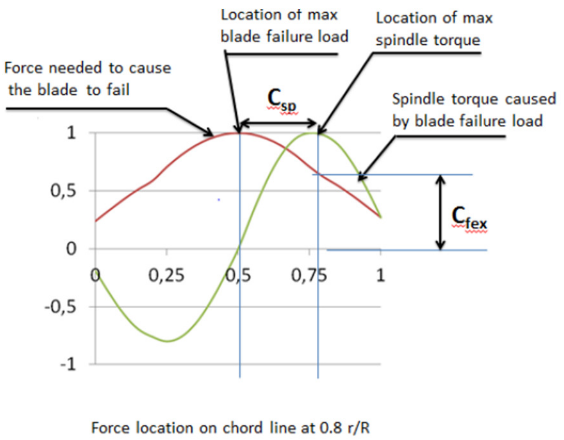


Figure 8.13.5.4.2 Schematic figure showing a blade failure load and the related spindle torque when the force acts at a different location on the chord line at radius *0,8R*

8.13.6 Design

8.13.6.1 Design principle

The strength of the propulsion line shall be designed according to the pyramid strength principle. This means that the loss of the propeller blade shall not cause any significant damage to other propeller shaft line components.

8.13.6.2 Propeller blade

8.13.6.2.1 Calculation of blade stresses

The blade stresses shall be calculated for the design loads given in Section 8.13.5.1. Finite element analysis shall be used for stress analysis for the final approval of all propellers. The following simplified formulae can be used for estimating the blade stresses for all propellers at the root area (r/R < 0,5). The root area dimensions based on following formula, can be accepted even if the FEM analysis would show greater stresses at the root area.

$$\sigma_{st} = C_1 \cdot \frac{M_{BL}}{100 \cdot c \cdot t^2} \quad , [\text{N/mm}^2],$$

where:

$$C_1 = \frac{actual\_stress}{stress\_obtained\_with\_beam\_equation}$$

If the actual value is not available, C_1 should be taken as 1,6.

$$M_{BL} = (0{,}75 - \frac{r}{R}) \cdot R \cdot F \text{, for relative radius } r/R < 0{,}5.$$

F is the force F_b or F_f, whichever has greater absolute value.

8.13.6.2.2 Acceptability criterion

The following criterion for calculated blade stresses has to be fulfilled:

$$\frac{\sigma_{ref2}}{\sigma_{st}} \geq 1{,}3$$

where:

σ_{st} is the calculated stress for the design loads.

If FEM analysis is used in estimating the stresses, von Mises stresses shall be used.

σ_{ref2} is reference stress, defined as:

$\sigma_{ref2} = 0{,}7 \cdot \sigma_u$, or

$\sigma_{ref2} = 0{,}6 \cdot \sigma_{0,2} + 0{,}4 \cdot \sigma_u$,whichever is lower.

8.13.6.2.3 Fatigue design of propeller blade

8.13.6.2.3.1 General

The fatigue design of the propeller blade is based on an estimated load distribution for the service life of the ship and the S-N curve for the blade material. An equivalent stress that produces the same fatigue damage as the expected load distribution shall be calculated and the acceptability criterion for fatigue should be fulfilled as given in Section 8.13.6.2.4.

The equivalent stress is normalized for 10^8 cycles.

For materials with a two-slope SN curve (Fig. 8.13.6.2.3.1-1), fatigue calculations in accordance with this chapter are not required if the following criterion is fulfilled.

$$\sigma_{\exp} \geq B_1 \cdot \sigma_{ref2}^{B_2} \cdot \log(N_{ice})^{B_3}$$

where B_1, B_2 and B_3 coefficients for open and ducted propellers are given in Table 8.13.6.2.3.1.

Table 8.13.6.2.3.1 Values of coefficients B_1, B_2 and B_3

	Open propeller	Ducted propeller
B_1	0,00246	0,00167
B_2	0,947	0,956
B_3	2,101	2,470

For calculation of equivalent stress two types of SN curves are available.

1. Two slope SN curve (slopes 4.5 and 10), see Fig. 8.13.6.2.3.1-1.
2. One slope SN curve (the slope can be chosen), see Fig. 8.13.6.2.3.1-2.

The type of the SN-curve shall be selected to correspond with the material properties of the blade. If the SN-curve is not known, the two slope SN curve shall be used.

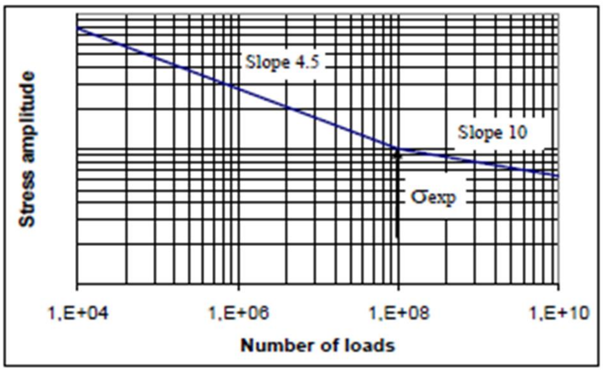


Figure 8.13.6.2.3.1-1 - Two-slope S-N curve

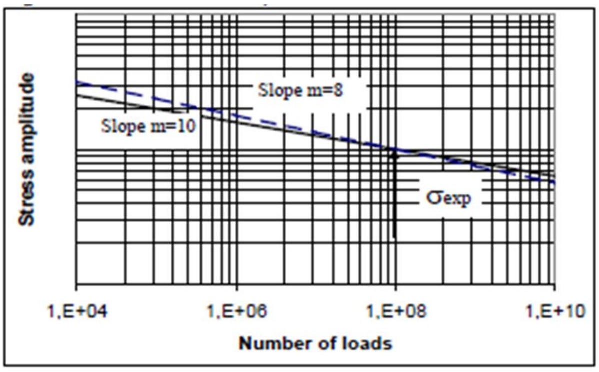


Figure 8.13.6.2.3.1-2 Constant-slope S-N curve

8.13.6.2.3.2 Equivalent fatigue stress

The equivalent fatigue stress for 10^8 stress cycles which produces the same fatigue damage as the load distribution for the service life of the ship is:

$$\sigma_{fat} = \rho \cdot (\sigma_{ice})_{\max}$$

where:

$$(\sigma_{ice})_{\max} = 0{,}5\left((\sigma_{ice})_{f\max} - (\sigma_{ice})_{b\max}\right)$$

$(\sigma_{ice})_{\max}$ = mean value of the principal stress amplitudes resulting from design forward and backward blade forces at the location being studied.

$(\sigma_{ice})_{f\max}$ = principal stress resulting from forward load

$(\sigma_{ice})_{b\max}$ = principal stress resulting from backward load

In calculation of $(\sigma_{ice})_{\max}$, case 1 and case 3 (or case 2 and case 4) are considered as a pair for $(\sigma_{ice})_{f\max}$, and $(\sigma_{ice})_{b\max}$ calculations. Case 5 is excluded from the fatigue analysis.

8.13.6.2.3.3 Calculation of parameter ρ for two-slope S-N curve

The parameter ρ relates the maximum ice load to the distribution of ice loads according to the regression formula

$$\rho = C_1 \cdot (\sigma_{ice})_{\max}^{C_2} \cdot \sigma_{fl}^{C_3} \cdot \log(N_{ice})^{C_4}$$

where:

$$\sigma_{fl} = \gamma_{\varepsilon 1} \cdot \gamma_{\varepsilon 2} \cdot \gamma_{v} \cdot \gamma_{m} \cdot \sigma_{\exp}$$

$\gamma_{\varepsilon 1}$ = reduction factor due to scatter (equal to one standard deviation)

$\gamma_{\varepsilon 2}$ = reduction factor for test specimen size effect

γ_{v} = reduction factor for variable amplitude loading

γ_{m} = reduction factor for mean stress

$\sigma_{\exp}$ = mean fatigue strength of the blade material at 10^8 cycles to failure in seawater. The following values should be used for the reduction factors if actual values are not available: $\gamma_{\varepsilon} = \gamma_{\varepsilon 1} \cdot \gamma_{\varepsilon 2} = 0,67$, $\gamma_{v} = 0,75$, $\gamma_{m} = 0,75$

The coefficients C_1 ,C_2 , C_3 , and C_4 are given in Table 8.13.6.2.3.3.

The applicable range of N_{ice} for calculating ρ is $5x10^6$ ÒN_{ice} Ò10^8.

Table 8.13.6.2.3.3

	Open propeller	Ducted propeller
C_1	00,000747	0,000534
C_2	0,0645	0,0533
C_3	-0,0565	-0,0459
C_4	2,22	2,584

8.13.6.2.3.4 Calculation of parameter ρ for constant-slope S-N curve

For materials with a constant-slope S-N curve, see Fig. 8.13.6.2.3.1-2, the factor ρ shall be calculated from the following formula:

$$\rho = \left(G \cdot \frac{N_{ice}}{N_R} \right)^{1/m} \cdot \left(\ln(N_{ice}) \right)^{-1/k}$$

Where:

k = shape parameter of the Weibull distribution k = 1.0 for ducted propellers and k =0.75 for open propellers,

N_R = reference number of load cycles (=10^8).

The applicable range of N_{ice} for calculating ρ is $5x10^6$ ÒN_{ice} Ò10^8.

Values for the parameter G are given in Table 8.13.6.2.3.4. Linear interpolation may be used to calculate the value of m/k ratios other than given in the Table 8.13.6.2.3.4.

Table 8.13.6.2.3.4

m/k	G	m/k	G	m/k	G
3	6	6,5	1871	10	3,629Ã0^6
3,5	11,6	7	5040	10,5	11,899Ã0^6
4	24	7,5	14034	11	39,917Ã0^6
4,5	52,3	8	40320	11,5	136,843Ã0^6
5	120	8,5	119292	12	479,002Ã0^6
5,5	287,9	9	362880		
6	720	9,5	$1,133 \cdot 10^6$		

8.13.6.2.4 Acceptability criterion for fatigue

The equivalent fatigue stress at all locations on the blade has to fulfil the following acceptability criterion:

$$\frac{\sigma_{fl}}{\sigma_{fat}} \geq 1,5$$

where:

$$\sigma_{fl} = \gamma_{\varepsilon 1} \cdot \gamma_{\varepsilon 2} \cdot \gamma_{v} \cdot \gamma_{m} \cdot \sigma_{\exp}$$

$\gamma_{\varepsilon 1}$ = reduction factor due to scatter (equal to one standard deviation)

$\gamma_{\varepsilon 2}$ = reduction factor for test specimen size effect

γ_{v} = reduction factor for variable amplitude loading

γ_{m} = reduction factor for mean stress

$\sigma_{\exp}$ = mean fatigue strength of the blade material at 10^8 cycles to failure in seawater. The following values should be used for the reduction factors if actual values are not available: $\gamma_{\varepsilon} = \gamma_{\varepsilon 1} \cdot \gamma_{\varepsilon 2} = 0,67$, $\gamma_{v} = 0,75$, $\gamma_{m} = 0,75$.

8.13.6.3 Propeller bossing and CP mechanism

The blade bolts, the CP mechanism, the propeller boss, and the fitting of the propeller to the propeller shaft shall be designed to withstand the maximum and fatigue design loads, as defined in 8.13.5. The safety factor against yielding shall be greater than 1,3 and that against fatigue greater than 1,5. In addition, the safety factor for loads resulting from loss of the propeller blade through plastic bending as defined in 8.13.5.4 shall be greater than 1,0 against yielding.

8.13.6.4 Propulsion shaft line

The shafts and shafting components, such as the thrust and stern tube bearings, couplings, flanges and sealings, shall be designed to withstand the propeller/ice interaction loads as given in 8.13.5. The safety factor is to be at least 1,3.

8.13.6.4.1 Shafts and shafting components

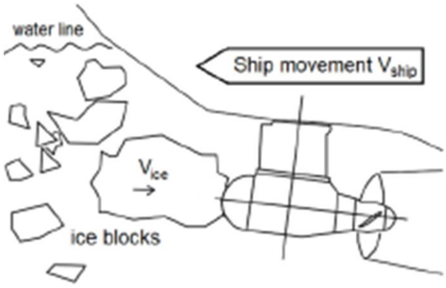
The ultimate load resulting from total blade failure as defined in 8.13.5.4 should not cause yielding in shafts and shaft components. The loading shall consist of the combined axial, bending, and torsion loads, wherever this is significant. The minimum safety factor against yielding is to be 1,0 for bending and torsional stresses.

8.13.6.5 Azimuthing main propulsors

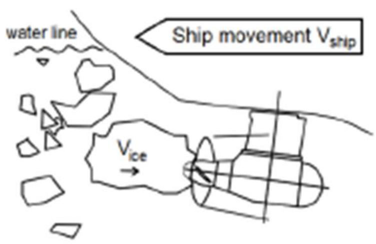
8.13.6.5.1 Design principle

In addition to the above requirements, for propeller blade dimensioning, azimuthing thrusters must be designed for thruster body/ice interaction loads. Load formulae are given for estimat-ing once in a lifetime extreme loads on the thruster body, based on the estimated ice condition and ship operational parameters. Two main ice load scenarios have been selected for defining the extreme ice loads. Examples of loads are illustrated in Fig. 8.13.6.5.1. In addition, blade order thruster body vibration responses may be estimated for propeller excitation. The following load scenario types are considered:

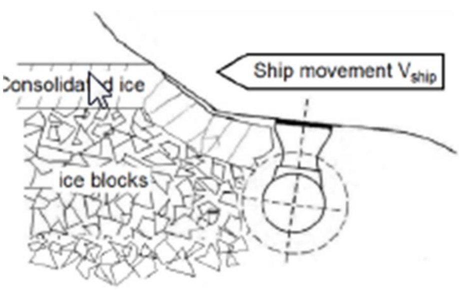
1. Ice block impact on the thruster body or propeller hub.
2. Thruster penetration into an ice ridge that has a thick consolidated layer.
3. Vibratory response of the thruster at blade order frequency.



Impact on thruster body



Impact on propeller hub



Thruster penetration into the ice ridge

Figure 8.13.6.5.1 Examples of load scenario types.

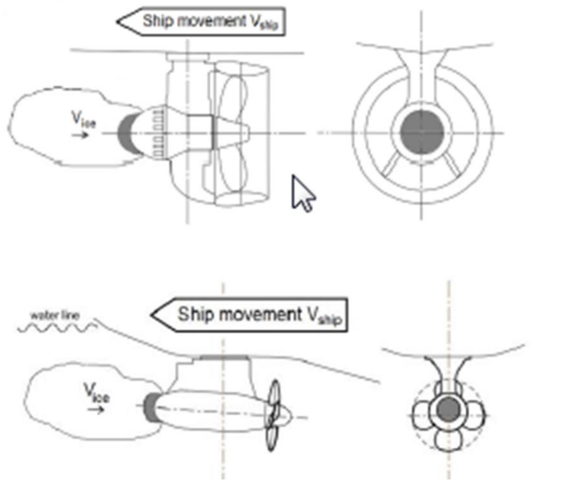
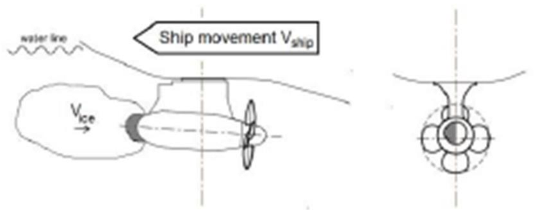
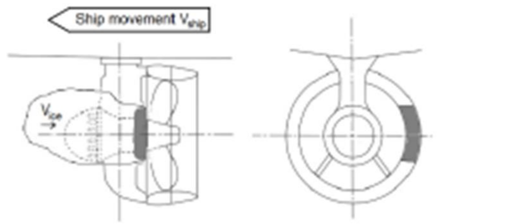
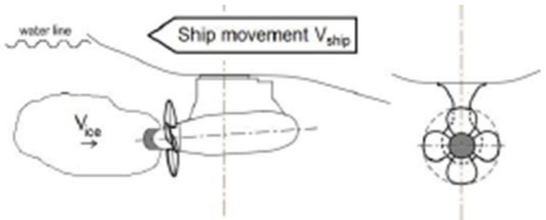
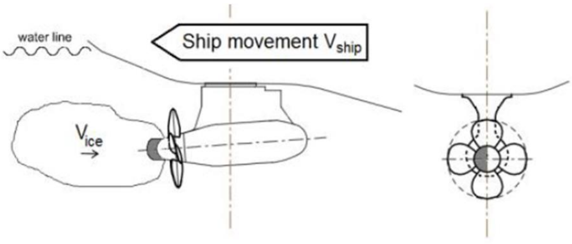
The steering mechanism, the fitting of the unit, and the body of the thruster shall be designed to withstand the loss of a blade without damage. The loss of a blade shall be considered for the propeller blade orientation which causes the maximum load on the component being studied. Top-down blade orientation typically places the maximum bending loads on the thruster body.

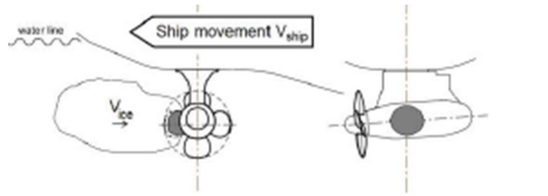
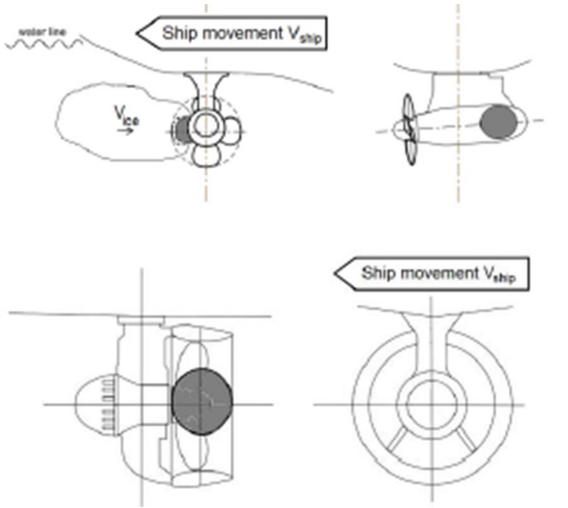
8.13.6.5.2 Extreme ice impact loads

When the ship is operated in ice conditions, ice blocks formed in channel side walls or from the ridge consolidated layer may impact on the thruster body and the propeller hub. Exposure to ice impact is very much dependent on the ship size and ship hull design, as well as the location of the thruster. The contact force will grow in terms of thruster/ice contact until the ice block reaches the ship speed.

The thruster must withstand the loads occurring when the design ice block defined in Table 8.13.3-2 impacts on the thruster body when the ship is sailing at a typical ice operating speed. Load cases for impact loads are given in Table 8.13.6.5.2-1. The contact geometry is estimated to be hemi-spherical in shape. If the actual contact geometry differs from the shape of the hemisphere, a sphere radius must be estimated so that the growth of the contact area as a function of pene-tration of ice corresponds as closely as possible to the actual geometrical shape penetration.

Table 8.13.6.5.2-1 Load cases for azimuthing thruster ice impact loads

	Force	**Loaded area**	
Load case T1a Symmetric longitudinal ice impact on thruster	F_{ti}	Uniform distributed load or uniform pressure, which are applied symmetrically on the impact area.	
Load case T1b Non-symmetric longitudinal ice impact on thruster	50% of F_{ti}	Uniform distributed load or uniform pressure, which are applied on the other half of the impact area.	
Load case T1c Non-symmetric longitudinal ice impact on nozzle	F_{ti}	Uniform distributed load or uniform pressure, which are applied on the impact area. Contact area is equal to the nozzle thickness (H_{nz}) x the contact height (H_{ice}).	
Load case T2a Symmetric longitudinal ice impact on propeller hub	F_{ti}	Uniform distributed load or uniform pressure, which are applied symmetrically on the impact area.	
Load case T2b Non-symmetric longitudinal ice impact on pro-pel-ler hub	50% of F_{ti}	Uniform distributed load or uniform pressure, which are applied on the other half of the impact area.	

	Force	**Loaded area**	
Load case T3a Symmetric lateral ice impact on thruster body	$\boldsymbol{F_{ti}}$	Uniform distributed load or uniform pressure, which are applied symmetrically on the impact area.	
Load case T3b Non-symmetric lateral ice impact on thruster body or nozzle	$\boldsymbol{F_{ti}}$	Uniform distributed load or uniform pressure, which are applied on the impact area. Nozzle contact radius R to be taken from the nozzle length (L_{nz}).	

The ice impact contact load must be calculated using formula below. The related parameter values are given in Table 8.13.6.5.2-2. The design operation speed in ice can be derived from Tables 8.13.6.5.2-3. and 8.13.6.5.2-4, or the ship in questionôs actual design operation speed in ice can be used. The longitudinal impact speed in Tables 8.13.6.5.2-3. and 8.13.6.5.2-4 refers to the impact in the thrusterôs main operational direction. For the pulling propeller configuration, the longitudinal impact speed is used for load case T2, impact on hub; and for the pushing propeller unit, the longitudinal impact speed is used for load case T1, impact on thruster end cap. For the opposite direction, the impact speed for transversal impact is applied.

$$F_{ti} = C_{DMI} \cdot 34{,}5 \cdot R_c^{0,5} \left(m_{ice} \cdot v_s^2\right)^{0,333}, \text{ [kN]},$$

where:

R_c = impacting part sphere radius, see Fig. 8.13.6.5.2, [m],

m_{ice} = ice block mass [kg]

v_s = ship speed at the time of contact, [m/s]

[illegible] = dynamic magnification factor for impact loads.

C_{DMI} shall be taken from Table 8.13.6.5.2-2 if unknown.

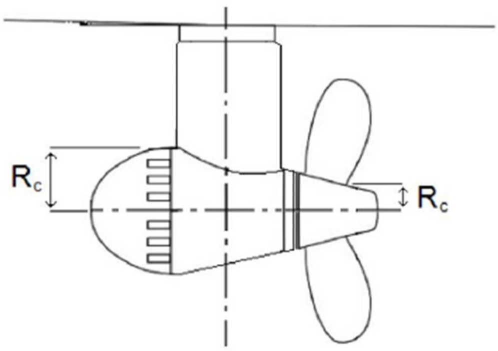


Figure 8.13.6.5.2 Dimensions used for $\boldsymbol{R_c}$

For impacts on non-hemispherical areas, such as the impact on the nozzle, the equivalent impact sphere radius must be estimated using the equation below.

$$R_{ceq} = \sqrt{\frac{A}{\pi}}, \text{ [m]},$$

If the $2xR_{ceq}$ is greater than the ice block thickness, the radius is set to half of the ice block thickness. For the impact on the thruster side, the pod body diameter can be used as a basis for determining the radius. For the impact on the propeller hub, the hub diameter can be used as a basis for the radius.

Table 8.13.6.5.2-2 Parameter values for ice dimensions and dynamic magnification

	1AS	1A	1B	1C
Thickness of the design ice block impacting thruster (2/3 of H_{ice})	1,17 m	1,0 m	0,8 m	0,67 m
Extreme ice block mass (m_{ice})	8670 kg	5460 kg	2800 kg	1600 kg
C_{DMI} (if not known)	1,3	1,2	1,1	1

Table 8.13.6.5.2-3 Impact speeds for aft centerline thrusters, [m/s]

Aft centreline thruster	1AS	1A	1B	1C
Longitudinal impact in main operational direction	6	5	5	5
Longitudinal impact in reversing direction (pushing unit propeller hub or pulling unit cover end cap impact)	4	3	3	3
Transversal impact in bow first operation	3	2	2	2
Transversal impact in stern first operation (double acting ship)	4	3	3	3

Table 8.13.6.5.2-4 Impact speeds for aft wing, bow centerline and bow wing thrusters, [m/s]

Aft wing, bow centreline and bow wing thruster	1AS	1A	1B	1C
Longitudinal impact in main operational direction	6	5	5	5
Longitudinal impact in reversing direction (pushing unit propeller hub or pulling unit cover end cap impact)	4	3	3	3
Transversal impact in stern first operation (double acting ship)	4	3	3	3

8.13.6.5.3 Extreme ice loads on thruster hull when penetrating an ice ridge

In icy conditions, ships typically operate in ice channels. When passing other ships, ships may be subject to loads caused by their thrusters penetrating ice channel walls. There is usually a consolidated layer at the ice surface, below which the ice blocks are loose. In addition, the thruster may penetrate ice ridges when backing. Such a situation is likely in the case of 1AS ships in particular, because they may operate independently in difficult ice conditions. However, the thrusters in ships with lower ice classes may also have to withstand such a situa-tion, but at a remarkably lower ship speed.

In this load scenario, the ship is penetrating a ridge in thruster first mode with an initial speed. This situation occurs when a ship with a thruster at the bow moves forward, or a ship with a thruster astern moves in backing mode. The maximum load during such an event is considered the extreme load. An event of this kind typically lasts several seconds, due to which the dy-namic magnification is considered negligible and is not taken into account.

The load magnitude must be estimated for the load cases shown in Table 8.13.6.5.3-1, using equation below. The parameter values for calculations are given in Table 8.13.6.5.3-2 and Table 8.13.6.5.3-3. The loads must be applied as uniform distributed load or uniform pressure over the thruster surface. The design operation speed in ice can be derived from Table 8.13.6.5.3-2 or Table 8.13.6.5.3-3. Alternatively, the actual design operation speed in ice of the ship in question can be used.

$$F_{tr} = 32 \cdot v_s^{0,66} H_r^{0,9} A_t^{0,74}, \text{ [kN]},$$

where:

v_s = ship speed, [m/s],
H_r = design ridge thickness (the thickness of the consolidated layer is 18% of the total ridge thickness), [m],
A_t = the projected area of the thruster, [m^2].

When calculating the contact area for thruster-ridge interaction, the loaded area in the vertical direction is limited to the ice ridge thickness, as shown in Fig. 8.13.6.5.3.

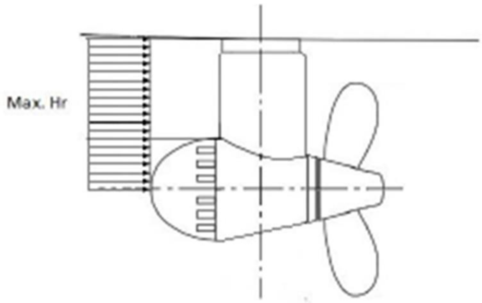
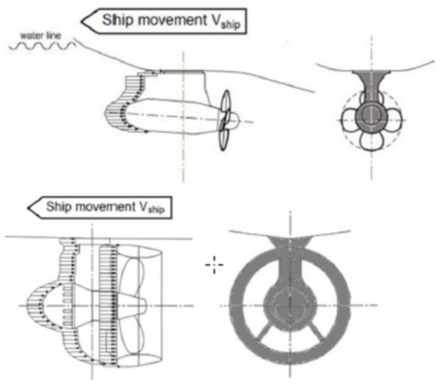
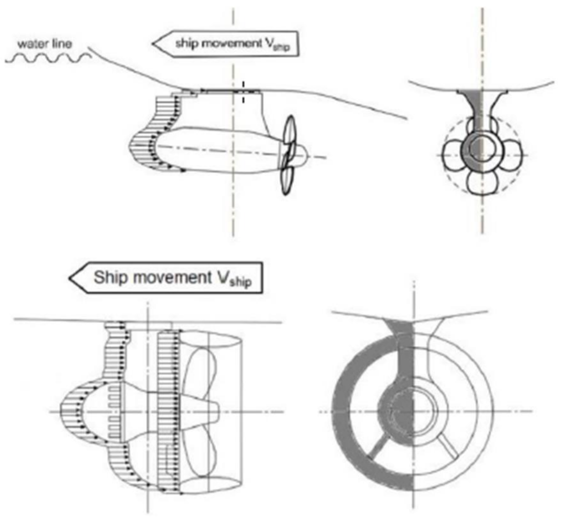


Figure 8.13.6.5.3 Schematic figure showing the reduction of the contact area by the maximum ridge thickness.

Table 8.13.6.5.3-3 Parameters for calculating maximum loads when the thruster penetrates an ice ridge. Thruster first mode such as double acting ships.

	1AS	1A	1B	1C
Thickness of the design ridge consolidated layer, [m]	1,5	1,5	1,2	1
Total thickness of the design ridge, H_r, [m]	8	8	6,5	5
Initial ridge penetration speed (longitudinal loads), [m/s]	6	4	4	4
Initial ridge penetration speed (transversal loads), [m/s]	3	2	2	2

Table 8.13.6.5.3-1 Load cases for ridge ice loads.

	Force	**Loaded area**	
Load case T4a Symmetric longitudinal ridge penetration loads	F_{tr}	Uniform distributed load or uniform pressure, which are applied symmetrically on the impact area.	
Load case T4b Non-symmetric longitudinal ridge penetration loads	50% of F_{tr}	Uniform distributed load or uniform pressure, which are applied on the other half of the impact area.	

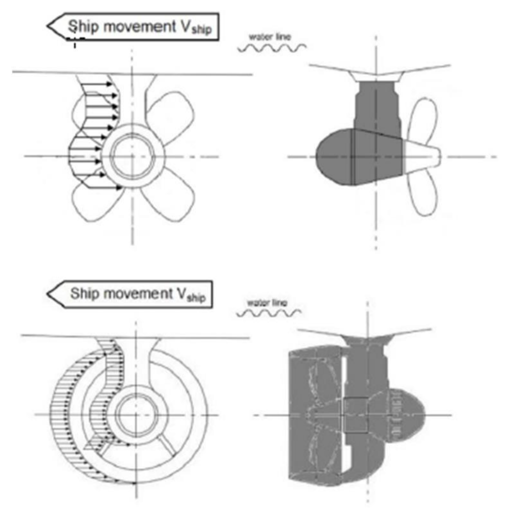
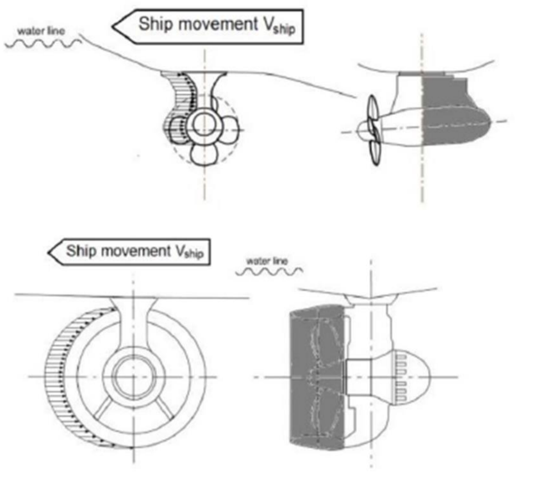
	Force	**Loaded area**	
Load case T5a Symmetric lateral ridge penetration loads for duc-ted azimuthing unit and pushing open propeller unit	F_{tr}	Uniform distributed load or uniform pressure, which are applied symmetrically on the contact area.	
Load case T5b Non-symmetric lateral ridge penetration loads for all azimuthng units.	F_{tr}	Uniform distributed load or uniform pressure, which are applied on the other half of the contact area	

Table 8.13.6.5.3-2 Parameters for calculating maximum loads when the thruster penetrates an ice ridge. Aft thrusters. Bow first operation.

	1AS	1A	1B	1C
Thickness of the design ridge consoli-dated layer, [m]	1,5	1,5	1,2	1,0
Total thickness of the design ridge, H_r, [m]	8	8	6,5	5
Initial ridge penetration speed (longitudinal loads), [m/s]	4	2	2	2
Initial ridge penetration speed (transversal loads), [m/s]	2	1	1	1

Table 8.13.6.5.3-3 Parameters for calculating maximum loads when the thruster penetrates an ice ridge. Thruster first mode such as double acting ships.

	1AS	1A	1B	1C
Thickness of the design ridge consolidated layer, [m]	1,5	1,5	1,2	1
Total thickness of the design ridge, H_r, [m]	8	8	6,5	5
Initial ridge penetration speed (longitudinal loads), [m/s]	6	4	4	4
Initial ridge penetration speed (transversal loads), [m/s]	3	2	2	2

8.13.6.5.4 Acceptability criterion for static loads

The stresses on the thruster must be calculated for the extreme once-in-a-lifetime loads de-scribed in Section 8.13.6.5. The nominal von Mises stresses on the thruster body must have a safety margin of 1,3 against the yielding strength of the material. At areas of local stress con-centrations, stresses must have a safety margin of 1,0 against yielding. The slewing bearing, bolt connections and other components must be able to maintain operability without incurring damage that requires repair when subject to the loads given in Sections 8.13.6.5.2 and 8.13.6.5.3 multiplied by a safety factor of 1,3.

8.13.6.5.5 Thruster body global vibration

Evaluating the global vibratory behavior of the thruster body is important, if the first blade order excitations are in the same frequency range with the thruster global modes of vibration, which occur when the propeller rotational speeds are in the high power range of the propulsion line. This evaluation is mandatory and it must be shown that there is either no global first blade order resonance at high operational propeller speeds (above 50% of maximum power) or that the structure is designed to withstand vibratory loads during resonance above 50% of maximum power.

When estimating thruster global natural frequencies in the longitudinal and transverse direc-tion, the damping and added mass due to water must be taken into account. In addition to this, the effect of ship attachment stiffness must be modelled.

8.13.7 Alternative design procedure

8.13.7.1 Scope

As an alternative to Sections 8.13.5 and 8.13.6, a comprehensive design study may be carried out to the satisfaction of *Register*. The study has to be based on ice conditions given for different ice classes in Section 8.13.3. It has to include both fatigue and maximum load design calculations and fulfil the pyramid strength principle, as given in Section 8.13.6.1.

8.13.7.2 Loading

Loads on the propeller blade and propulsion system shall be based on an acceptable estimation of hydrodynamic and ice loads.

8.13.7.3 Design levels

The analysis is to confirm that all components transmitting random (occasional) forces, excluding propeller blade, are not subjected to stress levels in excess of the yield stress of the component material, with a reasonable safety margin.

Cumulative fatigue damage calculations are to indicate a reasonable safety factor. Due account is to be taken of material properties, stress raisers, and fatigue enhancements.

A vibration analysis is to be performed and demonostrate that the overall dynamic system is free of the harmful torsional resonance resulting from propeller/ice interaction.

8.13.8 Requirements for the ice class notation 1D

8.13.8.1 Shell plating within the ice belt

8.13.8.1.1 Within the ice belt the shell plating is to have a strengthened strake extending over the bow region the thickness of which is to be determined according to 8.5.2.

8.13.8.1.2 The midship thickness of the side shell plating is to be maintained forward of amidships up to the strengthened plating.

8.13.8.2 Frames

8.13.8.2.1 In the bow region the section modulus of the frames is to comply with the requirements given in 8.6.

8.13.8.2.2 Tripping brackets spaced not more than 1.3 m apart are to be fitted within the ice belt in line with the tiers of beams and stringers required in the *Rules for the classification of ships*, *Part 2-Hull*, 8.1.5 in order to prevent tripping of the frames. The tripping brackets are to be extended over the bow region.

8.13.8.3 Stem

The thickness of welded plate stems up to 600 mm above UIWL is to be 1,1 times the thickness required according to the *Rules for the classification of ships, Part 2 - Hull,* 12.2.2, however, need not exceed 25 mm. The thickness above a point 600 mm above the UIWL may be gradually reduced to the thickness required according to the *Rules for the classification of ships, Part 2 - Hull,* 12.2.2.

8.13.8.4 Engine output

For ice class notation 1D the required engine output shall be not less than determined by the following formula:

$$P = 0{,}72 \cdot L \cdot B \text{ , [kW]}$$

where:

L = length of ship, in accordance with the *Rules for the classification of ships,Part 2 - Hull*, item 1.2.3.1, [m];

B = moulded breadth of ship, in accordance with the *Rules for the classification of ships*, *Part 2 - Hull*, item 1.2.3.2, [m].

8.13.8.5 Propellers

For ice class notation 1D the following requirements shall be applied:

.1 The propeller blade thickness s at the blade root and at 0,6 of propeller radius as required by *Rules for the classification of ships*, *Part 7 - Machinery Installation,* 3.2.1 shall be increased by 8%.

.2 The edges of the blades as required by *Rules for the classification of ships*, *Part 7 - Machinery Installation,* 3.2.2 shall be increased by 8%.

.3 In case of keyless propellers fitting the torque moment M_t calculated in accordance with *Rules for the classification of ships*, *Part 7 - Machinery Installation,* 2.8.9 shall be increased by 15%.

8.13.8.6 Propeller shaft

For ice class notation 1D the requirements for propeller shaft diameters are to be determined in accordance with item *Rules for the classification of ships, Part 7 - Machinery Installation,* 2.4.1 increased by 5%.

8.14 MISCELLANEOUS MACHINERY REQUIREMENTS

8.14.1 Starting arrangements

8.14.1.1 The capacity of the air receivers shall be sufficient to provide without reloading not less than 12 consecutive starts of the propulsion engine, if this has to be reversed for going astern, or 6 consecutive starts if the propulsion engine does not have to be reversed for going astern.

8.14.1.2 If the air receivers serve any other purposes than starting the propulsion engine, they shall have additional capacity sufficient for these purposes.

8.14.1.3 The capacity of the air compressors shall be sufficient for charging the air receivers from atmospheric to full pressure in one (1) hour, except for a ship with the ice class 1AS, if its propulsion engine has to be reversed for going astern, in which case the compressor shall be able to charge the receivers in half an hour.

8.14.2 Sea inlet and cooling water systems

8.14.2.1 The cooling water system shall be designed to ensure supply of cooling water when navigating in ice. For this purpose at least one cooling water inlet chest shall be arranged as follows:

.1 The sea inlet shall be situated near the centerline of the ship and well aft if possible.

.2 As guidance for design the volume of the chest shall be about one cubic meters for every 750 kW engine output of the ship including the output of auxiliary engines necessary for the ship's service.

.3 The chest shall be sufficiently high to allow ice to accumulate above the inlet pipe.

.4 A pipe for discharge cooling water, allowing full capacity discharge, shall be connected to the chest.

.5 The open area of the strainer plates shall not be less than four (4) times the inlet pipe sectional area.

If there are difficulties to meet the requirements of paragraphs 2 and 3 above, two smaller chests may be arranged for alternating intake and discharge of cooling water. Otherwise the arrangement and situation shall be as above.

8.14.2.2 Heating coils may be installed in the upper part of the sea chest.

8.14.2.3 Arrangements for using ballast water for cooling purposes may be useful as a reserve in ballast condition but cannot be accepted as a substitute for sea a inlet chest as described above.

8.14.2.4 The principle behind Sections 8.14.2.1 to 8.14.2.3 of these Rules is to ensure safe operation of the machinery also in ice conditions. Reference is also made to IMO MSC/Circ. 504 ñ*Guidance of Design and Construction of Sea Inlets under Slush Ice Conditions”*.

If the vessel is designed to operate also in southern latitudes and with a very high cooling system capacity due to high sea water temperatures, it shall be taken into consideration for design of the cooling water re-circulating line. The actual required cooling water capacity of the machinery in ice conditions will be smaller when the sea water temperature is much lower.

Box coolers can be an acceptable technical solution to ensure supply of cooling water when navigating in ice.

8.14.3 Bow thruster

8.14.3.1 In general, bow thrusters are not used in ice, because ice floes can damage the thruster blades. Ice floes can become jammed in the tunnel entrance, making operation of the thrusters impossible. Sometimes, a grid is recommended at the tunnel entrance in order to prevent ice floes from entering the tunnel. On the other hand, this can diminish the thrusterôs performance when used in open water.

If thrusters were designed specifically for ice loading, tunnels of transverse thrusters are to be fitted with grids for protection against ice impacts.

8.14.4 Fire pumps

8.14.4.1 The suction of at least one fire pump is to be connected to a sea inlet protected against icing.

8.14.5 Ballast tanks

8.14.5.1 Any ballast tank situated above the Lower ice waterline (LWL) and needed to load down the ship to this waterline is to be equipped with suitable devices to prevent the water from freezing. The devices shall be so designed as to avoid any ice formation in the tank which may be detrimental to the tank. For that purpose, the following may be accepted:

.1 heating systems by heating coils within ballast tanks,

.2 internal circulating/pumping systems,

.3 bubbling systems,

.4 steam injection systems.

8.14.5.2 Where bubbling systems are applied, following shall be complied with:

.1 sufficient number of air nozzles is to be distributed along the shell side bottom,

.2 the maximum air pressure induced in the tank is not to exceed the design pressure of tank structure,

.3 exposed vent pipe and vent heads shall be protected from possible blocking by ice,

.4 if the bubbling systems is not supplied by a dedicated compressed air plant, the general service air system may be used for that purpose if justified that its capacity takes into account the air consumption of the bubbling system.

8.14.5.3 Where ballast water exchange at sea is accepted as a process for the treatment of ballast water, ship side ballast discharge valves placed above the assigned lightest load line are to be protected from freezing by means of adequate heating arrangements. Suitable protection shall be provided also for ballast tanks vent heads, as well as for ballast overflows where existing.

8.14.6 Steering gear

8.14.6.1 In the case of ships with the notations ice class 1AS or ice class 1A, due regard is to be paid to the excessive loads caused by the rudder being forced out of the centerline position when backing into an ice ridge.

8.14.6.2 Effective relief valves are to be provided to protect the steering gear against hydraulic overpressure.

8.14.6.3 The scantlings of steering gear components are to be such as to withstand the yield torque of the rudder stock.

8.14.6.4 Where possible, rudder stoppers working on the blade or rudder head are to be fitted.