RULES FOR CLASSIFICATION

Ships

Edition July 2025

Part 6 Additional class notations

Chapter 6 Cold climate

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FOREWORD

DNV rules for classification contain procedural and technical requirements related to obtaining and retaining a class certificate. The rules represent all requirements adopted by the Society as basis for classification.

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CHANGES – CURRENT

This document supersedes the July 2023 edition of DNV-RU-SHIP Pt.6 Ch.6.
The numbering and/or title of items containing changes is highlighted in red.

Changes July 2025, entering into force 1 January 2026

Topic	*Reference*	*Description*
Class notations **DAT-B** and **DAT**	Sec.1 Table 1, Sec.1 Table 5	Removed design temperature, **t**, as qualifier. Clarified the definition of design temperature for selection of steel grades and renamed it to t_D. This parameter shall be entered as register information.
Design temperature, t_Da common parameter for the notations **PC**, **DAT-B** and **DAT**	Sec.1 [7], Sec.1 Table 7, Sec.7 [3.1.2]	Added information about inclusion of tD as register information. Included definition of design temperature. Specified the highest design temperature for the additional class notations PC(1) to PC(7).
Repositioning of definitions	Sec.1 [9], Sec.6 [1.6]	Moved definitions from Sec.6 to Sec.1 [1.9].
Class notation description tables	Sec.2 [1.4], Sec.3 [1.4], Sec.4 [1.4.1], Sec.5 [1.6.1], Sec.6 [1.4], Sec.7 [1.4.1], Sec.8 [1.5]	Removed tables including information duplicated from Sec.1 Table 1 covering all class notations described in this chapter.
Minimum thickness requirement	Sec.3 [9.4.2]	Updated minimum web thickness requirement for plated structures in lieu of an ice frame, to include stringers and transverse web frames.
Winterization plan	Sec.4 [2.1], Sec.5 [2.2]	New subsections for winterization plan, where expected content, as minimum requirement.
Navigation and communication equipment	Sec.4 Table 12, Sec.4 Table 13, Sec.4 Table 14, Sec.5 Table 17, Sec.5 Table 19, Sec.5 Table 20	— Updated navigation and communication equipment, if not certified for the assigned service temperature, PST/BST, is required to be tested and documented to be functional in ambient temperature down to PST/BST. — Added guidance notes, for recognized testing standard and proper documentation.
Polar as a stand-alone class notation	Sec.5 [1.2]	Updated objective to indicate that **Polar** class notation can be assigned as a stand-alone notation.
Reference to cold climate material requirements	Sec.5 Table 7	Corrected references.
Material requirements in **DAT** notation for cargo hatch covers	Sec.6 Table 2	Clarified applicability of the requirement only to cargo hatch covers intended for carrying cargo.

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Topic	*Reference*	*Description*
Forged and cast materials	Sec.6 [6.2], Sec.6 [6.3]	Updated test temperature for forged and cast materials, in exposed hull structural members, and subjected to design temperature t_D colder than -10^{o}C, shall be tested at temperature colder than design temperature.
Complete revision of machinery requirements for **PC** class notation based on IACS UR I3 Rev.2	Sec.7 [10], Sec.7 [11], Sec.7 [12], Sec.7 [13], Sec.7 [14], Sec.7 [15], Sec.7 [16], Sec.7 [17], Sec.7 [18], Sec.7 [19], Sec.7 [20]	Replaced previous rule text by text in IACS UR I3.
	Sec.7 Table 1	Added 'operational limitations, if any' to the documentation requirement 'technical information'.
	Sec.7 [3.3.4]	Added text from IACS UR I3 regarding that the propeller shall be fully submerged.
Yielding acceptance criteria	Sec.7 [8.3.1], Previous Sec.7 [8.3.1.5]	Removed yielding acceptance criteria. The acceptance criteria for permanent set analysis (both in-plane and out-of-plane deformation), along with a positive slope of the load-deflection curve up to 150% of the design load, are considered sufficient.

Editorial corrections

In addition to the above stated changes, editorial corrections may have been made.

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SECTION 1 GENERAL

1 Introduction

This rule chapter specifies additional notations intended for vessels that regularly or occasionally are operating in cold areas, ice infested waters, or polar waters.

2 Objective

The purpose of this chapter is to describe the various additional class notation available for vessels that will operate in cold climate and/or ice infested waters.

3 Scope

3.1

For navigation in ice infested waters, this chapter includes additional requirements for hull and machinery, covered by class notations **Ice**, **PC**, and **DAV**.

3.2

Requirements to materials for vessels intended to operate for longer periods with low air temperatures are provided in the class notations **DAT**, **DAT-B**, and **PC**.

3.3

For operation in cold temperatures outside polar waters, class notation **Winterized** specifies required equipment as well as functional and operation requirements similar to the requirements in the IMO Polar Code.

3.4

For operation within polar waters, class notation **Polar** specifies technical requirements based on the IMO Polar Code.

4 Application

4.1

This chapter applies to vessels occasionally or primarily intended for navigation in waters with sea ice conditions and/or low air temperatures.

4.2

The requirements in this chapter shall be regarded as supplementary to those given for the assignment for the main class.

5 Class notations

Vessels built in compliance with the requirements in this document may be assigned one or more of the additional notations listed in Table 1.

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Table 1 Additional class notations

Class notation	*Qualifier*	*Purpose*	*Application*
Ice Mandatory: no Design requirements: Sec.3 Retention requirements: NA	**1A*F**	High powered vessels for regular traffic in heavy Baltic ice.	Vessels constructed according to Finnish-Swedish ice rules.
	1A*	Vessels intended for navigation in ice-infested waters.	Constructed according to Finnish- Swedish ice rules (1A Super). Ice thickness 1.0 m.
	1A	Vessels intended for navigation in ice-infested waters.	Constructed according to Finnish- Swedish ice rules (1A). Ice thickness 0.8 m.
	1B	Vessels intended for navigation in ice-infested waters.	Constructed according to Finnish- Swedish ice rules (1B). Ice thickness 0.6 m.
	1C	Vessels intended for navigation in ice-infested waters.	Constructed according to Finnish- Swedish ice rules (1C). Ice thickness 0.4 m.
Ice-C Mandatory: no Design requirements: Sec.2 Retention requirements: NA	<None>	Vessels intended for navigation in light ice conditions.	
PC Mandatory: no Design requirements: Sec.7 Retention requirements: NA	**1**	Vessels intended for navigation in ice-infested polar waters.	Year-round operation in all polar waters.
	2		Year-round operation in moderate multi-year ice conditions.
	3		Year-round operation in second-year ice which may include multi-year ice inclusions.
	4		Year-round operation in thick first-year ice which may include old ice inclusions.
	5		Year-round operation in medium first-year ice which may include old ice inclusions.

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Class notation	*Qualifier*	*Purpose*	*Application*
	6		Summer and/or autumn operation in medium first-year ice which may include old ice inclusions.
	7		Summer and/or autumn operation in thin first-year ice which may include old ice inclusions.
DAV Mandatory: no Design requirements: Sec.8 Retention requirements: NA	**PC(1)**	For vessels intended to operate with stern first in ice infested polar waters.	Year-round operation in all polar waters.
	PC(2)		Year-round operation in moderate multi-year ice conditions.
	PC(3)		Year-round operation in second-year ice which may include multi-year ice inclusions.
	PC(4)		Year-round operation in thick first-year ice which may include old ice inclusions.
	PC(5)		Year-round operation in medium first-year ice which may include old ice inclusions.
	PC(6)		Summer/autumn operation in medium first-year ice which may include old ice inclusions.
	PC(7)		Summer/autumn operation in thin first-year ice which may include old ice inclusions.
	Ice(1A*)		Normally capable of navigating in difficult ice conditions without the assistance of icebreakers.
	Ice(1A)		Capable of navigating in difficult ice conditions, with the assistance of icebreakers when necessary.
	Ice(1B)		Capable of navigating in moderate ice conditions, with the assistance of icebreakers when necessary.

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Class notation	*Qualifier*	*Purpose*	*Application*
	Ice(1C)		Capable of navigating in light ice conditions, with the assistance of icebreakers when necessary.
	Icebreaker	For vessels intended to operate as icebreaker with stern first in ice infested polar waters.	Ice management and escort services.
Winterized Mandatory: no Design requirements: Sec.4 Retention requirements: Pt.7 Ch.4 Sec.4 [3]	<None>	Occasional operation in cold climate for short periods.	For ambient temperatures down to -20°C.
	BST	Operation in cold climate with low ambient temperature, see Table 7.	Mandatory for vessels intended to operate in low air temperatures with BST colder than -23°C.
Polar Mandatory: no Design requirements: Sec.5 Retention requirements: NA	**C**	Operation in ice free waters within polar waters. Operation in open waters within polar waters. Operation in ice conditions less severe than those included in categories A and B within polar waters.	
	B	Operation in other ice conditions within polar waters as listed in Sec.5 Table 6.	
	A	Operation in other ice conditions within polar waters as listed in Sec.5 Table 6.	
	PST	Operation in polar waters with cold climate and low ambient temperature, see Table 7.	Mandatory for vessels intended to operate in polar waters in low air temperatures with PST colder than -23°C.
DAT-B Mandatory: yes Design requirements: Sec.6 Retention requirements: NA	<None>	Providing material requirements for vessels intended to operate in low air temperatures.	Mandatory for vessels intended to operate in areas with low air temperatures, i.e. design temperature, t_D, colder than -10°C.

Class notation	*Qualifier*	*Purpose*	*Application*
DAT Mandatory: yes Design requirements: Sec.6 Retention requirements: NA	<None>	Providing material requirements for vessels intended to operate in low air temperatures in polar waters.	Mandatory for vessels intended to operate in polar waters with polar service temperature, PST, colder than -23°C.

6 References

Table 2 lists DNV references used in this document.

Table 2 DNV references

Document code	*Title*
DNV-CG-0041	Ice strengthening of propulsion machinery and hull appendages
DNV-CG-0127	Finite element analysis
DNV-CG-0308	IMO Polar Code operational requirements

Table 3 lists other references used in this document.

Table 3 Other references

Document code	*Title*
IACS UR I1	Polar Class
IACS UR I2	Structural Requirements for Polar Class Ships
IACS UR I3	Machinery Requirements for Polar Class Ships
IACS UR M34	Scantlings of coupling flanges - 1980
IACS UR S6	Use of Steel Grades for Various Hull Members - Ships of 90m in Length and Above
IACS UR W7	Hull and machinery steel forgings
IACS UR W27	Cast steel propellers
VDEH 1983 Bericht Nr. ABF11	Berechnung von Wöhlerlinien für Bauteile aus Stahl

7 Register information

Design temperature, t_D, if colder than -10°C, will be entered as register information for the vessel.

8 Documentation requirements

Details related to design, arrangement and strength shall be included in the plans specified for the main class, with additions as listed in Table 4 and as listed under the relevant sections of this document.

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Table 4 Documentation requirements

Object	*Documentation type*	*Additional description*	*Info*
Ship hull	H060 - Shell expansion drawing	For vessels with class notation **Ice**, **Ice-C** or **PC**, UIWL and LIWL, as defined in [9], shall be indicated together with the lines separating the bow, midbody and stern regions of the ice belt.	AP
		For vessels with class notations **Ice-C**, **ICE(1C)**, **Ice(1B)**, **Ice(1A)**, **Ice(1A*)** and **Ice(1A*F)**, displacement Δ_f, engine output, P_S, and minimum engine output, P_{min} (see Sec.3 [7.1.4]), shall be stated on the shell expansion drawing.	
		Design temperature, t_D , as defined in Table 7, if colder than -10 ^{o}C, shall be stated on the shell expansion drawing as a basis for hull structure material requirement. Design temperature, t_D, will be entered as a register information for the vessel.	
External communication equipment	Z090 - Equipment list	All exposed communication equipment and communication equipment with exposed subsystems shall be tested and verified down to the temperature defined by BST or PST by an accredited laboratory, when BST or PST is defined for the vessel	AP
Navigation systems	Z090 - Equipment list	All exposed navigation equipment and navigation equipment with exposed subsystems shall be tested and verified down to the temperature defined by BST or PST by an accredited laboratory, when BST or PST is defined for the vessel	AP

Object	*Documentation type*	*Additional description*	*Info*
AP = for approval			

9 Definitions

9.1 General definitions

General definitions used in this chapter are listed in Table 5.

Table 5 General definitions

Term	*Definition*
exposed structure	structure above the lowest ballast waterline (LBWL)
fore ship structure	bow and intermediate ice belt area, i.e. B and B_{II}, see Sec.7 Figure 1
register information	list of essential details about the vessel's specifications, classification status, and compliance with international regulations, which is available for all vessels classed by the Society

9.2 Draught definitions

Definitions of water lines, upon which the design of the vessel shall be based, are listed in Table 6.

Table 6 Draught definitions

Term	*Definition*
lowest ballast water line	applicable for ships intended to operate in ice
upper ice water line	envelope of the highest points of the waterline at which the ship is intended to operate in ice irrespective of water salinity. The line may be a broken line
lower ice water line	envelope of the lowest points of the waterline at which the ship is intended to operate in ice. The line may be a broken line

9.3 Temperature definitions

Definitions of temperatures, used as basis for estimation of design and service temperature are listed in Table 7.

Table 7 Temperature definitions

Term	*Definition*
lowest mean daily average temperature	lowest mean daily average temperature (MDAT) for the area and period of operation considered: $$LMDAT = \min\left(MDAT_j\right)$$ See Figure 1.

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Term	*Definition*
mean daily average temperature	statistical mean of daily average temperature for each day of the year over a minimum of 10 years period The mean daily average temperature for a specific calendar day, j, can be found as follows: $MDAT_j = \frac{\Sigma_i^n \left(t_{\min,\ i} + t_{\max,\ i}\right)}{2n}$ where: $t_{min,\ i}$ = 24 hours minimum (coldest) temperature for a specific calendar day over a minimum 10 years period $t_{max,\ i}$ = 24 hours maximum (warmest) temperatures for a specific calendar day over a minimum of 10 years period n = number of years considered. In polar regions, statistical mean over observation period shall be determined over a minimum of 10 years period.
mean daily low temperature	statistical mean of daily lowest temperature for each day of the year over a minimum of 10 years period The mean daily low temperature for a specific calendar day, j, can be found as follows: $MDLT_j = \frac{\Sigma_i^n t_{\min,\ i}}{n}$ where: $t_{min,\ i}$ = 24 hours minimum (lowest) temperature for a specific calendar day over a minimum 10 years period n = number of years considered. In polar regions, statistical mean over observation period shall be determined over a minimum of 10 years period. A data set acceptable to the administration may be used if ten years of data is not available. This temperature is considered to be comparable with MDAT - 3^{o}C, i.e. $MDLT = MDAT - 3^{o}C$
lowest mean daily low temperature	lowest MDLT for the area and period of operation considered $LMDLT = \min\left(MDLT_j\right)$ See Figure 1 **Guidance note:** A ship is, according to IMO Polar Code, considered to be intended to operate in low air temperature when the lowest mean daily low temperature is colder than -10 °C, i.e. $LMDLT < -10^{o}C$ ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
polar service temperature	lowest (ambient) air temperature the vessel is intended to operate in within polar waters, as defined in the IMO Polar Code

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Term	*Definition*
Baltic service temperature	lowest (ambient) air temperature the vessel is intended to operate in, within the northern Baltic Sea during the winter or areas with similar conditions outside polar waters
design temperature, t_D	reference temperature used as a criterion for selecting the grade of steel and rounded to the nearest integer: $t_D \leq LMDAT$ in relation to polar service temperature (PST) and BST the following applies: $t_D \leq PST + 13^oC$ $t_D \leq BST + 13^oC$ for **PC** class notation, see Sec.7 [3.1.2]

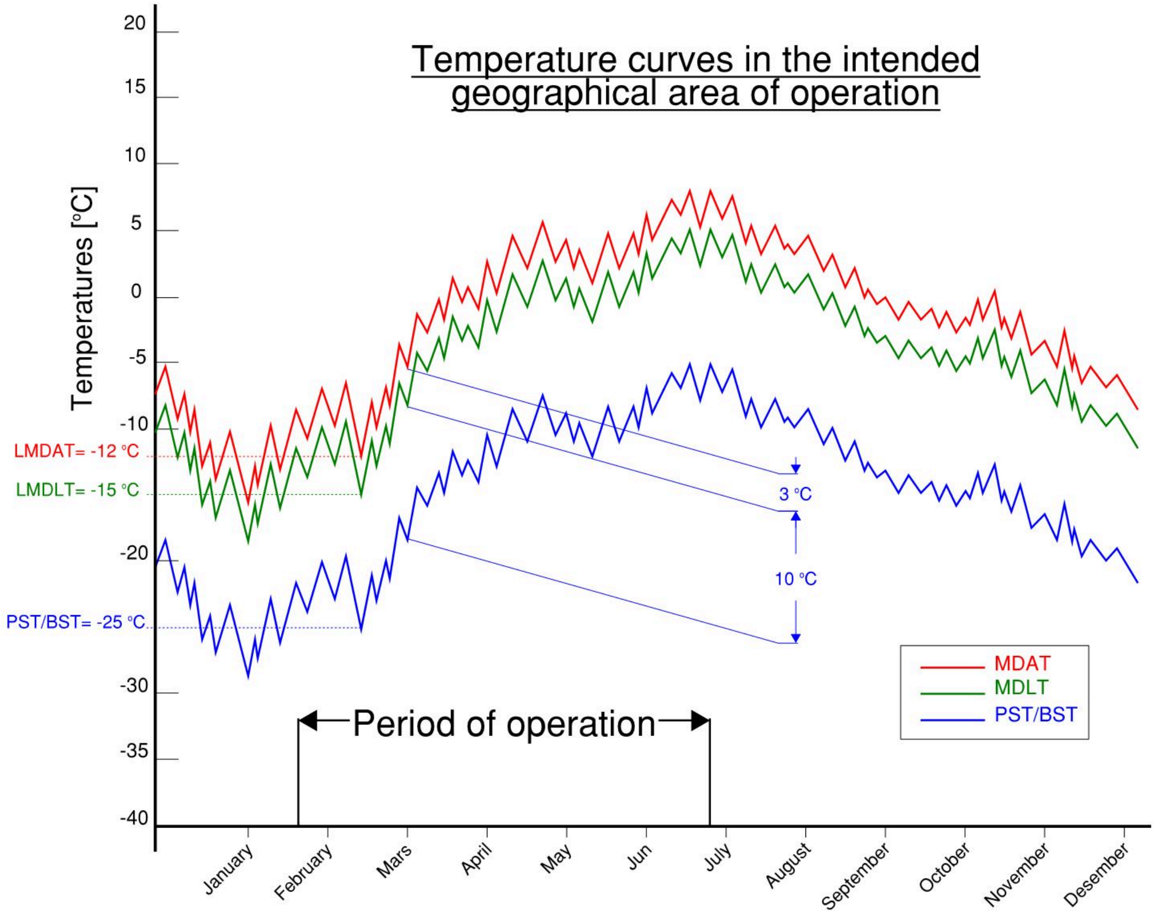

Figure 1 Example of temperature curves in the intended geographical area of operation

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9.4 Symbols

For symbols not defined in this section, see Pt.3 Ch.1 Sec.4.

9.5 Abbreviations

The abbreviations described in Table 8 are used in this document.

Table 8 Abbreviations

Abbreviation	*Description*
BST	baltic service temperature
PST	polar service temperature

10 Marking

10.1 General

10.1.1 If the summer load line in fresh water is anywhere located at a higher level than the UIWL, the ship sides shall be provided with a warning triangle and with ice class draught marks at the maximum permissible amidships draught, see Figure 2, and the maximum permissible draught amidships shall be explicitly indicated in the appendix to the classification certificate.

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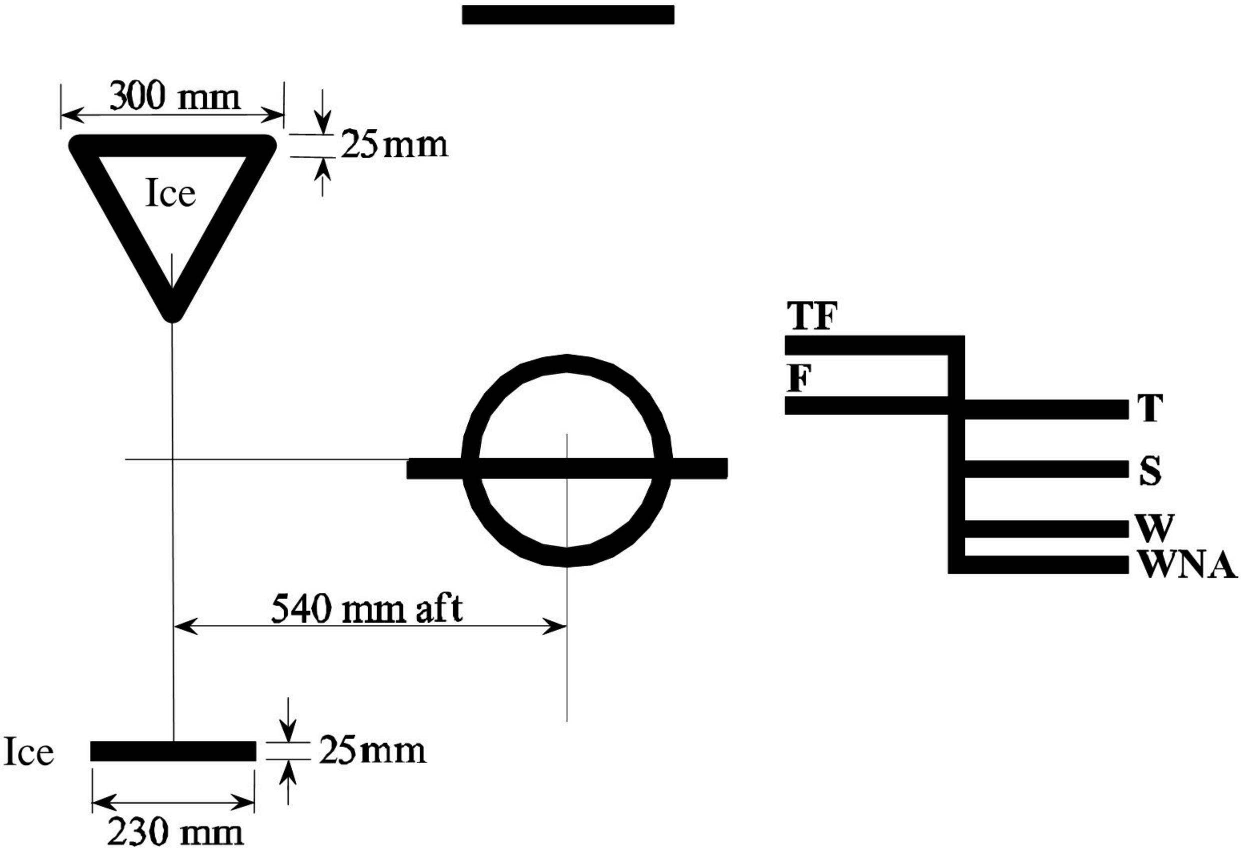

Figure 2 Ice class draught marking

10.1.2 Marking requirements

10.1.2.1 The ice class draught marking 'Ice' shall indicate the maximum ice class draught.

10.1.2.2 The upper edge of the warning triangle shall be located vertically above the 'Ice' mark, at the height 1000 mm above summer freshwater load line, but not higher than the deck line. The sides of the triangle shall be 300 mm in length.

10.1.2.3 The ice class draught mark shall 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.

10.1.2.4 The ice marks and letters shall be cut out of 5 mm to 8 mm plate and then welded to the ship's side or marking shall be indicated by weld seam directly on the ship side. The marks and letters shall be painted in a red or yellow reflecting colour in order to make the marks and figures plainly visible even in ice.

10.1.2.5 The dimensions of all letters shall be the same as those used in the load line mark.

10.1.2.6 For ships not having load line markings, the warning triangle and ice draught mark shall be vertically aligned with the draught mark. The warning triangle shall be placed 1000 mm above the draught mark, but in no case above the deck line.

10.1.3 For vessels not intended to operate within the Baltic Sea, the ice warning triangle is not required.

11 Material

11.1

For minimum material grade for ice strengthening ships, see Pt.3 Ch.3 Sec.1 Table 8. Shell strakes in way of ice strengthening area for plates shall be minimum grade B/AH.

11.2

The use of materials other than those specified in Pt.3 Ch.3 Sec.1 shall be agreed with the Society.

12 Loading conditions

All design loading conditions in ice, including trim, shall be within the draught envelope limited by the UIWL and LIWL. The lower ice waterline should further be determined with due regard to the ship's ice-going capability in the ballast loading conditions.

(IACS UR I 1.3)

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SECTION 2 BASIC ICE STRENGTHENING - ICE-C

1 General

1.1 Objective

The additional class notation **Ice-C** establishes requirements for ships intended for service in waters with light ice conditions and light localized drift ice, in river mouths, and coastal areas.

1.2 Scope

The scope for additional class notation **Ice-C** specifies requirements for hull strength, machinery systems and equipment, and includes the relevant procedural requirements applicable to ships operating in light ice and light localized drift ice conditions in river mouths and coastal areas.

1.3 Application

The additional class notation **Ice-C** applies to vessels intended for service in waters with light ice conditions and built in compliance with the requirements of this section.

1.4 Class notations

Vessels built in compliance with the requirements of this section may be assigned the additional class notation **Ice-C** as described in Sec.1 Table 1.

1.5 Definitions

1.5.1 Definitions of terms

For definitions, see Sec.1 [9].

1.5.2 Symbols

For symbols not defined in this section, see Pt.3 Ch.1 Sec.4.

2 Structural requirements for the class notation Ice-C

2.1 General

The requirements for the bow ice belt region, as defined in Sec.3 Table 1, for [2.2] to [2.7], shall be in accordance with Sec.3 as follows:

- In Sec.3 Table 6, the value of h_0 and h shall be as given for **Ice(1C)**.
- The ice pressure shall be determined in accordance with Sec.3 [7.3], where the factor c_1, as given in Sec.3 Table 7, is taken as being equal to 0.55.
- Vertical extension of the ice belt plating and framing shall be:

  Plating: 0.4 m above UIWL and 0.5 m below LIWL.

  Framing: 0.62 m above UIWL and 1.0 m below LIWL.

2.2 Plating

In the bow ice belt region as defined in [2.1], the shell plate thickness shall be as given in Sec.3 [8].

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2.3 Framing

In the bow ice belt region as defined in [2.1], the frames shall be as given in Sec.3 [9.1] to Sec.3 [9.3].

In addition, the following shall apply:

1) Frames shall be effectively attached to all supporting structures. Transverse and longitudinal frames crossing support structures shall be connected to these with lugs. Alternatively, top stiffener in combination with lug may be used. The upper end of intermediate frames may be sniped at a stringer or deck provided the ice belt covers not more than 1/3 of the span.
2) Frames where the angle between the web and the shell is less than 75 degrees shall be supported against tripping by brackets, intercostals, stringers or similar at a distance preferably not exceeding 2.5 m.

   Transverse frames perpendicular to shell which are of unsymmetrical profiles shall have tripping preventions if the span is exceeding 4.0 m.
3) The web thickness of the frames shall be at least one half of the thickness of the shell plating. Where there is a deck, tank top, bulkhead, web frame or stringer in lieu of a frame, at least one half of the thickness of shell plating shall be kept to a depth of not less than 0.0025 L, minimum 0.2 m.

2.4 Stringers and web frames

Stringers situated inside and outside the ice belt shall be as given in Sec.3 [10.1] to Sec.3 [10.2]. Web frames shall be as given in Sec.3 [11].

2.5 Weld connections

Weld connections to shell in fore peak shall be double continuous.

2.6 Rudder and steering arrangement

The rudder and steering arrangement shall comply with Sec.3 [14.2], given that the maximum service speed of the ship is not taken less than 14 knots.

2.7 Stem

The plate thickness of a shaped plate stem and any part of the bow which forms an angle of 60 degrees or more to the centreline in a horizontal plane shall comply with Sec.3 [13.1.2] up to 600 mm above UIWL.

3 Machinery requirements for class notation Ice-C

3.1 Output of propulsion machinery

3.1.1 The maximum continuous output, in kW, shall generally not be less than:

$$P_S = 0.73\ L\ B$$

For ships with a bow specially designed for navigation in ice, a reduced output may be accepted. In any case, the output, in kW, shall not be less than:

$$P_S = 0.59\ L\ B$$

3.1.2 If the ship is fitted with a controllable pitch propeller, the output may be reduced by 25%.

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3.2 Design of propeller and propeller shaft

3.2.1 The formula for scantlings is based on the following loads:

T_o = mean torque of propulsion engine at maximum continuous rating [Nm].

If multi-engine plant, T_o is the mean torque in an actual branch or after a common point. T_o is always referred to engine r.p.m.

Th_o = mean propeller thrust [N] at maximum continuous speed
R = as given in [3.2.2]
T_{ice} = ice torque [Nm], referred to propeller r.p.m.
= 35 200 R^2 for open propellers
= 35 200 R^2 (0.9 – 0.0622 $R^{-0.5}$) for ducted propellers.

Skewed propellers will be especially considered with respect to the risk of blade bending at outer radii if f_{sk} exceeds 1.15, see [3.2.4].

3.2.2 The particulars governing the requirements for propeller scantlings are:

R = propeller radius [m]
H_r = pitch [m] at radius in question
θ = rake in degrees at blade tip (backward rake positive)
Z = number of blades
t = blade gross thickness [mm], at cylindrical section considered:

$t_{0.25}$ = t at 0.25 R
$t_{0.35}$ = t at 0.35 R
$t_{0.6}$ = t at 0.6 R

c_r = blade width [m], at cylindrical section considered:

$c_{0.25}$ = c_r at 0.25 R
$c_{0.35}$ = c_r at 0.35 R
$c_{0.6}$ = c_r at 0.6 R

e = distance between skew line and generatrix [m], at cylindrical section considered, positive when skew line is forward of generatrix:

$e_{0.6}$ = e at 0.6 R
$e_{1.0}$ = e at 1.0 R

u = gear ratio:

u = 1, if the shafting system is directly coupled to engine

n_o = propeller speed at maximum continuous output, for which the machinery shall be approved, in revolutions per minute.

3.2.3 Propellers and propeller parts (defined in Pt.4 Ch.5 Sec.1 [1.7]) shall be of steel or bronze as specified in Pt.2 Ch.2. Nodular cast iron of grade NV 1 and NV 2 may be used for relevant parts in CP-mechanism.

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Other type of nodular cast iron with elongation ≥ 12% may be accepted upon special consideration for same purposes.

3.2.4 The blade gross thickness, in mm, of the cylindrical sections at 0.25 R (fixed pitch propellers only) and at 0.35 R shall not be less than:

$$t_{gr} = C_1\sqrt{\frac{2R \cdot K_1\left(U_2 \cdot C_4 + 0.2\right) + K_4}{Z \cdot c_r\left(K_{Mat} \cdot U_1 - U_2 \cdot S_r\right)}}$$

The gross thickness, in mm, at 0.6 R shall not be less than:

$$t_{gr} = t_{0.35}\sqrt{\frac{0.45 \cdot f_{sk} \cdot c_{0.35}}{c_{0.6}}}$$

where:

U_1 and U_2 = material constants shall be taken as given in Pt.4 Ch.5 Sec.1 Table 6.

$$f_{sk} = 1 + \left(\frac{e_{0.6} - e_{1.0}}{R}\right)^2$$

$$S_r = \left(\frac{2Rn_o}{100}\right)^2\left(C_2\theta + C_3\right)$$

$$K_1 = A_1 \cdot d \cdot Th_0 \cdot 0.85 + A_2\left(\frac{0.75 \cdot u \cdot T_0}{R}\right)$$

For fixed blade propellers:

$$K_1 = A_1 \cdot d \cdot Th_0 \cdot 1.25 + A_2 \cdot \frac{u \cdot T_0}{R}$$

For controllable pitch propellers:

K_4 = $k_i Z T_{ice} \sin\alpha$

C_1, C_2, C_3, C_4 = as given in Table 1

A = $q_0 + q_1 d + q_2 d^2 + q_3 d^3$

q_0, q_1, q_2, q_3 = as given in Table 2

d = $\frac{2\pi R}{H_r}$ for fixed blade propellers

d = $\frac{2\pi R}{0.7H_r}$ for controllable pitch propellers

k_i = 96 at 0.25 R

= 92 at 0.35 R

K_{Mat} = 1.0 for stainless steel propellers

= 0.8 for other materials

$\sin\alpha$ = $\frac{4}{\sqrt{d^2 + 16}}$ at 0.25 R

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$$= \frac{2.86}{\sqrt{d^2 + 8.18}} \text{ at 0.35 R}$$

K_1 as given above is only valid for propulsion by diesel engines (by about zero speed, it is assumed 85% thrust and 75% torque for fixed pitch propellers and 125% thrust and 100% torque for controllable pitch propellers).

For turbine, diesel-electric or similar propulsion machinery K_1 will be considered in each particular case.

Guidance note:

K_1 may be calculated for other than diesel driven propellers by replacing the constants 0.85 by 1.1 and 0.75 by 1.0 for FP provided that maximum torque of the driving engine is limited to 100% of the nominal torque. If driving torque exceeds 100%, the torque constant 1.0 shall be multiplied by the ratio T_{max}/T_o and corresponding thrust value (Th_o times constant) calculated based on the actual maximum torque.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

The thickness of other sections is governed by a smooth curve connecting the above section thicknesses.

Table 1 Values of C_1, C_2, C_3, C_4

r	*0.25 R*	*0.35 R*	*0.6 R*
C_1	0.278	0.258	0.150
C_2	0.026	0.025	0.020
C_3	0.055	0.049	0.034
C_4	1.38	1.48	1.69

Table 2 Values of q_0, q_1, q_2, q_3

R		q_0	q_1	q_2	q_3
0.25 *R*	A_1	8.30	0.370	-0.340	0.030
	A_2	63.80	-4.500	-0.640	0.0845
0.35 *R*	A_1	9.55	-0.015	-0.339	0.0322
	A_2	57.30	-7.470	-0.069	0.0472
0.6 *R*	A_1	14.60	-1.720	-0.103	0.0203
	A_2	52.90	-10.300	0.667	0.0

3.2.5 If found necessary by the torsional vibration calculations, minor deviations from the dimensions given in [3.2.4] may be approved upon special consideration.

3.2.6 The gross section modulus of the blade bolt connection, in cm^3, referred to an axis tangentially to the bolt pitch diameter, shall not be less than:

$$Z_{gr-b} = 0.1 \cdot c_{0.35} \cdot t_{0.35}^2 \cdot \frac{\sigma_b}{\sigma_y}$$

where:

σ_b = tensile strength of propeller blade material [N/mm^2]
σ_y = yield stress of bolt material [N/mm^2].

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The propeller blade foot shall have a strength (including stress concentration) not less than that of the bolts.

3.2.7 Fitting of the propeller to the shaft is given in Pt.4 Ch.4 Sec.1 as follows:

- flanged connection in [2.3]
- keyless cone connection in [2.4]
- keyed cone connection in [2.5].

Considering 0°C seawater temperature.

If the propeller is bolted to the propeller shaft, the bolt connection shall have at least the same bending strength as the propeller shaft.

The strength of the propeller shaft flange (including stress concentration) shall be at least the same as the strength of the bolts.

3.2.8 The propeller shaft diameter need not exceed 1.05 times the rule diameter given for main class, irrespective of the dimension required below.

The diameter of the propeller shaft at the aft bearing, in mm, shall not be less than:

$$d_p = 11.5\left(\frac{\sigma_u \cdot c_{0.35} \cdot t_{0.35}^2}{\sigma_{0.2}}\right)^{\frac{1}{3}}$$

where:

σ_u = tensile strength of propeller blade material [N/mm^2]
$\sigma_{0.2}$ = minimum specified yield strength or 0.2% proof stress of the propeller shaft material [N/mm^2]
$c_{0.35}$ = as defined in [3.2.2]
$t_{0.35}$ = as defined in [3.2.2].

Between the aft and second aft bearing, the shaft may be evenly tapered to 1.22 times the diameter of the intermediate shaft, as required for the main class.

Forward of the after peak bulkhead, the shaft may be evenly tapered down to 1.05 times the rule diameter of intermediate shaft, but not less than the actual diameter of the intermediate shaft.

3.3 Sea suctions and discharges

3.3.1 The sea cooling water inlet and discharge for main and auxiliary engines shall be so arranged so that blockage of strums and strainers by ice is prevented. In addition to requirements in Pt.4 Ch.6 Sec.5 [2.3.2] and Pt.6 the requirements in [3.3.2] and [3.3.3] shall be complied with.

3.3.2 One of the sea cooling water inlet sea chests shall be situated near the centre line of the ship and well aft. At least one of the sea chests shall be sufficiently high to allow ice to accumulate above the pump suctions.

3.3.3 A full capacity discharge branched off from the cooling water overboard discharge line shall be connected to at least one of the sea inlet chests. At least one of the fire pumps shall be connected to this sea chest or to another sea chest with de-icing arrangements.

Guidance note:

Heating coils may be installed in the upper part of the sea chest(s). Arrangement using ballast water for cooling purposes is recommended but will not be accepted as a substitute for sea inlet chest arrangement as described above.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

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SECTION 3 ICE STRENGTHENING FOR THE NORTHERN BALTIC - ICE

1 General

1.1 Objective

The objective with the additional class notation **Ice** is to provide requirements for vessels intended to operate in ice infested waters in the northern Baltic or areas with similar ice conditions.

1.2 Scope

The scope for additional class notation **Ice** includes requirements for:

- hull strength
- propulsion
- miscellaneous machinery items and equipment

and the relevant procedural requirements applicable to vessels operating in northern Baltic ice conditions.

1.3 Application

1.3.1 The additional class notation **Ice** applies to vessels intended for operation in ice infested waters, typically northern Baltic in winter or areas with similar ice conditions. The requirements are equivalent to the Finnish-Swedish Ice Class Rules. A series of qualifiers are available for this notation, see Sec.1 Table 1, related to navigation in ice infested waters, with different thickness of ice and varying degrees of assistance from icebreaker.

1.3.2 Where not stated otherwise, all requirements applicable to qualifier **1A*** applies also to **1A*F**.

Guidance note:

The class notation **Ice(1A*F)** is recommended for vessels normally operating according to fixed timetables irrespective of ice condition and that are to a certain degree independent of icebreaker assistance.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

1.4 Class notations

Vessels built in compliance with the requirements in this section will be assigned the additional class notation **Ice**, as specified in Sec.1 Table 1.

1.5 Definitions

1.5.1 Definition of terms

For definitions, see Sec.1 [9].

Definitions of the vertical and longitudinal extensions of the different regions within the ice reinforced area, are listed in Table 1.

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Table 1 Definition of terms

Term		*Definition*
extent of ice strengthening		determined from the upper ice water line (UIWL) to the lower ice water line (LIWL), which defines the extreme draughts For operation in Baltic, the upper ice waterline (UIWL) is, in general, the same as the freshwater summer load line. See also Sec.1 [9.2].
ice belt regions	bow region	from the stem to a line parallel to and 0.04 *L* aft of the forward borderline of the part of the hull where the waterlines run parallel to the centre line For ice classes **Ice(1A*F)**, **Ice(1A*)**, and **Ice(1A)** the overlap of the borderline need not exceed 6 m, for ice classes **Ice(1B)**, **Ice(1C)**, and **Ice-C**, this overlap need not exceed 5 m. See Figure 1.
	midbody region	from the aft boundary of the bow region to a line parallel to and 0.04 *L* aft of the aft borderline of the part of the hull where the waterlines run parallel to the centre line For ice classes **Ice(1A*F)**, **Ice(1A*)**, and **Ice(1A)** the overlap of the borderline need not exceed 6 m, for ice classes **Ice(1B)** and **Ice(1C)** this overlap need not exceed 5 m. See Figure 1.
	stern region	from the aft boundary of the midbody region to the stern See Figure 1.

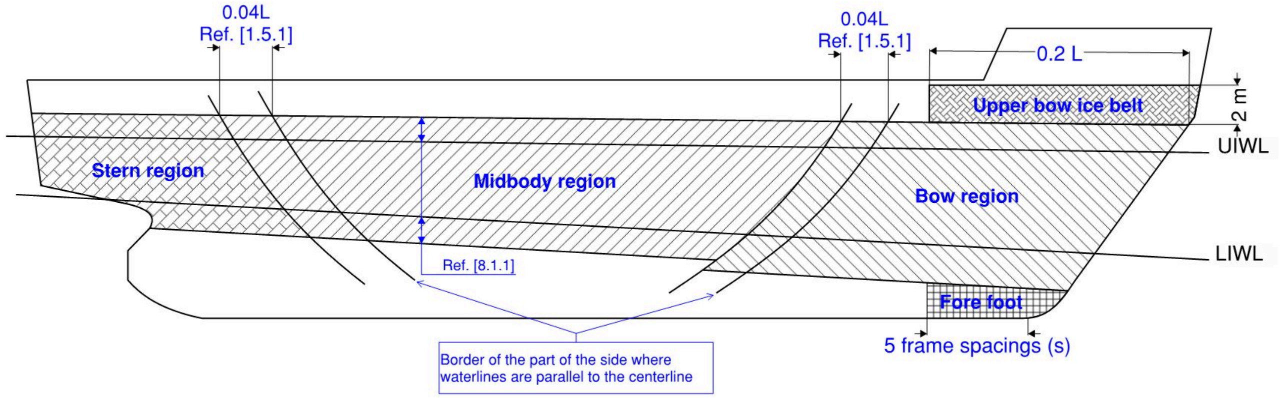

Figure 1 Ice belt regions

The upper ice water line (UIWL) and the lower ice water line (LIWL) are defined in Sec.1 [9.2].

1.5.2 Definition of forward draught during transit in ballast condition

The minimum forward draught, in m, shall be at least:

$$\left(2 + 0.00025\Delta_f\right)h_o$$

but need not exceed 4 h_o where:

Δ_f = displacement of the ship, in tonnes, on the maximum ice class draught according to [1.5.3]. Where multiple waterlines are used for determining the UIWL, the displacement shall be determined from the waterline corresponding to the greatest displacement

h_o = ice thickness according to Table 6.

1.5.3 Symbols

For symbols not defined in this section, see Pt.3 Ch.1 Sec.4.

2 Documentation requirements

Documentation shall be submitted as required by Table 2.

Table 2 Documentation requirements

Object	*Documentation type*	*Additional description*	*Info*
Technical information	Z100 – Specification	Displacement, machinery type, propulsion power.	FI
Propulsion and steering arrangement	Z265 – Calculation report	Minimum required propulsion power, P_{min}, see [7.1]. Hull particulars defined in [7.1.3].	FI
	C040 – Design analysis	Applicable if a first blade order torsional resonance is within operational speed range +/- 20%. Torsional vibration analysis of ice torque response.	AP
	C040 – Design analysis	Applicable for alternative designs, not applying loads defined in the rules. Comprehensive design analysis of entire system.	AP, R
	C040 – Design analysis	Applicable for azimuth propulsion units: body global vibration calculation.	AP
	C040 – Design analysis	Applicable for azimuth propulsion units: calculation of ice impact loads on unit structure.	AP
Propeller arrangement	C040 – Design analysis	Finite element analysis of blade stresses introduced by ice loads.	AP
AP = for approval, FI = for information, R = on request			

For general requirements to documentation, including definition of the info codes, see DNV-CG-0550 Sec.6. For a full definition of the documentation types, see DNV-CG-0550 Sec.5.

3 Marking and onboard documentation

For marking and on board documentation, see Sec.1 [10].

4 Assumptions

4.1 General

4.1.1 The method for determining the hull scantlings, engine output and other properties are based on certain assumptions concerning the nature of the ice load on the structure and operation of the ship as described in the Finnish-Swedish Ice Class Rules. These assumptions rest on full scale observations made in the northern Baltic.

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Guidance note:

For background documentation of this section, see Finnish Transport Safety Agency (TraFiCom) homepage: http://www.traficom.fi/en/transport/maritime/ice-classes-ships:

Finnish-Swedish Ice Class rules

Guidelines for the application of the Finnish-Swedish Ice Class Rules (hereafter called TraFiCom Guidelines)

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.1.2 Assistance from icebreakers is normally assumed when navigating in ice bound waters.

4.1.3 The formula given for plating, stiffeners and girders is based on special investigations as to the distribution of ice loads from plating to stiffeners and girders as well as redistribution of loads on stiffeners and girders. Special values have been given for distribution factors and certain assumptions have been made regarding boundary conditions.

4.1.4 For the formulae and values given in this section for the determination of the hull scantlings more sophisticated methods may be substituted subject to special approval. However, direct analysis is not to be utilized as an alternative to the analytical procedures prescribed by explicit requirements in [8], [9] and [10] (plates, frames and stringers), unless these are invalid or inapplicable for a given structural arrangement or detail.

Direct analyses shall be carried out using the load patch defined in [7] (P, h and ℓ_a). The pressure to be used is $1.8 \cdot P$ where P is determined according to [7.3]. The load patch shall be applied at locations where the capacity of the structure under the combined effects of bending and shear are minimized. In particular, the structure shall be checked with load centred at the UIWL, $0.5 \cdot h_o$ below the LIWL, and positioned several vertical locations in between. Several horizontal locations shall also be checked, especially the locations centred at the mid-span or -spacing. Further, 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.

Acceptance criteria for designs are that the combined stresses from bending and shear, using the von Mises yield criterion, are lower than the yield point R_{eH}. If the structure is analysed by the use of beam models, the allowable shear stress is not to be larger than $0.9 \cdot \tau_{eH}$, where $\tau_{eH} = R_{eH}/\sqrt{3}$.

4.1.5 If scantlings derived from these regulations are less than those required for a non-ice-strengthened ship, the latter shall be used.

4.1.6 Effective frames bending and shear spans, ℓ_{bdg} and ℓ_{shr}, defined in this section shall be as given in Pt.3 Ch.3 Sec.7.

For plating, frame spacing is assumed to be measured along the plate and perpendicular to the axis of the stiffener. For curved members, frame spacing is defined as the cord length between spacing points. Figure 2 illustrates the determination of spacing for curved members.

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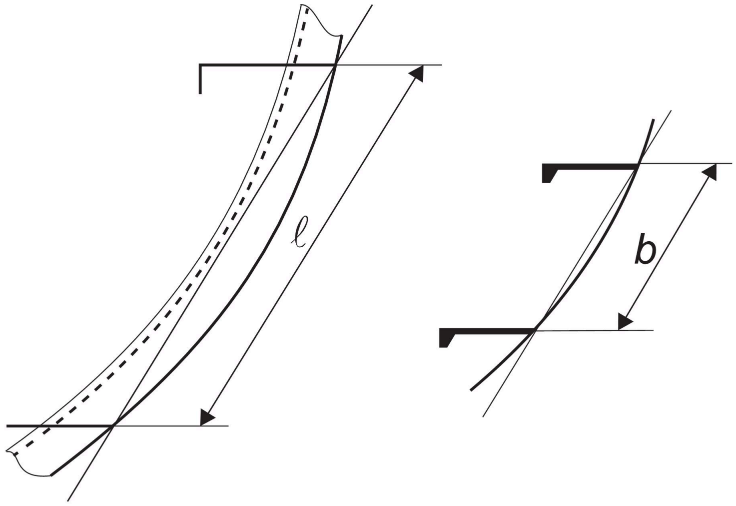

Figure 2 Definition of the frame span (left) and frame spacing (right) for curved members

4.1.7 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 shall be taken as given in Pt.3 Ch.3 Sec.7 [1.3].

4.1.8 The requirements for the section modulus and shear area of the frames, stringers and web frames in [9], [10] and [11] with respect to the effective member cross-section, where the member is not normal to the plating, the section properties shall be calculated in accordance with Pt.3 Ch.3 Sec.7 [1.4].

5 Materials

For minimum material grade for ice strengthening ships, see Sec.1 [11].

6 Loading conditions

For design loading conditions in ice, see Sec.1 [12].

7 Design loads

7.1 Engine output

7.1.1 Definition of engine output

The engine total output P_S 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_S 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.

7.1.2 Documentation on board

The restricted engine output in ice shall be given in the appendix to classification certificate.

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7.1.3 Required engine output for ice classes

The dimensions of the ship and some other parameters are defined below:

L_{BOW} = length of the bow [m], see Figure 3
L_{PAR} = length of the parallel midship body [m], see Figure 3
T = actual ice class draughts of the ship [m], according to [7.1.4]
A_{wf} = area of the waterline of the bow [m^2], see Figure 3
α = the angle of the waterline at $B/4$, in degrees, see Figure 3
φ_1 = the rake of the stem at the centre line, in degrees, see Figure 3
φ_2 = the rake of the bow at $B/4$, in degrees, see Figure 3
ψ = flare angle, in degrees, calculated as ψ = arc tan(tan φ/sin α) using angles α and φ at each location. For [7.1], flare angle is calculated using $\varphi = \varphi_2$
D_P = diameter of the propeller or outer diameter of nozzle for the nozzle propeller, maximum 1.2 times propeller diameter [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]
R_{CH} = resistance [N], of the ship in a channel with brash ice and a consolidated layer (see formula in [7.1.4])
K_e = factor depending on no. of propellers, CPP (or similar), fixed pitch type, see Table 3
P_{min} = minimum required engine output [kW]
C = empirical coefficients (misc. sub index)
f = empirical factors (misc. sub index)
g = empirical factors (misc. sub index)
L = length of the ship between the perpendiculars [m]
B = maximum breadth of ship [m].

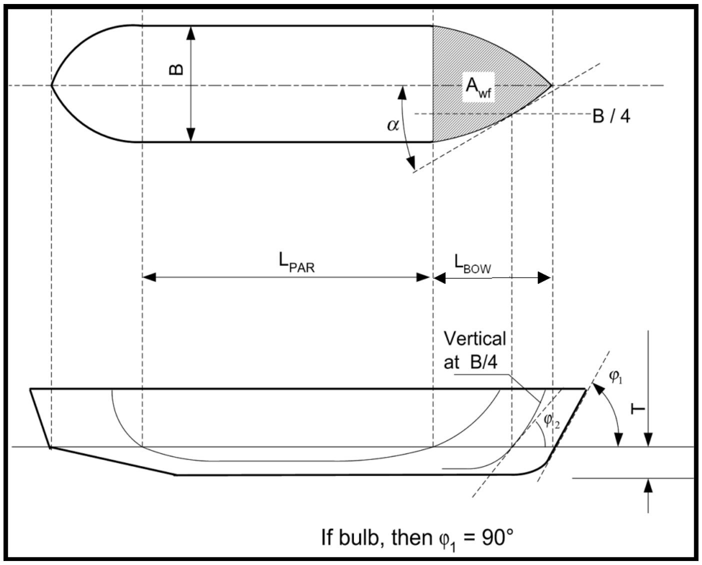

Figure 3 Definitions

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7.1.4 The engine output requirement shall be calculated for:

- upper ice waterlines (UIWL)
- lower ice waterlines (LIWL)

as defined in Sec.1 [9.2].

In the calculations the ship's parameters which depend on the draught shall be determined at the appropriate draught, but *L* and *B* shall 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 formulae and in no case less than given in Table 4.

$$P_{\min} = K_e \cdot \frac{\left(\frac{R_{CH}}{1000}\right)^{\frac{3}{2}}}{D_P}$$

Table 3 Value of factor K_e for conventional propulsion systems[1)]

	Propeller type or machinery	
Numbers of propellers	*Controllable pitch propeller or electric or hydraulic propulsion machinery*	*Fixed pitch propeller*
1 propeller	2.03	2.26
2 propellers	1.44	1.6
3 propellers	1.18	1.31
[1)] For advanced systems, see [7.1.5].		

Table 4 Minimum engine output P_{min}

Ice class	*P_{min} [kw]*
Ice(1A), **Ice(1B)**, and **Ice(1C)**	1000
Ice(1A*F) and **Ice(1A*)**	2800

R_{CH} is the resistance, in N, of the ship in a channel with brash ice and a consolidated layer:

$$R_{CH} = C_1 + C_2 + C_3 C_\mu \left(H_F + H_M\right)^2 \left(B + C_\psi H_F\right) + C_4 L_{PAR} H_F^2 + C_5 \left(\frac{LT}{B^2}\right)^3 \frac{A_{wf}}{L}$$

where:

C_μ = $0.15 \cos \varphi_2 + \sin \psi \sin \alpha$
$C_\mu \geq 0.45$ (minimum value)
C_ψ = $0.047\ \psi - 2.115$ and 0 if $\psi \leq 45°$
H_F = $0.26 + (H_M B)^{0.5}$
H_M = 1.0 for **Ice(1A)**, **Ice(1A*)**, and **Ice(1A*F)**
= 0.8 for **Ice(1B)**

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= 0.6 for **Ice(1C)**.

C_1 and C_2 take into account a consolidated upper layer of the brash ice and can be taken as zero for ice class **Ice(1A)**, **Ice(1B)**, and **Ice(1C)**.

For ice classes **Ice(1A*F)** and **Ice(1A*)**:

$$C_1 = f_1 \frac{BL_{PAR}}{2\frac{T}{B}+1} + \left(1 + 0.021\varphi_1\right)\left(f_2 B + f_3 L_{BOW} + f_4 BL_{BOW}\right)$$

$$C_2 = \left(1 + 0.063\varphi_1\right)\left(g_1 + g_2 B\right) + g_3\left(1 + 1.2\frac{T}{B}\right)\frac{B^2}{\sqrt{L}}$$

For a ship with a bulbous bow, φ_1 shall be taken as 90°.

f_1 = 23 N/m^2
f_2 = 45.8 N/m
f_3 = 14.7 N/m
f_4 = 29 N/m^2
g_1 = 1 530 N
g_2 = 170 N/m
g_3 = 400 N/m$^{1.5}$
C_3 = 845 kg/m^{2}s^2
C_4 = 42 kg/m^{2}s^2
C_5 = 825 kg/s^2

$$\psi = \arctan\left(\frac{\tan\varphi_2}{\sin\alpha}\right)$$

$\left(\frac{LT}{B^2}\right)^3$ shall not be taken less than 5 and not more than 20.

7.1.5 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 Table 3 and [7.1.4], the use of K_e or R_{CH} values based on more exact calculations or values based on model tests may be approved. Such approval will be given on the understanding that it can be revoked if experience of the ship's performance in practice motivates this.

Guidance note:

For ships intended for trading in Finnish waters and having the propulsion power determined by model tests or by means other than the rule formula, additional approval by Finnish or Swedish authorities is necessary.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

The design requirement for ice classes shall be a minimum speed of 5 knots in the following brash ice channels, see Table 5.

Table 5 Values of H_M

Ice class	H_M
Ice(1A*F) and **Ice(1A*)**	1.0 m and a 0.1 m thick consolidated layer of ice
Ice(1A)	1.0 m

Ice(1B)	0.8 m
Ice(1C)	0.6 m

7.2 Height of the ice load area

An ice strengthened ship is assumed to operate in open sea conditions corresponding to a level ice thickness not exceeding h_o. The design ice 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 6.

Table 6 Values of h_o and h

Ice class	*h_o [m]*	*h [m]*
Ice(1A*F) and **Ice(1A*)**	1.0	0.35
Ice(1A)	0.8	0.30
Ice(1B)	0.6	0.25
Ice(1C)	0.4	0.22

7.3 Ice pressure

The design ice pressure (based on a nominal ice pressure of 5600 kN/m^2), in kN/m^2, is determined by the formula:

$$P = 5600 \cdot c_d \cdot c_1 \cdot c_a$$

where:

c_d = factor which takes account of the influence of the size and engine output of the ship. This factor is taken as maximum c_d = 1. It is calculated by the formula:

$$c_d = \frac{a_1 \cdot k_1 + b_1}{1000}$$

$$k_1 = \frac{\sqrt{\Delta_f P_S}}{1000}$$

a_1 and b_1 are given in Table 7.

Table 7 Values of a_1 and b_1

	Region			
	Bow		*Midbody and stern*	
	$k_1 \leq 12$	*$k_1 > 12$*	*$k_1 \leq 12$*	*$k_1 > 12$*
a_1	30	6	8	2
b_1	230	518	214	286

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Δ_f = displacement, in tonnes, as defined in [1.5.3]

P_S = machinery output, available when sailing in ice, in kW. 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 scantling calculations. The engine output used for the calculation of the hull scantlings shall be clearly stated on the shell expansion drawing. $P_S \geq P_{min}$, where P_{min} is defined in [7.1.4]

c_1 = factor that reflects the magnitude of the load expected in the hull area in question relative to the bow area.

The value of c_1 is given in Table 8.

Table 8 Values of c_1

Ice class	*Region*		
	Bow	*Midbody*	*Stern*
Ice(1A*F) and **Ice(1A*)**	1.0	1.0	0.75
Ice(1A)	1.0	0.85	0.65
Ice(1B)	1.0	0.70	0.45
Ice(1C)	1.0	0.50	0.25

For ice class **Ice(1A*F)** an additional lower bow ice belt, see [8.1.2], is defined with factor c_1 = 0.20.

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 by the formula:

$$c_a = \sqrt{\frac{\ell_0}{\ell_a}}$$

, maximum 1.0, minimum 0.35, ℓ_0 = 0.6 m

ℓ_a shall be taken as given in Table 9.

Table 9 Values of ℓ_a

Structure	*Type of framing*	ℓ_a
Shell	transverse	frame spacing
	longitudinal	1.7 × frame spacing
Frames	transverse	frame spacing
	longitudinal	span of frame
Ice stringer		span of stringer
Web frame		2 × web frame spacing

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8 Shell plating

8.1 Vertical extension of ice strengthening for plating

8.1.1 The vertical extension of the ice belt, see Figure 1, shall not be less than given in Table 10.

Table 10 Vertical extension of ice belt

Ice class	*Region*	*Above UIWL [m]*	*Below LIWL [m]*
Ice(1A*F) and **Ice(1A*)**	Bow	0.60	1.20
	Midbody		
	Stern		1.0
Ice(1A)	Bow	0.50	0.90
	Midbody		0.75
	Stern		
Ice(1B) and **Ice(1C)**	Bow	0.40	0.70
	Midbody		0.60
	Stern		

8.1.2 In addition the following areas shall be strengthened:

Fore foot: for ice class **Ice(1A*)** and **Ice(1A*F)**, the shell plating below the ice belt from the stem to a position five main frame spacings 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.

Upper bow ice belt: for ice classes **Ice(1A*)** and **Ice(1A)** 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 the forward perpendicular, 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.

For ice class **Ice(1A*F),** the upper bow ice belt shall be taken 3 m above the normal ice belt, extending within the bow region.

Lower bow ice belt: for ice class **Ice(1A*F),** a lower bow ice belt below the normal ice belt is defined covering the bow region aft of the forefoot and down to the lower turn of bilge.

8.1.3 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 deck, the bulwark shall be given 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.

8.2 Plate thickness in the ice belt

8.2.1 For transverse framing, the thickness of the shell plating, in mm, shall be determined by the formula:

$$t = 21.1 \cdot s_1 \sqrt{\frac{f_1 \cdot P_{PL}}{R_{eH}}} + t_c$$

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For longitudinal framing the thickness of the shell plating, in mm, shall be determined by the formula:

$$t = 21.1 \cdot s_1 \sqrt{\frac{P}{f_2 \cdot R_{eH}}} + t_c$$

where:

P_{PL} = 0.75 P
P = as given in [7.3]
s_1 = stiffener spacing measured along the plating between ordinary and/or intermediate stiffeners, in m
f_1 = $1.3 - \frac{4.2}{\left(\frac{h}{s_1} + 1.8\right)^2}$, maximum 1.0
f_2 = $0.6 + \frac{0.4}{\frac{h}{s_1}}$, when $\frac{h}{s_1} \leq 1$
= $1.4 - 0.4\ (h/s_1)$, when $1 \leq h/s_1 \leq 1.8$
h = As given in [7.2]
t_c = Increment for abrasion and corrosion in mm, normally 2 mm. If abrasion resistant coating which is type approved according to DNV-CP-0293 is used, t_c may be reduced by 1 mm.

Guidance note:

Abrasion resistant coating which is not type approved according to DNV-CP-0293 may be accepted based on adequate documentation of satisfactory service experience and laboratory tests.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

8.2.2 For ice class **Ice(1A*F)** the following additional requirements are given:

— bottom plating in the bow region, below the lower bow ice belt defined in [8.1.2], shall have a gross thickness [mm], not less than:

$$t_{gr} = \max\left\{0.7 \cdot \left(s_1 + 0.8\right) \cdot \sqrt{\frac{235 \cdot L}{R_{eH}}}; 12\right\}$$

— side and bottom plating in the stern region below the ice belt shall have a gross thickness [mm], not less than:

$$t_{gr} = \max\left\{0.6 \cdot \left(s_1 + 0.8\right) \cdot \sqrt{\frac{235 \cdot L}{R_{eH}}}; 10\right\}$$

9 Frames

9.1 Vertical extension of ice framing

9.1.1 The vertical extension of the ice strengthening of the framing shall be at least as given in Table 11:

Table 11 Vertical extension of ice strengthening of the framing

Ice class	*Region*	*Above UIWL [m]*	*Below LIWL [m]*
Ice(1A*F), **Ice(1A*)**	Bow	1.2	to double bottom or below top of floors
	Midbody		2.0
	Stern		1.6

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Ice class	*Region*	*Above UIWL [m]*	*Below LIWL [m]*
Ice(1A), (1B), (1C)	Bow	1.0	1.6
	Midship		1.3
	Stern		1.0

Where an upper bow ice belt is required, see [8.1.2], the ice strengthened part of the framing shall be extended at least to the top of this ice belt.

9.1.2 Where the ice strengthening would go beyond a deck or a tank top (or tank bottom) by not more than 250 mm, it can be terminated at that deck or tank top (or tank bottom).

9.2 Transverse frames

9.2.1 The gross section modulus of a main or intermediate transverse frame, in cm^3, shall be calculated by the formula:

$$Z_{gr} = \frac{P \cdot s_1 \cdot h \cdot \ell_{bdg}}{m_t \cdot R_{eH}} \cdot 10^3$$

and the effective gross shear area, in cm^2, is calculated from:

$$A_{gr} = \frac{8.7 \cdot f_3 \cdot P \cdot h \cdot s_1}{R_{eH}}$$

where:

P = ice pressure as given in [7.3]

s_1 = stiffener spacing measured along the plating between ordinary and/or intermediate stiffeners [m]

h = height of load area as given in [7.2]

m_t = $\dfrac{7m_o}{7 - \dfrac{5h}{\ell_{bdg}}}$

f_3 = is a factor which takes into account the maximum shear force versus the load location and the shear stress distribution, $f_3 = 1.2$

m_o = values as given in Table 12

ℓ_{bdg} = effective frame bending span, see [4.1.6].

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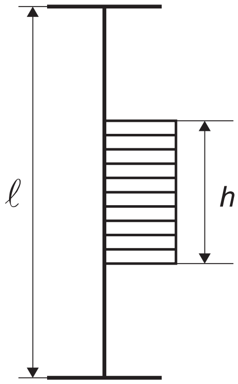
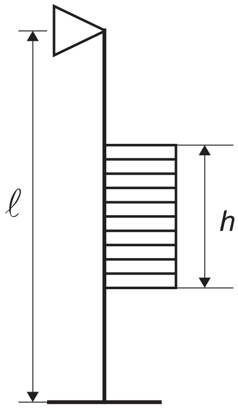
Table 12 Values of m_o

Boundary condition	m_o	*Example*
	7	Frames in a bulk carrier with top wing tanks
	6	Frames extending from the tank top to a single deck

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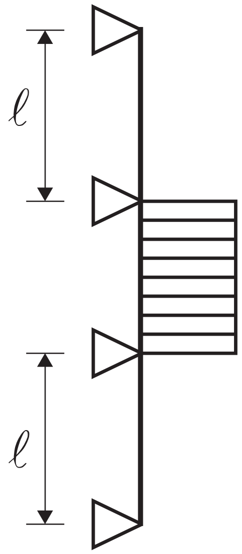
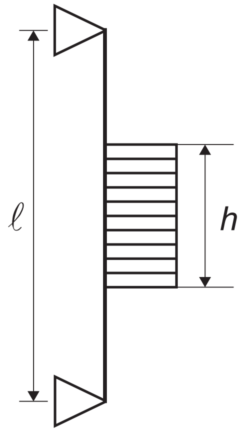
Boundary condition	m_o	*Example*
	5.7	Continuous frames between several decks or stringers
	5	Frames extending between two decks only

The boundary conditions are those for the main and intermediate frames. Possible different conditions for main and intermediate frames are assumed to be taken care of by interaction between the frames and may be calculated as mean values. Load is applied at mid span.

If the ice belt covers less than half the span of a transverse frame, ($b_2 < 0.5\ \ell$) the following modified formula may be used for the gross section modulus in cm^3:

$$Z_{gr} = \frac{P \cdot s_1 \cdot h \cdot b_2 \cdot \left(\ell_{bdg} - b_2\right)^2}{\ell_{bdg}{}^2 \cdot R_{eH}} \cdot 10^3$$

where:

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b_2 = distance [m] between upper or lower boundary of the vertical extension of ice strengthening for framing as given in Table 11 and the nearest deck or stringer within the extension

s_1 = stiffener spacing measured along the plating between ordinary and/or intermediate stiffeners [m].

Where less than 15% of the span, ℓ_{bdg}, of the frame is situated within the ice-strengthening zone for frames as defined in [9.1.1], ordinary frame scantlings may be used.

9.2.2 Upper end of transverse framing

1) The upper end of the strengthened part of a main frame and of an intermediate ice frame shall be attached to a deck or an ice stringer, see [10].
2) Where an intermediate frame terminates above a deck or an ice stringer which is situated at or above the upper limit of the ice belt, see [8.1], the part above the deck or stringer may have the scantlings required for a non-ice-strengthened ship and the upper end be connected to the adjacent main frames by a horizontal member of the same scantlings as the main frame.

9.2.3 Lower end of transverse framing

1) The lower end of the strengthened part of a main frame and of an intermediate ice frame shall be attached to a deck, tank top (or tank bottom) or ice stringer, see [10].
2) Where an intermediate frame terminates below a deck, tank top (or tank bottom) or ice stringer which is situated at or below the lower limit of the ice belt, see [7.2], the lower end shall 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 shall be ice strengthened, see [8.1.1].

9.3 Longitudinal frames

The gross section modulus of longitudinal frame with and without brackets, in cm^3, shall be calculated by the formula:

$$Z_{gr} = \frac{f_4 \cdot P \cdot h \cdot \ell_{bdg}^{\,2}}{m_1 \cdot R_{eH}} \cdot 10^3$$

The shear effective gross area of a longitudinal frame, in cm^2, shall be:

$$A_{gr} = \frac{8.7 \cdot f_4 \cdot f_5 \cdot P \cdot h \cdot \ell_{shr}}{R_{eH}}$$

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

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

f_4 = $(1 - 0.2\, h/s_1)$

s_1 = stiffener spacing measured along the plating between ordinary and/or intermediate stiffeners [m]

f_5 = factor which takes into account the maximum shear force versus load location and the shear stress distribution:

f_5 = 2.16

P = ice pressure as given in [7.3]

h = height of load area as given in [7.2]

m_1 = is a boundary condition factor, m_1= 13.3 for a continuous beam, where the boundary conditions deviate significantly from those of a continuous beam, e.g. in an end field, a smaller boundary factor may be required. For frames without brackets a value m_1= 11.0 shall be used

ℓ_{bdg} = effective frame bending span, see [4.1.6]

ℓ_{shr} = effective frame shear span, see [4.1.6].

9.4 Structural details

9.4.1 Within the ice strengthened area all frames shall be effectively attached to all supporting structures. Longitudinal or transverse frames crossing supporting structures, such as web frames or stringers, shall be connected to these structures on both sides (by collar plates or lugs in way of cut-outs).

Brackets or top stiffeners shall be fitted, in order to provide proper transfer of forces to supporting elements, as necessary. Connection of non-continuous frames to supporting structures shall be made by brackets or similar construction. When a bracket is installed, it shall have at least the same thickness as the web plate of the frame, and the edge shall be appropriately stiffened against buckling.

9.4.2 Further requirements are as follows:

1) 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. Direct calculation methods may be applied to demonstrate the equivalent level of support provided by alternative arrangements.
2) For frames with spans greater than 4 m, the extent of antitripping supports shall be applied to all regions and for all ice classes. For frames with spans less than or equal to 4 m, the extent of anti-tripping supports shall be applied to all regions for **Ice(1A*F)** and **Ice(1A*)**, to the bow and midbody regions for **Ice(1A)**, and to the bow region for **Ice(1B)** and **Ice(1C)**. Direct calculation methods may be applied to demonstrate the equivalent level of support provided by alternative arrangements.
3) Frames shall be attached to the shell by double continuous welds. No scalloping is allowed (except when crossing shell plate butts).
4) The minimum thickness of the frames, $t_{w,min}$, in mm, shall be at least the maximum of a), b), or c):
   a) 9 mm
   b) $\frac{1}{2}\left(t - t_c\right)$

   where:

   t = shell plate thickness requirement [mm], according to [8.2.1], considering yield stress, R_{eH}, for the attached frame

   t_c = increment for abrasion and corrosion [mm], as defined in [8.2.1]

   c) $\frac{h_w\sqrt{R_{eH}}}{C}$

   where:

   h_w = web height [mm]

   C = 805 for profiles

   C = 282 for flat bars.

   Where there is a deck, tank top (or tank bottom) or bulkhead, stringer or transverse web frame, in lieu of a frame, the plate thickness of this shall be as above, to a depth corresponding to the height of adjacent frames.

10 Ice stringers

10.1 Stringers within the ice belt

The gross section modulus of a stringer situated within the ice belt, see [8.1], in cm^3, shall be calculated by the formula:

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$$Z_{gr} = \frac{f_6 \cdot f_7 \cdot P \cdot h \cdot \ \ell^2}{m_1 \cdot R_{eh}} \cdot 10^3$$

The gross shear area, in cm^2, shall not be less than:

$$A_{gr} = \frac{8.7 \cdot f_6 \cdot f_7 \cdot f_8 \cdot P \cdot h \cdot \ \ell}{R_{eH}}$$

where:

P = ice pressure as given in [7.3]
h = height of load area as given in [7.2].
The product Ph shall not be taken as less than 150
ℓ = span of stringer [m]
m_1 = boundary condition factor as given in [9.3]
f_6 = which takes account of the distribution of load to the transverse frames, to be taken as 0.9
f_7 = factor of stringers, f_7 = 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.

10.2 Stringers outside the ice belt

The gross section modulus of a stringer situated outside the ice belt but supporting ice strengthened frames, in cm^3, shall be calculated by the formula:

$$Z_{gr} = \frac{f_9 \cdot f_{10} \cdot P \cdot h \cdot \ \ell^2}{m_1 \cdot R_{eH}} \left(1 - \frac{h_s}{\ell_s}\right) \cdot 10^3$$

The gross shear area, in cm^2, shall not be less than:

$$A_{gr} = \frac{8.7 \cdot f_9 \cdot f_{10} \cdot f_{11} \cdot P \cdot h \cdot \ \ell}{R_{eH}} \left(1 - \frac{h_s}{\ell_s}\right)$$

where:

P = ice pressure as given in [7.3]
h = height of load area as given in [7.2].

The product Ph shall not be taken as less than 150.

ℓ = span of stringer [m]
m_1 = boundary condition factor as given in [9.3]
ℓ_s = the distance to the adjacent ice stringer [m]
h_s = the distance to the ice belt [m]
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, f_{10} = 1.8
f_{11} = factor that takes into account the maximum shear force versus load location and the shear stress distribution, f_{11} = 1.2.

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10.3 Deck strips

10.3.1 Narrow deck strips abreast of hatches and serving as ice stringers shall comply with the section modulus and shear area requirements in [10.1] and [10.2] respectively. In the case of very long hatches the lower limit of the product *Ph* may be reduced to 100.

10.3.2 Regard shall be paid to the deflection of the ship's sides due to ice pressure in way of very long hatch openings (more than *B*/2), when designing weather deck hatch covers and their fittings.

11 Web frames

11.1 Design ice load

The design ice load transferred to a web frame from an ice stringer or from longitudinal framing, in kN, shall be calculated by the formula:

$$F = f_{12} \cdot P \cdot h \cdot S$$

where:

P = ice pressure as given in [7.3], when calculating factor c_a, however, ℓ_a shall be taken as 2 S

h = height [m] of load area as given in [7.2].

The product *Ph* shall not be taken less than 150.

S = web frame spacing [m]

f_{12} = factor of web frames, f_{12} = 1.8.

In case the supported stringer is outside the ice belt, the load *F* may be multiplied by:

$$\left(1 - \frac{h_s}{\ell_s}\right)$$

as given in [10.2].

11.2 Section modulus and shear area

11.2.1 The gross section modulus requirement, in cm^3, is given by:

$$Z_{gr} = \frac{M}{R_{eH}} \sqrt{\frac{1}{1 - \left(\gamma \frac{A}{A_a}\right)^2}} \cdot 10^3$$

where:

M = maximum calculated bending moment [kNm], under the ice load *F*, as given in [11.1]. This shall be taken as $M = 0.193 \cdot F \cdot \ell$

γ = as given in Table 13

A = required gross shear area from [11.2.2] [cm^2]

A_a = actual gross cross-sectional area of web frame, $A_a = A_f + A_w$ [cm^2].

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11.2.2 With boundary conditions as given in [11.2.1], the gross shear area of a web frame [cm^2], is given by:

$$A_{gr} = \frac{17.3 \cdot \alpha \cdot f_{13} \cdot Q}{R_{eH}}$$

where:

Q = maximum calculated shear force under the load *F* [kN], as given in [11.1]
f_{13} = factor that takes into account the shear force distribution, f_{13} = 1.1
α = factor given in Table 13
A_f = gross cross-sectional area of free flange, [cm^2]
A_w = actual effective gross cross-sectional area of web plate [cm^2].

Table 13 Values of α and γ

$\frac{A_f}{A_w}$	*0.0*	*0.2*	*0.4*	*0.6*	*0.8*	*1.0*	*1.2*	*1.4*	*1.6*	*1.8*	*2.0*
α	1.5	1.23	1.16	1.11	1.09	1.07	1.06	1.05	1.05	1.04	1.04
γ	0	0.44	0.62	0.71	0.76	0.80	0.83	0.85	0.87	0.88	0.89

12 Bilge keels

12.1 Arrangement

12.1.1 The connection of bilge keels to the hull shall be so designed that the risk of damage to the hull, in case a bilge keel is ripped off, is minimized.

12.1.2 For class **Ice(1A*F)** bilge keels are normally to be avoided and should be replaced by roll-damping equipment. Specially strengthened bilge keels may be considered.

13 Special arrangement and strengthening forward

13.1 Stem, Baltic ice strengthening

13.1.1 The stem may be made of rolled, cast or forged steel or of shaped steel plates as shown in Figure 4.

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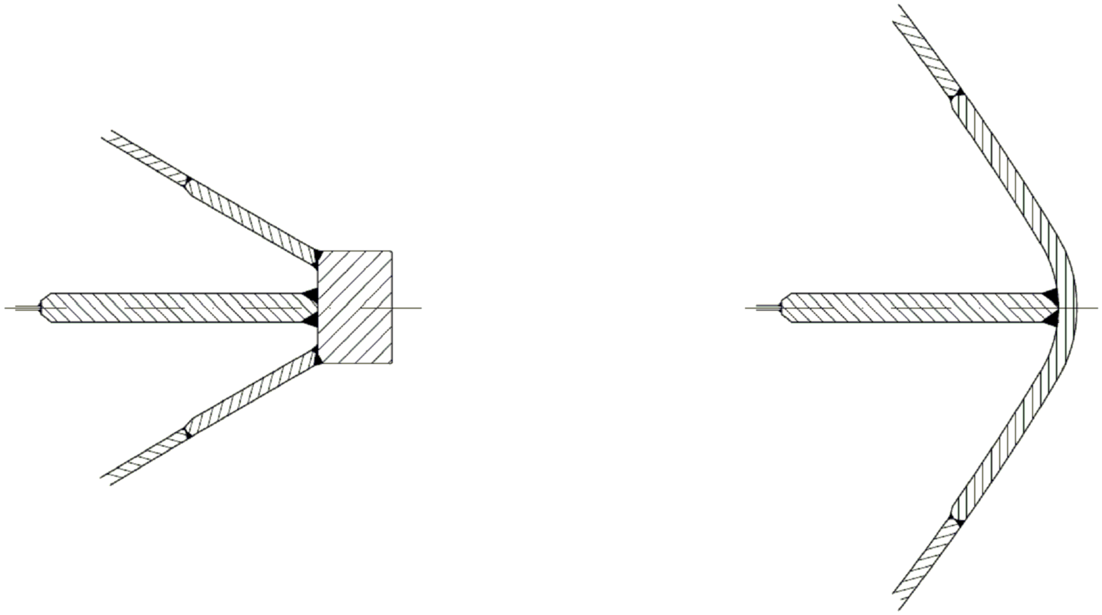

Figure 4 Examples of suitable stems

13.1.2 The plate thickness of a shaped plate stem and in the case of a blunt bow, any part of the shell where $\alpha \geq 30°$ and $\psi \geq 75°$, see [7.1.3] for angle definitions, shall be calculated according to the formulae in [8.2] assuming that:

s = spacing of elements supporting the plate [m]
P_{PL} = P, see [7.3]
ℓ_a = spacing of vertical supporting elements [m], see Table 9.

For class **Ice(1A*F)** the front plate and upper part of the bulb and the stem plate up to a point 3.6 m above UIWL (lower part of bow door included) shall have a minimum gross thickness [mm], of:

$$t_{gr} = c\sqrt{\frac{235L}{R_{eH}}}$$

where:

c = 2.3 for the stem plate
= 1.8 for the bulb plating.

The width of the increased bulb plate shall not be less than 0.2 *b* on each side of the centre line, *b* = breadth of the bulb at the forward perpendicular.

13.1.3 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 be extend from the keel to a point 0.75 m above UIWL or, in case an upper bow ice belt is required, see [8.1.2] to the upper limit of this.

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13.2 Arrangements for towing

13.2.1 The ship shall be arranged for towing.

13.2.2 A bitt or other means for securing a towline, dimensioned to stand the breaking force of the towline of the ship shall be fitted.

14 Special arrangement and strengthening aft

14.1 Stern

14.1.1 The introduction of new propulsion arrangements with azimuth thrusters or podded propellers, which provide an improved manoeuvrability, will result in increased ice loading of the stern region and stern area. This fact should be considered in the design of the aft/stern structure.

14.1.2 In order to avoid very high loads on propeller blade tips, the minimum distance between propeller(s) and hull (including stern frame) shall not be less than h_0, see [7.2].

This requirement is not applicable for propellers with nozzle.

14.1.3 On twin and triple screw ships the ice strengthening of the shell and framing shall be extended to the double bottom for 1.5 metre forward and aft of the side propellers.

14.1.4 Shafting and stern tubes of side propellers are normally to be enclosed within plated bossings. If detached struts are used, their design, strength and attachment to the hull shall be duly considered.

For class **Ice(1A*F)** the gross skin plating of propeller shaft bossings, in mm, shall not be less than:

$$t_{gr} = 0.9\left(s_1 + 0.8\right)\sqrt{\frac{235L}{R_{eH}}}$$

14.1.5 The part of a transom stern situated within the ice belt shall be strengthened as for the midship region.

14.2 Rudder and steering arrangements

14.2.1 The scantlings of rudder, rudder post, rudder stock, pintles, steering gear etc. as well as the capacity of the steering gear shall be determined according to the rules. The maximum service speed of the ship to be used in these calculations shall not be taken less than that stated in Table 14:

Table 14 Maximum service speed

Ice class	*Maximum service speed*
Ice(1A*F) and **Ice(1A*)**	20 knots
Ice(1A)	18 knots
Ice(1B)	16 knots
Ice(1C)	14 knots

If the actual maximum service speed of the ship is higher, that speed shall be used.

When calculating the rudder force according to the formula given in Pt.3 Ch.14 Sec.1 [2] and with the speed V in ahead condition as given above, the factors K_2 = K_3 = 1.0 irrespective of condition, rudder profile type or arrangement, shall be used. In the astern condition half the speed values shall be used.

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14.2.2 For the ice classes **Ice(1A*F)**, **Ice(1A*)** and **Ice(1A)**, the upper part of the rudder and the rudder stock shall be protected from direct contact with intact ice by an ice horn that extends below the LIWL. Special consideration shall be given to the design of the rudder and the ice horn for ships with flap-type rudders.

14.2.3 For ice classes **Ice(1A*F)**, **Ice(1A*)** and **Ice(1A)**, 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.

14.2.4 Relief valves for hydraulic pressure in rudder turning mechanism(s) shall be installed. The components of the rudder actuator, rudder stock and rudder coupling shall be dimensioned to withstand loading corresponding to the required diameter of the rudder stock.

14.2.5 The local scantlings of rudders shall be determined assuming that the whole rudder belongs to the ice belt. Further, the rudder plating and frames shall be designed using the ice pressure *P* for the plating and frames in the midbody region.

15 Propulsion machinery

15.1 Scope

These rules apply to propulsion machinery covering open and ducted type propellers with a controllable pitch or fixed pitch design for ice classes **Ice(1A*F)**, **Ice(1A*)**, **Ice(1A)**, **Ice(1B)** and **Ice(1C)**. The given propeller loads are the expected ice loads for the entire ship's 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. Further, the load models of the rules do not include propeller/ice interaction loads when ice enters the propeller of a turned azimuthing thruster from the side (radially).

The rules 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 ship's 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.

15.2 Definitions

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
C_{fex}	-	non-dimensional parameter accounting for the reduction of the blade failure force at the location of the maximum spindle torque
$C_{LE0.8}$	m	leading edge portion of the chord length at 0.8 *R*
C_{sp}	-	non-dimensional parameter accounting for the spindle arm
$C_{TE0.8}$	m	trailing edge portion of the chord length at 0.8 *R*
CP	-	controllable pitch
D	m	propeller diameter

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Symbol	*Unit*	*Definition*
d	m	external diameter of propeller hub
D_{limit}	m	limit value for propeller diameter
EAR	-	expanded blade area ratio
F_b	kN	maximum backward blade force for the ship’s service life
F_{ex}	kN	ultimate blade load resulting from blade loss through plastic bending
F_f	kN	maximum forward blade force for the ship’s service life
F_{ice}	kN	ice load
$(F_{ice})_{max}$	kN	maximum ice load for the ship’s service life
FP	-	fixed pitch
h_0	m	depth of the propeller centreline from the winter 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 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
K_{AP}	-	peak application factor for torsional loads
$LIWL$	m	lower ballast waterline in ice
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 propeller rotational speed per ice class
N_{ice}	-	total number of ice loads on propeller blade for the ship’s 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

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Symbol	*Unit*	*Definition*
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 ship's service life
Q_{sex}	kNm	maximum spindle torque due to blade failure caused by plastic bending
Q_{vib}	kNm	vibratory torque at considered component, taken from frequency domain open water torsional 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 ship's service life
T_f	kN	maximum forward propeller ice thrust for the ship's 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	deg	duration of propeller blade/ice interaction expressed in rotation angle
α_1	deg	phase angle of propeller ice torque for first blade order excitation component
α_2	deg	phase angle of propeller ice torque for second blade order excitation component
$\gamma_{\varepsilon 1}$	-	reduction factor for fatigue, scatter effect
$\gamma_{\varepsilon 2}$	-	reduction factor for fatigue, test specimen size effect
γ_v	-	reduction factor for fatigue, variable amplitude loading effect
γ_m	-	reduction factor for fatigue, mean stress effect
ρ	-	reduction factor for fatigue correlating the maximum stress amplitude to the equivalent fatigue stress for 10^8 stress cycles
$\sigma_{0.2}$	MPa	proof yield strength of blade material
σ_{exp}	MPa	mean fatigue strength of blade material at 10^8 cycles to failure in sea water
σ_{fat}	MPa	equivalent fatigue ice load stress amplitude for 10^8 stress cycles
σ_{fl}	MPa	characteristic fatigue strength for blade material
σ_{ref1}	MPa	reference stress (ultimate strength) $\sigma_{ref} = 0.6\ \sigma_{0.2} + 0.4\ \sigma_u$
σ_{ref2}	MPa	reference stress (blade scantlings) $\sigma_{ref2} = 0.7\ \sigma_u$, or $\sigma_{ref2} = 0.6\ \sigma_{0.2} + 0.4\ \sigma_u$ whichever is less

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Symbol	*Unit*	*Definition*
σ_{st}	MPa	maximum stress resulting from F_b or F_f
σ_u	MPa	ultimate tensile strength of blade material
$(\sigma_{ice})_{bmax}$	MPa	principal stress caused by the maximum backward propeller ice load
$(\sigma_{ice})_{fmax}$	MPa	principal stress caused by the maximum forward propeller ice load
$(\sigma_{ice})_{max}$	MPa	maximum ice load stress amplitude

Table 15 Definition of ice loads

Load	*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 0.7 *R* chord line. See Figure 5.	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 hydrodynamic loads on that blade. The direction of the force is perpendicular to 0.7 *R* 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 hydrodynamic 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.
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 T_r. T_b 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 T_r. T_f 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 (Q_r) 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 shall be taken as 2/3 of the distance between the axis of blade rotation and leading or 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 shall 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.

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Load	Definition	Use of the load in design process
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.

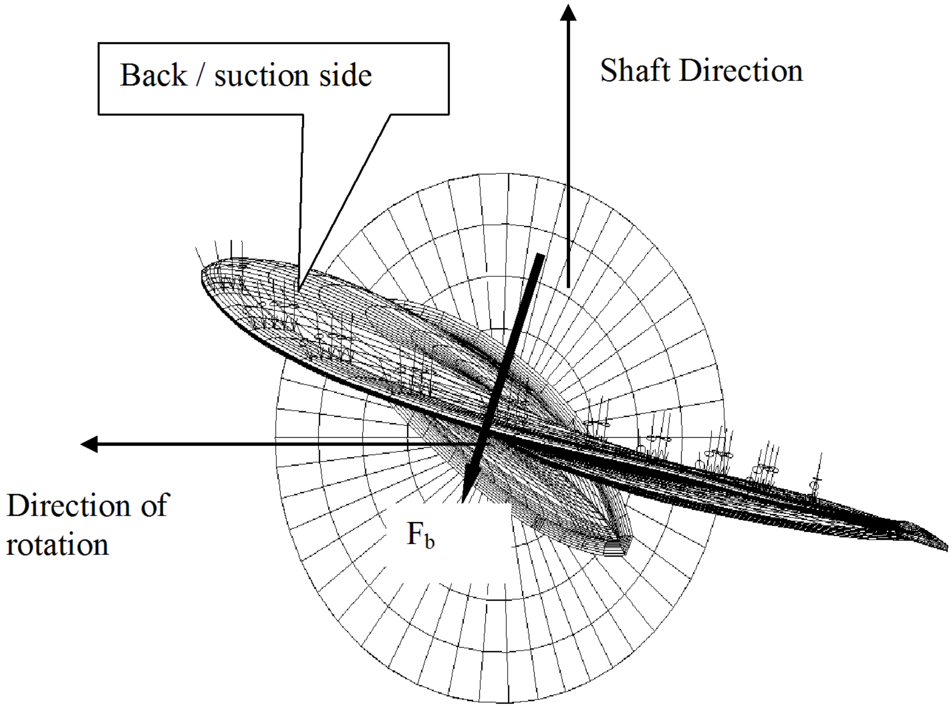

Figure 5 Direction of the resultant backward blade force taken perpendicular to the chord line at 0.7 *R*. The ice contact pressure at the leading edge is indicated with small arrows.

15.3 Design ice conditions

In estimating the ice loads of the propeller for various ice classes, different types of operation as given in Table 16 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} × $2H_{ice}$ × $3H_{ice}$. The thickness of the ice block (H_{ice}) is given in Table 17.

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Table 16 Operation of the ship - design basis

Ice(1A*F) and **Ice(1A*)**	Operation in ice channels and in level ice. The ship may proceed by ramming.
Ice(1A), Ice(1B), Ice(1C)	Operation in ice channels.

Table 17 Thickness of the design maximum ice block H_{ice} entering the propeller.

Ice class	**Ice(1A*F)** and **Ice(1A*)**	**Ice(1A)**	**Ice(1B)**	**Ice(1C)**
H_{ice}	1.75 m	1.5 m	1.2 m	1.0 m

15.4 Materials

15.4.1 Materials exposed to seawater

Materials of components exposed to seawater, 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 austenitic stainless steel. An average impact energy value of 20 J taken from three tests shall be obtained at minus 10ºC. For nodular cast iron, average impact energy of 10 J at minus 10ºC is required accordingly.

15.4.2 Materials exposed to seawater temperature

Materials exposed to seawater temperature shall be made of steel or another ductile material. An average impact energy value of 20 J taken from three tests shall be obtained at minus 10ºC. This requirement applies to the propeller shaft, blade bolts, CP mechanisms, shaft bolts, strut-pod connecting bolts, etc. This does not apply to surface hardened components, such as bearings and gear teeth. 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 10ºC.

15.5 Design loads

15.5.1 Design loads on propeller blades

15.5.1.1 General

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, not acting simultaneously. Hence they shall be applied to one blade separately.

15.5.1.2 Maximum backward blade force F_b for open propellers

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

when $D \leq D_{limit}$

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

when $D > D_{limit}$

where:

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

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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.

15.5.1.3 Maximum forward blade force F_f for open propellers

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

$$\text{when } D \le D_{limit}$$

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

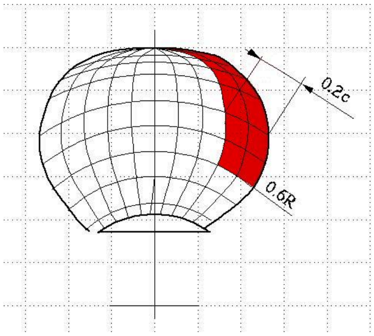
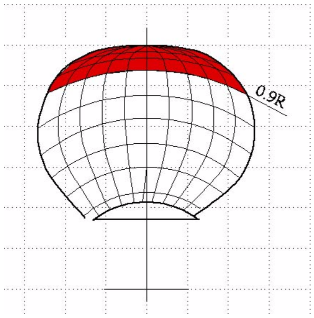
$$\text{when } D > D_{limit}$$

where:

$$D_{limit} = \frac{2}{1 - \frac{d}{D}} \cdot H_{ice} \text{ [m]}$$

15.5.1.4 Loaded area on the blade for open propellers.

Table 18 Load cases for open propellers

Load case	*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.	

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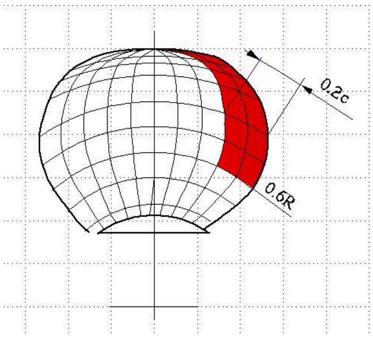
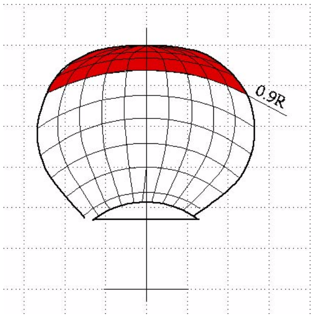
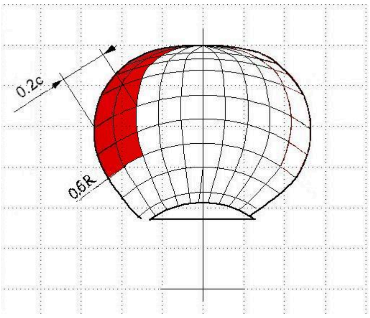
Load case	*Force*	*Loaded area*	*Right-handed propeller blade seen from behind*
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6 *R* to the tip and from the leading edge to 0.2 times the chord length.	
Load case 4	50% of F_f	Uniform pressure applied on propeller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

15.5.1.5 Maximum backward blade ice force F_b for ducted propellers

$$F_b = 9.5 \cdot (n \cdot D)^{0.7} \cdot \left(\frac{EAR}{Z}\right)^{0.3} \cdot D^2 \text{ [kN]}$$

when $D \leq D_{limit}$

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

when $D > D_{limit}$

where:

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$$D_{limit} = 4 \cdot H_{ice}\ [\mathrm{m}]$$

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.

15.5.1.6 Maximum forward blade ice force F_f for ducted propellers

$$F_f = 250 \cdot \frac{EAR}{Z} \cdot D^2\ [\mathrm{kN}]$$

$$\text{when } D \leq D_{limit}$$

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

$$\text{when } D > D_{limit}$$

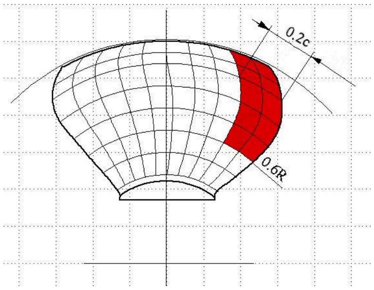
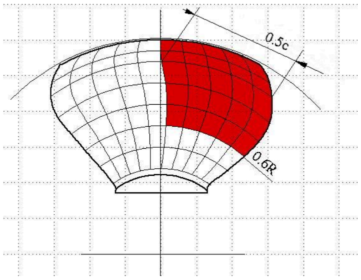
where:

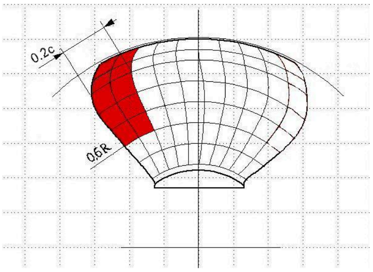
$$D_{limit} = \frac{2}{1-\frac{d}{D}} \cdot H_{ice}\ [\mathrm{m}]$$

15.5.1.7 Loaded area on the blade for ducted propellers

Load cases 1 and 3 shall be covered as given in Table 19 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 19 Load cases for ducted propellers

Load case	*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 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 0.5 times the chord length.	

Load case	*Force*	*Loaded area*	*Right handed propeller blade seen from behind*
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 0.6 *R* to the tip and from the trailing edge to 0.2 times the chord length.	

15.5.1.8 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 18 and Table 19. The larger of the obtained torques shall be used as the dimensioning spindle torque. If the above method gives a value which is less than the minimum value given by the formula below, the minimum value shall be used.

$$\text{Minimum value: } Q_{\text{smax}} = 0.25 \cdot F \cdot c_{0.7} \text{ [kNm]}$$

where $c_{0.7}$ is the length of the blade section at 0.7 R radius and F is either F_b or F_f, whichever has the greater absolute value.

15.5.1.9 Load distributions for blade loads

The Weibull-type distribution (probability of F_{ice} exceeding $(F_{ice})_{max}$), as given in Figure 6, is used for the fatigue design of the blade.

$$P\left(\frac{F_{ice}}{\left(F_{ice}\right)_{\max}} \geq \frac{F}{\left(F_{ice}\right)_{\max}}\right) = e^{\left(-\left(\frac{F}{\left(F_{ice}\right)_{\max}}\right)^{k} \cdot \ln\left(N_{ice}\right)\right)}$$

Here, 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.

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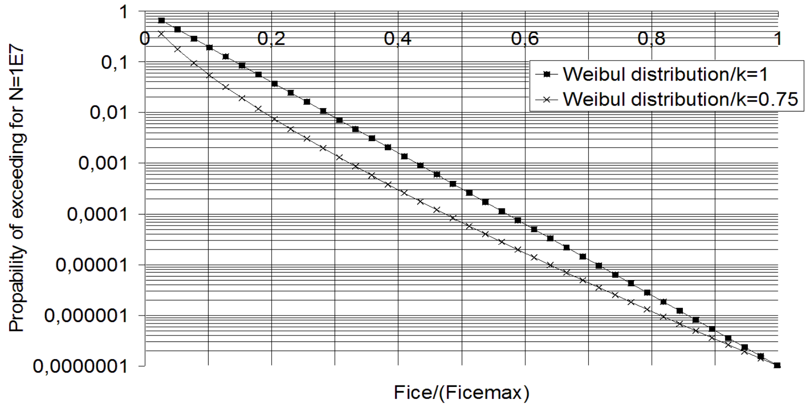

Figure 6 The Weibull-type distribution (probability of F_{ice} exceeding $(F_{ice})_{max}$) used for fatigue design

15.5.1.10 Number of ice loads

The number of load cycles per propeller blade in the load spectrum shall be determined according to the formula:

$$N_{ice} = k_1 k_2 k_3 N_{class} n_n$$

where the values for N_{class} are given in Table 20 and the propeller location factor k_1 is given in Table 21.

Table 20 Values of N_{class}

Ice class	**Ice(1A*F)** and **Ice(1A*)**	**Ice(1A)**	**Ice(1B)**	**Ice(1C)**
Impacts in life/n_n	$9 \cdot 10^6$	$6 \cdot 10^6$	$3.4 \cdot 10^6$	$2.1 \cdot 10^6$

Table 21 Values of the propeller location factor k_1

	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

$$k_2 = 0.8 - f \text{ when } f < 0$$

$$k_2 = 0.8 - 0.4 \cdot f \text{ when } 0 \le f \le 1$$

$$k_2 = 0.6 - 0.2 \cdot f \text{ when } 1 < f \le 2.5$$

$$k_2 = 0.1 \text{ when } f > 2.5$$

where the immersion function f is:

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$$f = \frac{h_o - H_{ice}}{\frac{D}{2}} - 1$$

where h_o is the depth of the propeller centreline at the lower ice waterline (LIWL) of the ship.

Table 22 Propulsion machinery factor *k₃*

Type	*Fixed*	*Azimuting*
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}) shall be multiplied by the number of propeller blades (Z).

15.5.2 Axial design loads for open and ducted propellers

15.5.2.1 Design ice thrust on propeller T_b and T_f for open and ducted propellers

The maximum forward and backward ice thrusts are:

$$T_f = 1.1 \cdot F_f \text{ [kN]}$$

$$T_b = 1.1 \cdot F_b \text{ [kN]}$$

15.5.2.2 Design thrust along the propulsion shaft line for open and ducted propellers

The design thrust along the propeller shaft line shall be calculated using 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 a forward direction:

$$T_r = T + 2.2 \cdot T_f \text{ [kN]}$$

In a backward direction:

$$T_r = 1.5 \cdot T_b \text{ [kN]}$$

If the hydrodynamic bollard thrust, T, is not known, T shall be taken from Table 23, where T_n is the nominal propeller thrust at MCR in free running open water condition.

Table 23 Default values for hydrodynamic bollard thrust, *T*

Propeller type	*T*
CP propellers (open)	1.25 T_n
CP propellers (ducted)	1.1 T_n
FP propellers driven by turbine or electric motor	T_n
FP propellers driven by diesel engine (open)	0.85 T_n
FP propellers driven by diesel engine (ducted)	0.75 T_n

15.5.3 Torsional design loads

15.5.3.1 Design ice torque on propeller Q_{max} for open propellers

Q_{max} is the maximum torque on a propeller during the service life of the ship resulting from ice/propeller interaction.

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$$Q_{\max} = 10.9 \cdot \left(1 - \frac{d}{D}\right) \cdot \left(\frac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^{3} \text{ [kNm]}$$

when $D \le D_{limit}$

$$Q_{\max} = 20.7 \cdot \left(1 - \frac{d}{D}\right) \cdot \left(\frac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^{1.9} \cdot {H_{ice}}^{1.1} \text{ [kNm]}$$

when $D > D_{limit}$

where:

$$D_{limit} = 1.8 \cdot H_{ice} \text{ [m]}$$

n is the rotational propeller speed at MCR in bollard condition. If unknown, n shall be taken as described in Table 24.

Table 24 Default rotational propeller speed at MCR in bollard condition

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

Here n_n is the nominal rotational speed at MCR in free running open water condition.

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

15.5.3.2 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.

$$Q_{\max} = 7.7 \cdot \left(1 - \frac{d}{D}\right) \cdot \left(\frac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^{3} \text{ [kNm]}$$

when $D \le D_{limit}$

$$Q_{\max} = 14.6 \cdot \left(1 - \frac{d}{D}\right) \cdot \left(\frac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^{1.9} \cdot {H_{ice}}^{1.1} \text{ [kNm]}$$

when $D > D_{limit}$

where:

$$D_{limit} = 1.8 \cdot H_{ice} \text{ [m]}$$

n is the rotational propeller speed at MCR in bollard condition. If unknown, n shall be taken as described in Table 24.

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

15.5.3.3 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.

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Directly coupled two stroke diesel engines without flexible coupling:

$$Q_{peak} = Q_{\mathrm{emax}} + Q_{vib} + Q_{\mathrm{max}} \frac{I_e}{I_t} \text{ [kNm]}$$

and other plants:

$$Q_{peak} = Q_{\mathrm{emax}} + Q_{\mathrm{max}} \frac{I_e}{I_t} \text{ [kNm]}$$

where:

I_e = equivalent mass moment of inertia of all parts on the engine side of the component under consideration

I_t = equivalent mass moment of inertia of the whole propulsion system

Q_{vib} = vibratory torque at considered component, taken from frequency domain open water torsional vibration calculation

Q_{emax} = maximum engine torque. Taken as given in Table 25 if unknown.

All the torques and the inertia moments shall be reduced to the rotation speed of the component being examined.

Table 25 Default values for prime mover maximum torque Q_{emax}

Propeller type	Q_{emax}
Propellers driven by electric motor	Q_{motor} 1)
CP propellers not driven by electric motor	Q_n
FP propellers driven by turbine	Q_n
FP propellers driven by diesel engine	0.75 Q_n
1) Q_{motor} is the electric motor peak torque.	

15.5.3.4 Design torque for shaft lines having resonances

If there is a 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.

15.5.3.4.1 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.

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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 considerations at specific shaft speeds are performed, a relevant Q_{max} may be calculated using the relevant speed according to [15.5.3].

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 rotational 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 frequency 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:

$$Q(\varphi) = C_q \cdot Q_{\max} \cdot \sin\left(\varphi\left(\frac{180}{\alpha_i}\right)\right)$$

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 is the rotation angle from when the first impact occurs and parameters C_q and α_i are given in Table 26.

Table 26 Ice impact magnification and duration factors for different blade numbers

	Propeller/ ice interaction	C_q	α_i *[deg]*			
			Z=3	*Z=4*	*Z=5*	*Z=6*
Case 1	Single ice block	0.75	90	90	72	60
Case 2	Single ice block	1.0	135	135	135	135
Case 3	Two ice blocks (phase shift 360/(2·Z) deg.)	0.5	45	45	36	30
Case 4	Single ice block	0.5	45	45	36	30

α_i is the duration of propeller blade/ice interaction expressed in terms of the propeller rotation angle, see Figure 7.

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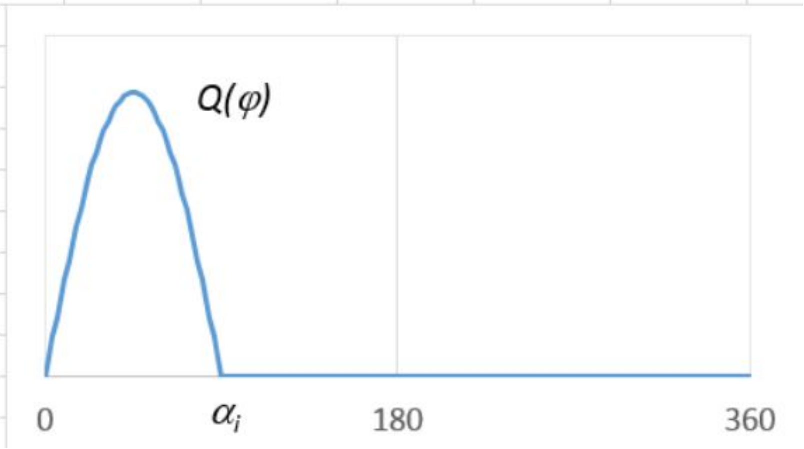

Figure 7 Schematic ice torque due to a single blade ice impact as a function of the propeller rotation angle

The total ice torque is obtained by summing the torque of single blades, while taking account of the phase shift 360 deg./Z, see Figure 8. At the beginning and end of the milling sequence (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 for different blade numbers in Figure 8).

The number of propeller revolutions during a milling sequence shall be obtained from the formula:

$$N_Q = 2 \cdot H_{ice}$$

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 Figure 8.

A dynamic simulation shall be performed for all excitation cases at the operational rotational speed range. For a fixed pitch propeller propulsion plant, a dynamic simulation shall also cover the bollard 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 shall be used.

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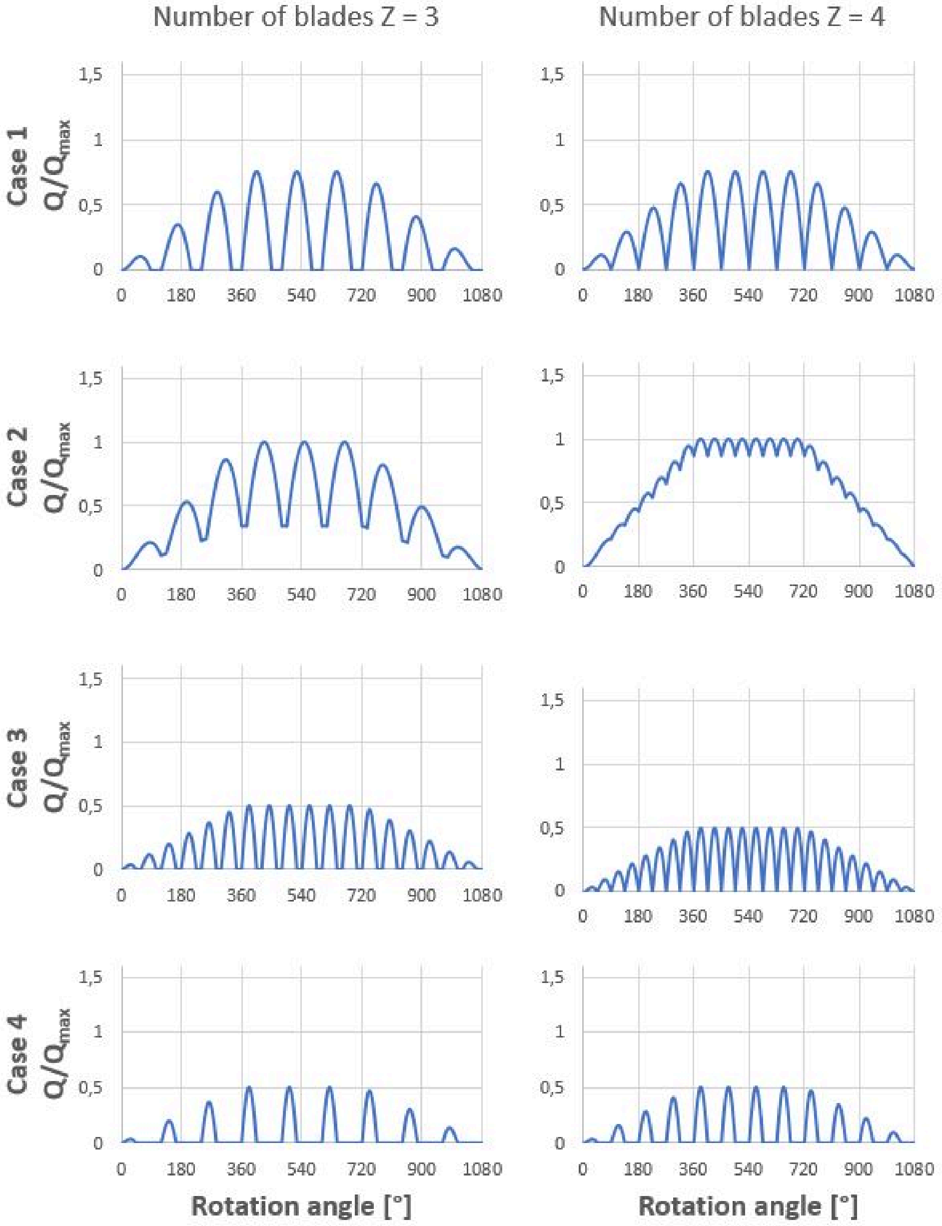

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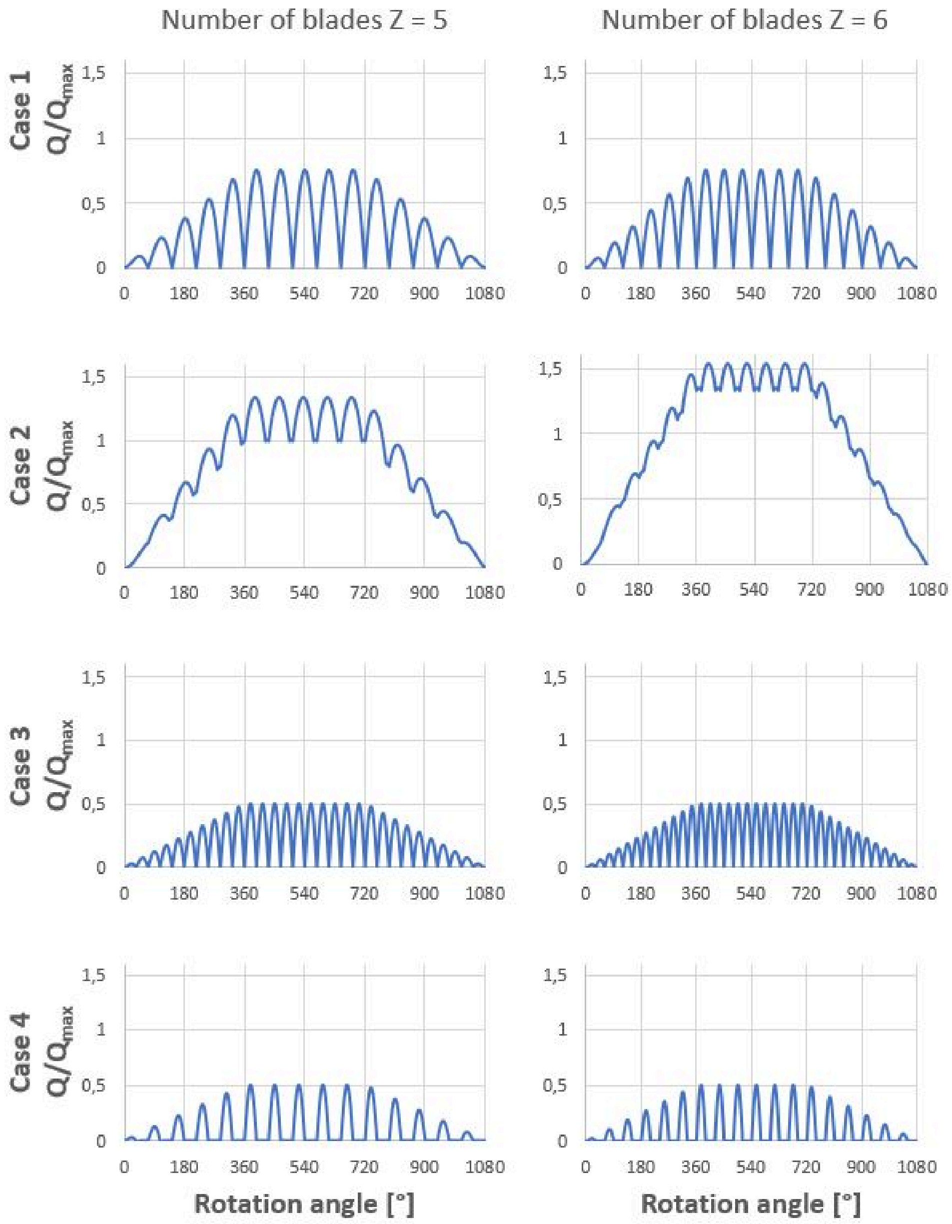

Figure 8 The shape of the propeller ice torque excitation sequences for propellers with 3, 4, 5 and 6 blades (given for ice class Ice(1A))

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 shall be obtained using the formula:

$$Q_{peak} = Q_{e\max} + Q_{rtd} \text{ [kNm]}$$

where Q_{rtd} is the maximum simulated torque obtained from the time domain analysis.

15.5.3.4.2 Frequency domain calculation of torsional response

For frequency domain calculations, first and second blade order excitation may be used. The amplitudes for the first and second blade order sinusoidal excitation have been derived based on the assumption that the time domain half sine impact sequences are continuous, and the Fourier series components for first and second blade order components have been derived. The propeller ice torque is then:

$$Q_F(\varphi) = Q_{\max}\left(C_{q0} + C_{q1}\sin\left(ZE_0\varphi + \alpha_1\right) + C_{q2}\sin\left(2ZE_0\varphi + \alpha_2\right)\right) \text{ [kNm]}$$

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 these parameters are given in Table 27:

Table 27 Coefficient values for frequency domain excitation calculation

	C_{q0}	C_{q1}	α_1	C_{q2}	α_2	E_0
Torque excitation (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
Torque excitation (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
Torque excitation (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
Torque excitation (Z=6)						

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	C_{q0}	C_{q1}	α_1	C_{q2}	α_2	E_0
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

The design torque for the frequency domain excitation case shall be obtained using the formula:

$$Q_{peak} = Q_{\mathrm{emax}} + Q_{vib} + \left(Q^{n}_{\mathrm{max}} C_{q0}\right)\frac{I_e}{I_t} + Q_{rf1} + Q_{rf2} \text{ [kNm]}$$

where:

$Q^{n}{}_{max}$ = maximum propeller ice torque at the considered operational speed
C_{q0} = mean static torque coefficient from Table 27
Q_{rf1} = first blade order torsional response from the frequency domain analysis
Q_{rf2} = second blade order 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 25. All torque values shall be scaled to the shaft rotational speed for the component in question.

15.5.3.4.3 Guidance for torsional vibration calculation

The aim of time domain torsional vibration simulations is to estimate the extreme torsional load for the ship’s 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 analysis of the continuous sequence of half sine load sequences. First and second blade order components should be used for excitation.

The calculation should cover the entire relevant rotational speed range and the simulation of responses at torsional vibration resonances.

15.5.4 Blade failure load

15.5.4.1 Bending force, F_{ex}

The ultimate load resulting from blade failure as a result of plastic bending around the blade root shall be calculated using 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 the propeller diameter D.

$$F_{ex} = \frac{300 \cdot c \cdot t^2 \cdot \sigma_{ref}}{0.8 \cdot D - 2 \cdot r} \text{ [kN]}$$

where:

$$\sigma_{ref} = 0.6 \cdot \sigma_{0.2} + 0.4 \cdot \sigma_u \text{ [MPa]}$$

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 typically located at the point where the fillet terminates at the blade profile.

15.5.4.2 Spindle torque, 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 by using the equation given below.

$$Q_{sex} = \max\left(C_{LE0.8}; 0.8C_{TE0.8}\right)C_{spex}F_{ex} \text{ [kNm]}$$

where:

$$C_{spex} = C_{sp}C_{fex} = 0.7\left(1 - \left(\frac{4EAR}{Z}\right)^3\right)$$

C_{sp} = non-dimensional parameter accounting for 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
$C_{LE0.8}$ = leading edge portion of the chord length at 0.8 *R*
$C_{TE0.8}$ = trailing edge portion of the chord length at 0.8 *R.*

If C_{spex} is below 0.3, a value of 0.3 shall be used for C_{spex}.

Figure 9 illustrates the spindle torque values due to blade failure loads across the entire chord length.

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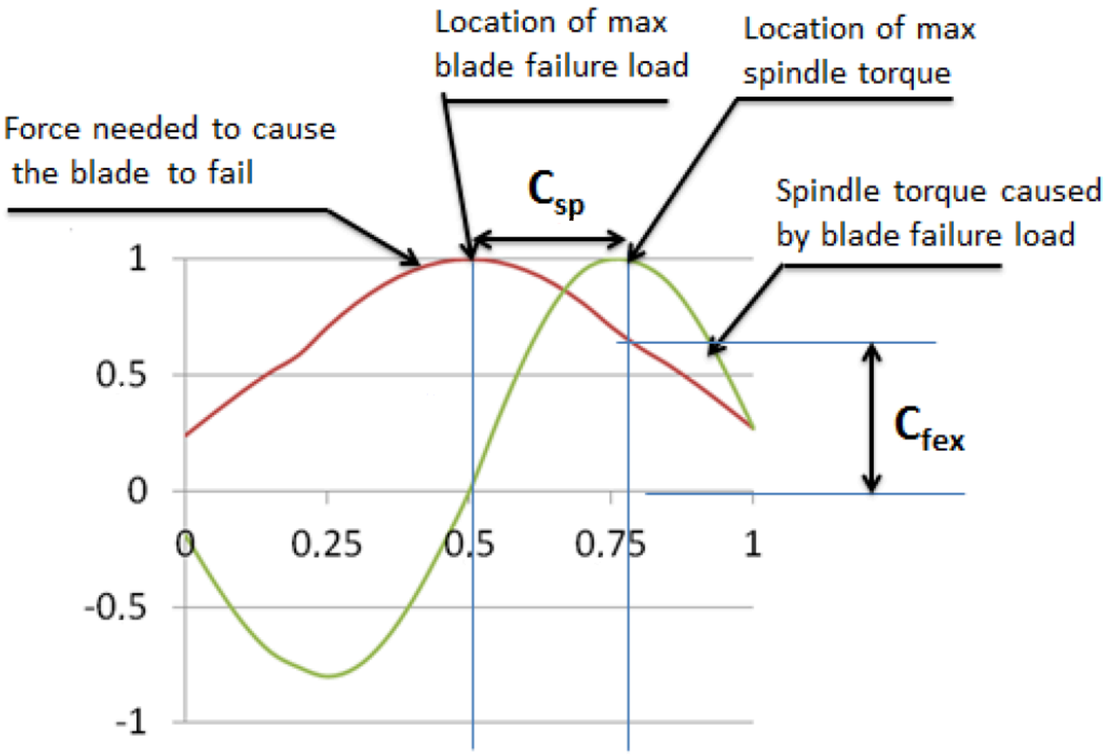

Figure 9 Schematic figure showing a blade failure load and the related spindle torque when the force acts at a different location on the chord line at radius 0.8*R*

15.6 Design

15.6.1 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.

15.6.2 Propeller blades

15.6.2.1 General

The values of the parameters in the formulae in this section shall be given in the units shown in the symbol list.

15.6.2.2 Calculation of blade stresses

The blade stresses shall be calculated for the design loads given in [15.5.1]. 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). Root area dimensions based on the formula below can be accepted, even if the FEM analysis would show greater stresses at the root area.

$$\sigma_{st} = C_1 \frac{M_{BL}}{100 \cdot c \cdot t^2} \text{ [MPa]}$$

where:

C_1 = ratio of actual stress to stress obtained from beam equation. If the actual value is not available, C_1 shall be taken as 1.6.

M_{BL} = $(0.75 - r/R)R\,F$, for relative radius $r/R < 0.5$

F = F_b or F_f, whichever has the greatest absolute value.

15.6.2.3 Acceptability criterion

The following criterion for calculated blade stresses shall be fulfilled:

$$\frac{\sigma_{ref2}}{\sigma_{st}} \geq 1.3$$

where σ_{st} is the calculated stress for the design load. If FEM analysis is used in estimating the stresses, von Mises stresses shall be used.

σ_{ref2} is the reference stress, defined as:

$\sigma_{ref2} = 0.7 \cdot \sigma_u$ or

$\sigma_{ref2} = 0.6 \cdot \sigma_{0.2} + 0.4\,\sigma_u$

whichever is lower.

15.6.2.4 Fatigue design of propeller blades

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 shall be fulfilled as given in [15.6.2.5]. The equivalent stress is normalized for 10^8 cycles.

For materials with a two-slope SN curve, see Figure 10, fatigue calculations in accordance with this chapter are not required if the following criterion is fulfilled:

$$\sigma_{exp} \geq B_1 \cdot \sigma_{ref2}^{\,B_2} \cdot \log\left(N_{ice}\right)^{B_3}$$

where the B_1, B_2 and B_3 coefficients for open and ducted propellers are given in Table 28.

Table 28 Values of coefficients B_1, B_2 and B_3

Coefficient	*Open propeller*	*Ducted propeller*
B_1	0.00328	0.00223
B_2	1.0076	1.0071
B_3	2.101	2.471

For calculation of equivalent stress, two types of SN curves are available:

1) two-slope SN curve (slopes 4.5 and 10), see Figure 10
2) one-slope SN curve (the slope can be chosen), see Figure 11.

The type of the SN-curve shall be selected to correspond to the material properties of the blade. If SN-curve is not known the two slope SN curve shall be used.

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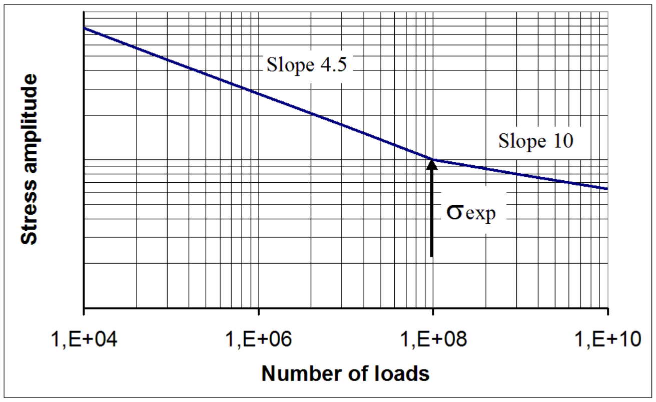

Figure 10 Two-slope S-N curve

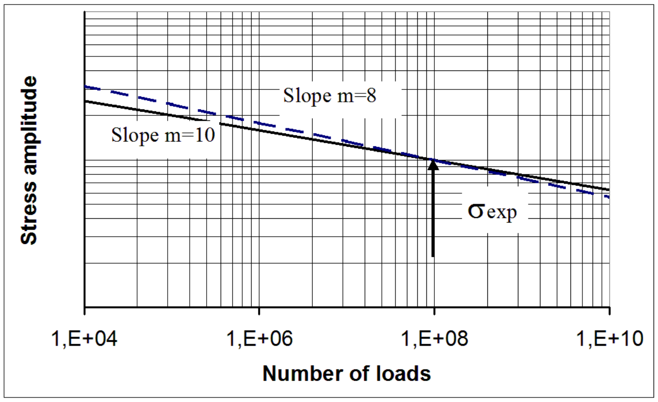

Figure 11 Constant-slope S-N curve

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:

$$(\sigma_{ice})_{\max} = 0.5 \cdot \left[(\sigma_{ice})_{f\,\max} - (\sigma_{ice})_{b\,\max}\right]$$

$(\sigma_{ice})_{max}$ = 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.

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In calculation of $(\sigma_{ice})_{max}$, load case 1 and load case 3 (or case 2 and case 4) are considered as a pair for $(\sigma_{ice})_{f\,max}$, and $(\sigma_{ice})_{b\,max}$ calculations. Load case 5 is excluded from the fatigue analysis.

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:

$$\rho = C_1 \cdot \left(\sigma_{ice}\right)_{\max}{}^{C_2} \cdot \sigma_{fl}{}^{C_3} \cdot \log\left(N_{ice}\right)^{C_4}$$

where:

$$\sigma_{fl} = \gamma_{\varepsilon 1} \cdot \gamma_{\varepsilon 2} \cdot \gamma_v \cdot \gamma_m \cdot \sigma_{\exp}$$

$\gamma_{\varepsilon 1}$ = reduction factor for scatter effect (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
σ_{exp} = mean fatigue strength of the blade material at 10^8 cycles to failure in seawater.

The following values shall be used for the reduction factors if actual values are not available: $\gamma_\varepsilon = \gamma_{\varepsilon 1} \cdot \gamma_{\varepsilon 2} = 0.67$, $\gamma_v = 0.75$, and $\gamma_m = 0.75$.

The coefficients C_1, C_2, C_3, and C_4 are given in Table 29. The applicable range of N_{ice} for calculating ρ is $5 \cdot 10^6 \leq N_{ice} \leq 10^8$.

Table 29 Parameters for *ρ* determination

Coefficient	*Open propeller*	*Nozzle propeller*
C_1	0.000747	0.000534
C_2	0.0645	0.0533
C_3	-0.0565	-0.0459
C_4	2.22	2.584

Calculation of parameter ρ *for constant slope S-N curve*

For materials with a constant-slope S-N curve, see Figure 11, the factor ρ shall be calculated using the following formula:

$$\rho = \left(G \frac{N_{ice}}{N_R}\right)^{\frac{1}{m}} \cdot \left(\ln\left(N_{ice}\right)\right)^{-\frac{1}{k}}$$

where k is the shape parameter of the Weibull distribution, k = 1.0 for ducted propellers and k = 0.75 for open propellers.

N_R is the reference number of load cycles (=10^8).

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The applicable range of N_{ice} for calculating ρ is $5 \cdot 10^6 \leq N_{ice} \leq 10^8$.

Values for the parameter G are given in Table 30. Linear interpolation may be used to calculate the G value for other m/k ratios than given in Table 30.

Table 30 Value of the parameter *G* for different *m/k* ratios

m/k	G	m/k	G	m/k	G
3	6	6.5	1 871	10	$3.629 \cdot 10^6$
3.5	11.6	7	5 040	10.5	$11.899 \cdot 10^6$
4	24	7.5	14 034	11	$39.917 \cdot 10^6$
4.5	52.3	8	40 320	11.5	$136.843 \cdot 10^6$
5	120	8.5	119 292	12	$479.002 \cdot 10^6$
5.5	287.9	9	362 880		
6	720	9.5	$1.133 \cdot 10^6$		

15.6.2.5 Acceptability criterion for fatigue

The equivalent fatigue stress at all locations on the blade shall 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 for scatter effect (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
σ_{exp} = mean fatigue strength of the blade material at 10^8 cycles to failure in seawater.

The following values shall be used for the reduction factors if actual values are not available: $\gamma_\varepsilon = \gamma_{\varepsilon 1} \cdot \gamma_{\varepsilon 2} = 0.67$, $\gamma_v = 0.75$, and $\gamma_m = 0.75$.

15.6.3 Propeller boss 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 [15.5]. 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 [15.5.4], shall be greater than 1.0 against yielding.

15.6.4 Propulsion shaft line

15.6.4.1 General

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 [15.5]. The safety factor shall be at least 1.3 against yielding for extreme operational loads, 1.5 for fatigue loads and 1.0 against yielding for the blade failure load.

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15.6.4.2 Shafts and shafting components

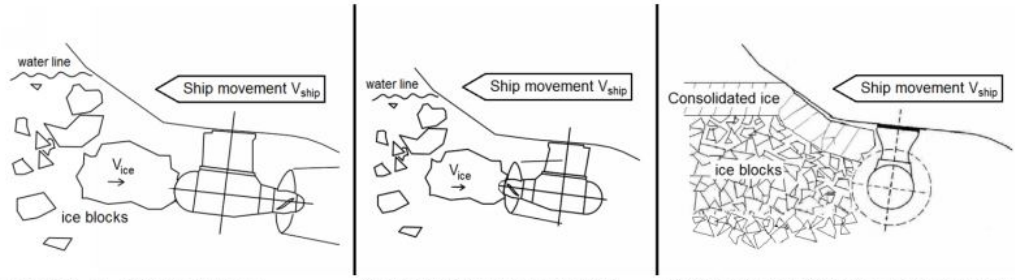
The ultimate load resulting from total blade failure as defined in [15.5.4] shall not cause yielding in shafts and shaft components. The loading shall consist of the combined axial, bending, and torsion loads, wherever this is significant. The minimum safety factor against yielding shall be 1.0 for bending and torsional stresses.

15.6.5 Azimuthing main propulsors

15.6.5.1 Design principle

In addition to the above requirements for propeller blade dimensioning, azimuthing thrusters shall be designed for thruster body/ice interaction loads. Load formulae are given for estimating 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 Figure 12. 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 12 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 plastic bending of a blade without damage. The loss of a blade shall be taken into account for the propeller blade orientation causing the maximum load on the component being studied. Top-down blade orientation typically places the maximum bending loads on the thruster body.

15.6.5.2 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 shall withstand the loads occurring when the design ice block defined in Table 17 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 31. The contact geometry is estimated to be hemispherical in shape. If the actual contact geometry differs from the shape of the hemisphere, a sphere radius shall be estimated so that the growth of the contact area as a function of penetration of ice corresponds as closely as possible to the actual geometrical shape penetration.

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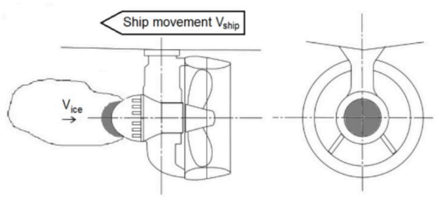
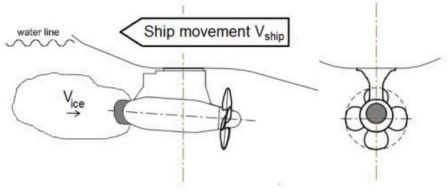
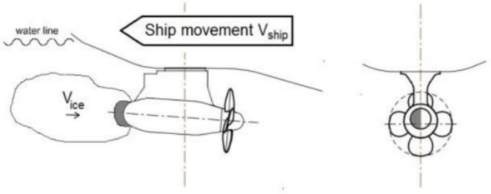
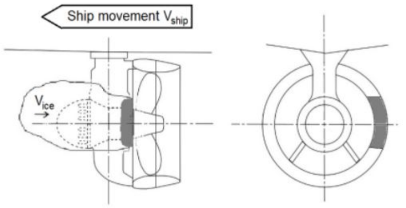
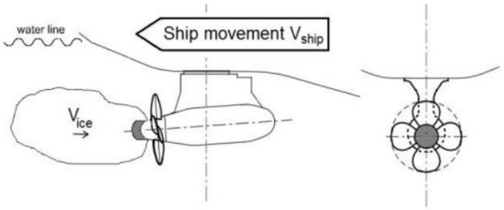
Table 31 Load cases for azimuthing thruster ice impact loads

	Force	*Loaded area*	*Illustration*
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})* 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.	

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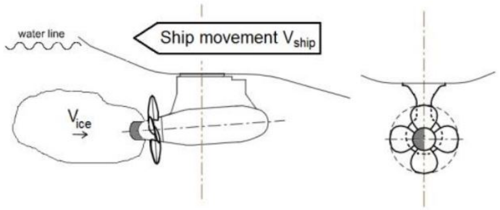
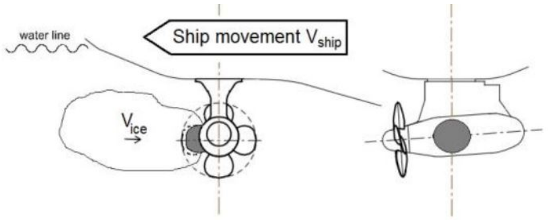
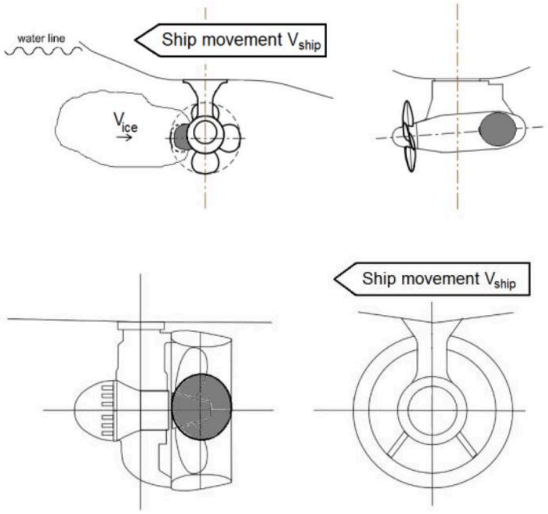
	Force	*Loaded area*	*Illustration*
Load case T2b Non-symmetric longitudinal ice impact on propeller hub	50% of F_{ti}	Uniform distributed load or uniform pressure, which are applied on the other half of the impact area.	
Load case T3a Symmetric lateral ice impact on thruster body	F_{ti}	Uniform distributed 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	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 shall be calculated using the formula below. The related parameter values are given in Table 32. The design operation speed in ice can be derived from Table 33 and Table 34, or the ship in question's actual design operation speed in ice can be used. The longitudinal impact speed in Table 33 and Table 34 refers to the impact in the thruster's main operational direction. For 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 transverse impact is applied.

$$F_{ti} = C_{DMI} 34.5\, R_c^{0.5} \left(m_{ice} v_s^2\right)^{0.333} \text{ [kN]}$$

where:

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R_c = impacting part sphere radius, see Figure 13 [m]
m_{ice} = ice block mass [kg]
v_s = ship speed at time of contact [m/s]
C_{DMI} = dynamic magnification factor for impact loads.

C_{DMI} shall be taken from Table 32 if unknown.

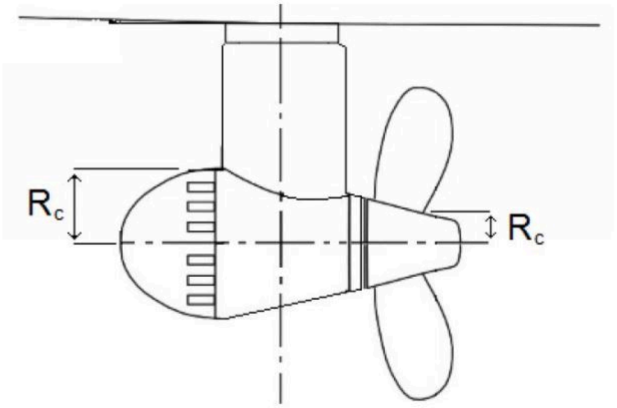

Figure 13 Dimensions used for R_c

For impacts on non-hemispherical areas, such as impact on the nozzle, the equivalent impact sphere radius shall be estimated using the equation below.

$$R_{ceq} = \sqrt{\frac{A}{\pi}} \text{ [m]}$$

If the 2*R_{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 32 Parameter values for ice dimensions and dynamic magnification

	Ice(1A*F) *and* ***Ice(1A*)***	***Ice(1A)***	***Ice(1B)***	***Ice(1C)***
Thickness of the design ice block impacting thruster (2/3 of H_{ice}) [m]	1.17	1.00	0.80	0.67
Extreme ice block mass (m_{ice}) [kg]	8670	5460	2800	1600
C_{DMI} (if not known)	1.3	1.2	1.1	1.0

Table 33 Impact speeds for aft centerline thruster [m/s]

Aft centreline thruster	***Ice(1A*F)*** *and* ***Ice(1A*)***	***Ice(1A)***	***Ice(1B)***	***Ice(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

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Aft centreline thruster	***Ice(1A*F)*** *and* ***Ice(1A*)***	***Ice(1A)***	***Ice(1B)***	***Ice(1C)***
Transversal impact in bow first operation	3	2	2	2
Transversal impact in stern first operation (double acting ship)	4	3	3	3

Table 34 Impact speeds for aft wing, bow centerline and bow wing thrusters [m/s]

Aft wing, bow centreline and bow wing thruster	***Ice(1A*F)*** *and* ***Ice(1A*)***	***Ice(1A)***	***Ice(1B)***	***Ice(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
Transverse impact	4	3	3	3

15.6.5.3 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 **Ice(1A*F)** and **Ice(1A*)** 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 situation, 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 dynamic magnification is considered negligible and is not taken into account.

The load magnitude shall be estimated for the load cases shown in Table 35, using the equation further below. The parameter values for calculations are given in Table 36 and Table 37. The loads shall be applied as uniform distributed load or uniform pressure over the thruster surface. The design operation speed in ice may be derived from Table 36 or Table 37. Alternatively, the actual design operation speed in ice of the ship in question may be used.

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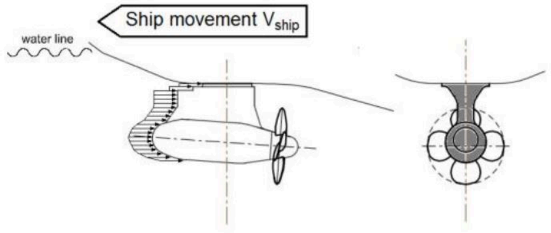
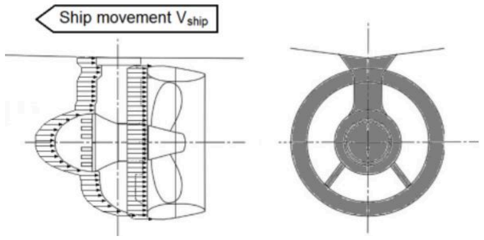
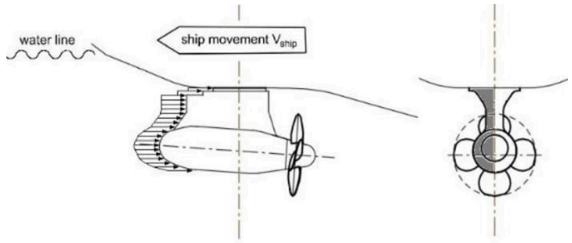
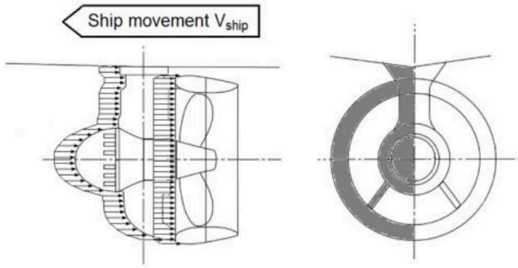
Table 35 Load cases for ridge ice loads

	Force	*Loaded area*	*Illustration*
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 contact area.	 

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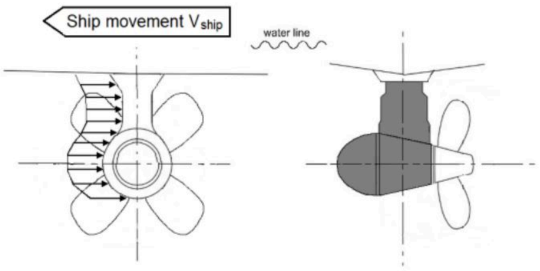
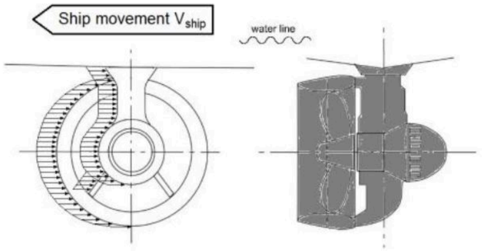
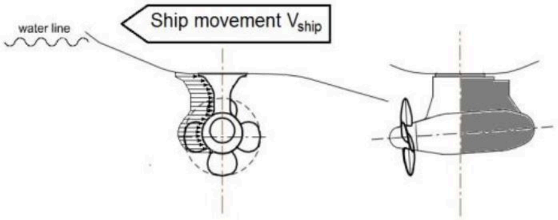
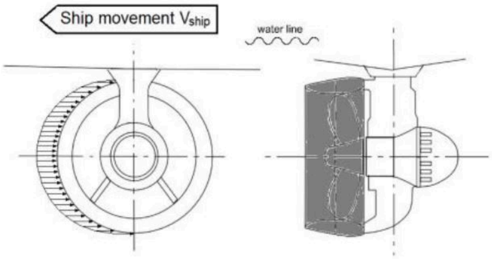
	Force	*Loaded area*	*Illustration*
Load case T5a Symmetric lateral ridge penetration loads for ducted azimuthing unit and pushing open propeller unit	F_{tr}	Uniform distributed load or uniform pressure, which are applied symmetrically on the contact area.	 
Load case T5b Non-symmetric lateral ridge penetration loads for all azimuthing units	50% of F_{tr}	Uniform distributed load or uniform pressure, which are applied on the other half of the contact area.	 

$$F_{tr} = 32 v_s^{0.66} H_r^{0.9} A_t^{0.74} \text{ [kN]}$$

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 = 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 Figure 14.

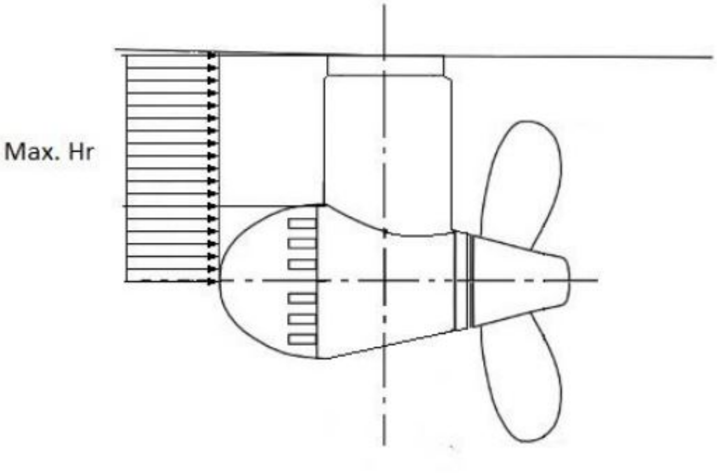


Figure 14 Schematic figure showing the reduction of the contact area by the maximum ridge thickness

Table 36 Parameters for calculating maximum loads when the thruster penetrates an ice ridge. Aft thrusters. Bow first operation.

	Ice(1A*F) *and* ***Ice(1A*)***	***Ice(1A)***	***Ice(1B)***	***Ice(1C)***
Thickness of the design ridge consolidated 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 (transverse loads) [m/s]	2	1	1	1

Table 37 Parameters for calculating maximum loads when the thruster penetrates an ice ridge. Thruster first mode such as double acting ships.

	Ice(1A*F) *and* ***Ice(1A*)***	***Ice(1A)***	***Ice(1B)***	***Ice(1C)***
Thickness of the design ridge consolidated 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]	6	4	4	4
Initial ridge penetration speed (transverse loads) [m/s]	3	2	2	2

15.6.5.4 Acceptability criterion for static loads

The stresses on the thruster shall be calculated for the extreme once-in-a-lifetime loads described in [15.6.5]. The nominal von Mises stresses on the thruster body shall have a minimum safety margin of 1.3

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against the yield strength of the material. At areas of local stress concentrations, stresses shall have a minimum safety margin of 1.0 against yielding. The slewing bearing, bolt connections and other components shall be able to maintain operability without incurring damage that requires repair when subject to the loads given in [15.6.5.2] and [15.6.5.3] multiplied by a safety factor of 1.3.

15.6.5.5 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 shall 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 direction, the damping and added mass due to water shall be taken into account. In addition to this, the effect of ship attachment stiffness shall be modelled.

15.7 Alternative design procedure

15.7.1 Scope

As an alternative to [15.5] and [15.6], a comprehensive design study may be performed to the satisfaction of the Society. The study shall be based on the ice conditions given for different ice classes in [15.3]. It shall include both fatigue and maximum load design calculations and fulfil the pyramid strength principle, as given in [15.6.1].

15.7.2 Loading

Loads on the propeller blade and propulsion system shall be based on an acceptable estimation of hydrodynamic and ice loads.

15.7.3 Design levels

The analysis shall 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 shall give a reasonable safety factor. Due account shall be taken of material properties, stress raisers, and fatigue enhancements.

A vibration analysis shall be performed and demonstrate that the overall dynamic system is free of the harmful torsional resonances resulting from propeller/ice interaction.

15.8 Design of shaft line components not specifically mentioned in FSICR

15.8.1 General

The following paragraph describes how to determine scantlings of intermediate shafts, gears, couplings and crank shafts subjected to ice loads. For static and low cycle torsional load criteria, the peak application factor shall be taken as $K_{AP} = Q_{peak}/Q_n$.

For components where fatigue may be dimensioning, e.g. shafts and reduction gears, cumulative fatigue analyses are required. The applicable Q_{peak} and the corresponding load spectrum shall be determined for the component or connection in question, as described in [15.5.3].

Guidance note:

The torsional response load spectrum is assumed to follow the same shape as the excitation load spectrum. If the peak response load is resonance-induced, the response load spectrum may be especially considered.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

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15.8.2 Shafts

Static strength and fatigue evaluation of shafts shall be carried out based on one of the methods given in Pt.4 Ch.4 Sec.1 [2.2]. For plants with $K_{AP} > 1.4$, the method in DNV-CG-0038 shall be applied.

Forward of the inboard stern tube seal the propeller shaft may be evenly tapered down to 1.05 times the required diameter for the intermediate shafts (calculated using the material data of the propeller shaft), however not less than the actual diameter of the intermediate shafts.

15.8.3 Shaft connections

Shaft connections shall be calculated using the formulas in Pt.4 Ch.4 Sec.1 [2.3], Pt.4 Ch.4 Sec.1 [2.4], and Pt.4 Ch.4 Sec.1 [2.5]. A safety factor of 1.6 against Q_{peak} shall be applied. Where torque is transferred as a combination of shear and friction (e.g. friction bolts with shear pins, and keyed connections), the friction connection shall withstand 2* Q_r, where Q_r is calculated for 10^6 cycles.

Guidance note:

10^6 is considered the number of cycles above which fretting start to develop on the mating surfaces.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Connections transmitting axial loads determined in [15.5.2] and [15.5.4] from the propeller to the thrust bearing shall be capable of transmitting relevant loads without consequential damage.

15.8.4 Reduction gears

Evaluation of gears shall be carried out based on the methods given in Pt.4 Ch.4 Sec.2 [2.1].

15.8.5 Clutches

The static friction capacity of clutches shall as a minimum be $K_{AP}*T_0$, but not less than $1.8*T_0$, as described in Pt.4 Ch.4 Sec.3 [2.1].

15.8.6 Torsionally elastic couplings

With reference to Pt.4 Ch.4 Sec.5, torsionally elastic couplings shall be chosen so that they have a value T_{kmax1} exceeding Q_r calculated for 50 000 load cycles. Q_{peak} shall not exceed T_{kmax2}.

15.8.7 Crank shafts

For crank shafts in direct coupled diesel engines, see Pt.4 Ch.3 Sec.1 [2.5.7].

15.9 Thrusters for other purposes than propulsion

15.9.1 Tunnel thrusters

Ice strengthening of tunnel thrusters is not required.

15.9.2 Other thrusters

Thrusters other than propulsion thrusters and tunnel thrusters need only comply with the relevant requirements in [15] if they shall be used in ice conditions or for any reason be exposed to ice loads.

For thrusters that are not intended for use in ice conditions, this will be stated in the class certificate and on signboards fitted at all relevant manoeuvring stands.

The relevant structure parts of non-retractable thrusters shall be strengthened with respect to ice loads, independent of whether they are used in ice conditions or not.

16 Miscellaneous machinery requirements

16.1 Starting arrangements

The capacity of the air receivers shall be according to the requirements in Pt.4 Ch.6 Sec.5 [9.4].

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If the air receivers serve any other purposes than starting the propulsion engine, they shall have additional capacity sufficient for such purposes.

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 classes **Ice(1A*F)** and **Ice(1A*)** if its propulsion engine has to be reversed for going astern, in which case the compressors shall be able to charge the receivers in half an hour.

16.2 Sea inlet and cooling water systems

The cooling water system shall be designed to ensure supply of cooling water when navigating in ice. The sea cooling water inlet and discharge for main and auxiliary engines shall be so arranged that blockage of strums and strainers is prevented.

For this purpose, at least one cooling water inlet chest shall be arranged as follows:

1) The sea inlet shall be situated near the centre line of the ship and well aft if possible. The inlet grids shall be specially strengthened.
2) As a guidance for design the volume of the chest shall be about one cubic metre for every 750 kW engine output of the ship including the output of the auxiliary engines necessary for the ship's service.
3) To allow for ice accumulation above the pump suction the height of the sea chest shall not be less than:

$$h_{\min} \geq 1.5\sqrt[3]{V_s}$$

where:

V_s = volume of sea chest according to item 2.

The suction pipe inlet shall be located not higher than $h_{min}/3$ from top of sea chest.

4) A pipe for discharge cooling water, allowing full capacity discharge, shall be connected to the chest. Where the sea chest volume and height specified in 2 and 3 are not complied with, the discharge shall be connected to both sea chests. At least one of the fire pumps shall be connected to this sea chest or to another sea chest with de-icing arrangements.
5) The area of the strum holes shall be not less than four (4) times the inlet pipe sectional area.

If there are difficulties in meeting the requirements of 2) and 3) above, two smaller chests may be arranged for alternating intake and discharge of cooling water. The arrangement and situation otherwise shall be as above.

Heating coils may be installed in the upper part of the chest or chests.

Arrangements using ballast water for cooling purposes may be useful as a reserve in ballast condition but cannot be accepted as a substitute for sea inlet chests as described above.

16.3 Ballast system

16.3.1 An arrangement to prevent freezing of the ballast water shall be provided for inside ballast tanks located fully or partly above the LIWL, adjacent to the ship's shell, and which shall be filled for operation in ice conditions according to [1.5.2]. For this purpose the following ambient temperatures shall be taken as design conditions:

— sea water temperature: 0°C
— air temperature: –10°C.

Necessary calculations shall be submitted.

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16.3.2 When a tank is situated partly above the LIWL, an air-bubbling arrangement or a vertical heating coil, capable of maintaining an open hole in the ice layer, will normally be accepted.

The required heat-balance calculations may then be omitted.

Guidance note:

It is assumed that, before pumping of ballast water is commenced, proper functioning of level gauging arrangements is verified and air pipes are checked for possible blockage by ice.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

17 Guidelines for strength analysis of the propeller blade using finite element method

See App.A for guidelines on strength analysis of the propeller blade using finite element method.

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SECTION 4 OPERATIONS IN COLD CLIMATE - WINTERIZED

1 General

1.1 Objective

The objective of the additional class notation **Winterized** is to provide requirements for vessels intended for service in the northern Baltic Sea during winter, or in any other sea area with similar conditions.

1.2 Scope

The scope of the additional class notation **Winterized** includes functions, systems and equipment essential for safety of the vessel, personnel and the environment, operating in adverse cold climate conditions. Such conditions include: freezing sea spray, atmospheric icing, wind chill factor, and material properties in cold temperatures. Winterization measures encompass: protection of important shipboard functions, systems and equipment, provisioning suitable equipment and supplies, and implementing procedures for safe operation and personnel welfare. Other functions, such as systems and equipment important for commercial operations may also be affected by cold climate and may benefit from winterization measures. However, the **Winterized** notation does not address issues that are not essential to safety, nor do they address hull and propulsion machinery requirements necessary for safe navigation through sea ice, which are addressed in the ice class rules.

1.3 Application

1.3.1 The additional class notation **Winterized** applies to vessels intended for service in the northern Baltic Sea during winter or in areas with similar conditions.

1.3.2 The rules in this section consist mainly of functional and prescriptive requirements supporting each other consecutively.

The functional requirements, under each part of this section, are meant to provide the rationale and intent behind each prescriptive rule, where requirements are described in more details supported by guidance notes, as applicable. The prescriptive rules provide a set of generally acceptable solutions to meet the corresponding functional requirements.

1.4 Class notations

1.4.1 Vessels built in compliance with the requirements of this section may be assigned the additional class notations **Winterized** or **Winterized(BST)** as described in Sec.1 Table 1.

Guidance note:

Examples of the class notation:

- **Winterized**
- **Winterized(-25°C)**.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

1.4.2 The additional class notation **DAT-B** is mandatory for vessels intended to operate in low air temperature, and where Baltic service temperature (BST) is colder than -23^{o}C.

Design temperature t_D, as defined in Sec.6 for class notation **DAT-B**, shall be equal or colder than BST +13°C.

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1.5 Design environmental conditions

1.5.1 Baltic service temperature (BST), as defined in Sec.1 Table 7, shall be the temperature specified for a vessel intended to operate in low air temperature, which shall be set at least 10°C below the lowest mean daily low temperature (LMDLT) for the intended area and season of operation in northern Baltic waters.

> **Guidance note:**
>
> The vessel is considered as intended for low air temperature when lowest mean daily low air temperature (LMDLT), as defined in Sec.1 Table 7, is colder than -10°C, i.e. BST colder than -20°C.
>
> The Baltic service temperatures (BST) should reflect the short term ambient temperature by which systems and equipment onboard shall be fully functional.
>
> ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

1.5.2 For vessels not intended to operate in low air temperatures, it is assumed that all equipments necessary for safe operation of the vessel are tested and will be fully operational in ambient temperatures down to -20°C.

1.5.3 The coldest temperatures to be expected in Baltic waters are listed in Table 1.

Table 1 Coldest anticipated temperatures in the northern Baltic Sea area

Measure	*Coldest anticipated temperature [°C]*
Lowest Mean daily low temperature (LMDLT)	-20
Sea temperature	-2
Corresponding Baltic service temperature (BST)	≤ -30
Corresponding design temperature (t_D)	≤ -17

1.6 Definitions

For general definitions, see Sec.1 [9].

Table 2 lists definitions of terms used in this section.

Table 2 Definition of terms

Term	*Definition*
escorted operation	any operation in which a vessel's movement is facilitated through the intervention of an escort
fire main	sea water supply system for fire hydrants, it consists of sea inlets, suction piping, fire pumps and a distributed piping system supplying the hydrants, hoses and nozzles located through the vessel
machinery installations	equipment and machinery and its associated piping and cabling, which is necessary for the safe operation of the vessel
vessel intended to operate in low air temperature	vessel which is intended to undertake voyages to or through areas where the Baltic service temperature is colder than -20°C

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1.7 References

Table 3 lists DNV references used in this section.

Table 3 DNV references

Document code	*Title*
DNV-CG-0308	IMO Polar Code operational requirements

Table 4 lists other references used in this section.

Table 4 Other references

Document code	*Title*
SOLAS regulations V	Safety of navigation
SOLAS Ch. XIV	IMO Polar Code
IEC 60945	Maritime navigation and radiocommunication equipment and systems-General requirements-Methods of testing and required test results
MSC.1/Circ. 1612 Module A.1	Guidance for navigation and communication equipment intended for use on ships operating in polar waters

1.8 Documentation requirements

Documentation shall be submitted as required by Table 5.

Table 5 Documentation requirements

Object	*Documentation type*	*Additional description*	*Info*	*Qualifier*
Winterization plan	Z030 - Winterization arrangement plan	Including anti-icing, anti-freezing and de-icing systems. See also [2.1].	FI	
Heat balance calculation	Z265 Calculation report	For anti-freezing systems used in fresh water and ballast water tanks, indicating heating capacities required and provided.	FI	**BST**
Navigation	Z030 - Navigation bridge arrangement plan	Including ice searchlights and their total area of coverage (360°).	AP	
Stability	B050 - Preliminary Stability manual	Including loading conditions with ice accretion.	AP	

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Object	*Documentation type*	*Additional description*	*Info*	*Qualifier*
	B120 - Final Stability manual	Including loading conditions with ice accretion.	AP	
	B070 - Preliminary damage stability calculation	Including loading conditions with ice accretion.	AP	
	B130 - Final damage stability calculation	Including loading conditions with ice accretion.	AP	
Fire and safety	G040 - Fire control plan		FI	**BST**
	G050 - Safety plan	Arrangement drawing showing escape routes, muster stations, embarkation areas, LSA, survival crafts with launching appliances and access, etc.	FI	**BST**
FI = for information, AP = for approval				

For general requirements to documentation, including definition of the info codes, see DNV-CG-0550 Sec.6.

For a definition of the documentation types, see DNV-CG-0550 Sec.5.

2 Winterization plan

2.1 General

A winterization plan shall be submitted for class notation **Winterized**, and shall include descriptions and arrangements of all the winterization measures for protecting the relevant exposed structures, systems, and equipment.

2.2 Expected content in winterization plans

The plan shall include descriptions and relevant arrangements of the following systems or functions when such systems, or functions are available:

- anti-icing systems
- anti-freezing systems
- de-icing systems
- type of hydraulic fluid and/or measures for heating of hydraulic systems.

For more information regarding anti-icing, anti-freezing, and de-icing systems, see DNV-CG-0308 Sec.3 [1].

2.3 Additional content for vessels intended to operate in low air temperature

For vessels intended to operate in low air temperature, the winterization plan shall when applicable include:

- special procedures intended to compensate for additional testing to extend the coverage of a TAC
- procedures used as alternative to systems used for anti-icing and/or anti-freezing.

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3 Subdivision and stability

Subdivision and stability requirements, listed in Table 6, shall be complied with, as applicable.

Table 6 Requirements for subdivision and stability

General functional requirements	*Prescriptive requirements*
.1 Stability in icing conditions: vessels shall have sufficient stability in intact and damage conditions when subject to ice accretion.	.1 For vessels with class notation **Winterized**, the following icing allowance shall be made in the stability calculations: — 30 kg/m^2 on exposed weather decks and gangways — 7.5 kg/m^2 for the projected lateral area of each side of the vessel above the water plane — the projected lateral area of discontinuous surfaces of rail, sundry booms, spars (except masts), and rigging of vessels having no sails and the projected lateral area of other small objects shall be computed by increasing the total projected area of continuous surfaces by: — 5% of the total projected area, including both sides of the vessel. — 10% of the static vertical moments of this area. **Guidance note:** For vessels with open deck areas which are protected from sea spray by a deck or other structure above, the area of such may be excluded from the calculations. Examples: balconies, area below helideck. In general, it is sufficient to include the exposed horizontal projected areas. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
	.2 Vessels operating in areas and during periods where ice accretion is likely to occur shall be equipped with such means for removing ice, for example, electrical and pneumatic devices, and/or special tools such as axes or wooden clubs for removing ice from bulwarks, rails and erections. See DNV-CG-0308 Sec.3 [1.4].

4 Watertight and weathertight integrity

Watertight and weathertight integrity requirements, listed in Table 7, shall be complied with, as applicable.

Table 7 Requirements for watertight and weathertight integrity

General functional requirements	*Prescriptive requirements*
.1 All closing appliances and doors relevant to watertight and weathertight integrity of the vessel shall be operable.	.1 All doors and hatches along the defined escape routes shall be provided with anti-icing measures. See DNV-CG-0308 Sec.3 [1.3].
Specific functional requirements	*Prescriptive requirements*

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.2 Intended to operate in low air temperatures: all closing appliances and doors relevant to watertight and weathertight integrity of the vessel shall be operable.	.1 If the hatches or doors are hydraulically operated, hydraulic oil shall be suitable for the specified BST. Alternatively, means shall be provided to prevent freezing or excessive viscosity of liquids.

5 Machinery installations

Machinery installations requirements, listed in Table 8, shall be complied with, as applicable.

Table 8 Requirements for machinery installations

General functional requirements		*Prescriptive requirements*
.1 Exposed machinery installations shall provide functionality under the anticipated environmental conditions	.1 Ice accretion and/or snow accumulation.	.1 See DNV-CG-0308 Sec.3 [1].
	.2 Snow ingestion.	.1 Machinery shall be protected from the harmful effects of ingestion or accumulation of ice or snow. Where continuous operation is necessary, the air intakes for machinery shall be located on both sides of the vessel. Alternatively, means shall be provided to purge the system of accumulated icing and/or snow.
	.3 Increased viscosity of liquids.	.1 Hydraulic fluid shall either be of a type that maintains an acceptable viscosity in temperatures down to BST, or the hydraulic system shall have heating/circulation arrangements to keep fluids at an appropriate temperature. Type of hydraulic fluid and/or measures for heating of hydraulic system shall be documented in the winterization plan. See DNV-CG-0308 Sec.3 [2].
	.4 Ice ingestion from seawater. The sea cooling water inlet for main and auxiliary engines shall be arranged so that blockage of strums and strainers by ice is prevented.	.1 A vessel with an ice class notation shall comply with the requirements in either Sec.2 [3.3] or Sec.3 [16.2].
Specific functional requirements		*Prescriptive requirements*
.2 Intended to operate in low air temperatures	.1 Exposed machinery and electrical installation and appliances shall function at BST.	.1 — exposed electric cables shall be made from material suitable for BST — exposed machinery and electrical installation such as: — emergency generators — deck lights — winches and other pulling accessories — cranes — etc. shall be able to start and operate with an outside ambient air temperature down to BST.

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	.2 Means shall 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.	.1 If combustion air is taken from outside engine room, the engine manufacture temperature limitations on combustion air shall not be warmer than BST. Alternatively, means for air intake heating shall be provided.
	.3 Materials of exposed machinery and foundations shall be approved based on the BST.	.1 For Baltic service temperature colder than -23ºC, i.e. design temperatures colder than t_D = -10ºC, steel grades material for equipment or parts of equipment fabricated from plated structure, shall be selected as follows, according to Sec.6 [6]. Class II: — anchoring and mooring equipment — emergency towing arrangement (Tankers) Class I: — cargo securing devices — mast with derrick having load greater than 3 tons — others not specified as class II , unless upgraded or downgraded on a case-by-case basis due to special considerations of loading rate, level and type of stress, stress concentrations and load transfer points and/or consequences of failure. Foundation and main supporting structure for heavy machinery are covered by [1.4.2] for required additional class notation.
	.4 Freezing of ballast and freshwater tanks.	.1 Heat balance calculation shall be carried out, unless recognized anti-freezing measures, as listed in DNV-CG-0308 Sec.3 [2], are implemented. **Guidance note:** If the heat balance calculation shows a significant loss of heat in the tank, additional heat sources such as heating coils should be provided. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6 Fire safety and protection

Fire safety and protection requirements, listed in Table 9, shall be complied with, as applicable.

Table 9 Requirements for fire safety and protection

General functional requirements	*Prescriptive requirements*

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.1 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	.1 All components of fire safety systems and appliances if installed in exposed positions shall be protected from ice accretion and snow accumulation.	.1 Isolation and pressure/vacuum valves in exposed locations shall be protected from ice accretion and remain accessible at all time. See DNV-CG-0308 Sec.3 [1].
	.2 Local equipment and machinery controls shall be arranged so as to avoid freezing, snow accumulation and ice accretion and their location to remain accessible at all time.	.1 Fire pumps including emergency fire pumps, water mist and water spray pumps shall be located in compartments maintained above freezing.
		.2 The fire main shall be arranged so that exposed sections can be isolated and means of draining of exposed sections shall 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.
		.3 Firefighter's outfits shall be stored in warm locations on the vessel.
	.3 Sea suction for fire system shall be protected from ice accumulation.	.1 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 shall be also capable of being cleared of ice accumulation. See DNV-CG-0308 Sec.3 [1]
Specific functional requirements		*Prescriptive requirements*
.2 Intended to operate in low air temperature	.1 All components of fire safety systems and appliances shall be designed to ensure availability and effectiveness under the Baltic service temperature.	.1 Portable and semi-portable extinguishers shall be located in positions protected from freezing temperatures, as far as practical. Locations subject to freezing shall be provided with extinguishers capable of operation under BST.
	.2 Materials used in exposed fire safety systems shall be suitable for operation at the Baltic service temperature.	.1 Material of exposed fire safety system shall be documented to be operable at BST.

7 Life-saving appliances and arrangements

7.1 Escape

Life-saving appliances and arrangements requirements, listed in Table 10, shall be complied with, as applicable.

Table 10 Requirements for escape life-saving appliances and arrangements

Functional requirements	*Prescriptive requirements*

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.1 Exposed escape routes shall remain accessible and safe, taking into consideration the potential icing of structures and snow accumulation.	.1 For vessels exposed to ice accretion, means shall be provided to remove or prevent ice and snow accretion from escape routes, muster stations, embarkation areas, survival craft, its launching appliances and access to survival craft. See DNV-CG-0308 Sec.3 [1].
	.2 Exposed escape routes shall be arranged so as not to hinder passage by persons wearing suitable cold climate clothing: — personnel shall be able to move safely up and down the accommodation ladder and gangway in the design environmental conditions, including freezing precipitation (snow and ice) — all emergency access (e.g. escape routes, muster areas, embarkation areas to survival craft), shall be provided anti-icing protection.

7.2 Survival

Survival requirements, listed in Table 11, shall be complied with, as applicable.

Table 11 Requirements for survival life-saving appliances and arrangements

General functional requirements	*Prescriptive rules*
.1 Adequate thermal protection shall be provided for all persons on board, taking into account the intended voyage, the anticipated weather conditions (cold and wind), and the potential for immersion in northern Baltic waters, where applicable.	.1 For passenger vessels, a proper sized immersion suit or a thermal protective aid shall be provided for each person on board.
	.2 Where immersion suits are required, they shall be of the insulated type.
	.3 Lifeboat shall be of partially or totally enclosed type.
Specific functional requirements	*Prescriptive requirements*
.2 Intended to operate in low air temperatures	.1 — lifeboats and their securing and launching systems shall be tested to operate in ambient air temperatures down to BST — lifeboat engines shall be fitted with a heater — lifeboat engine fuel oil shall be suitable for operation with ambient air temperatures down to BST without waxing or gelling — life rafts and their release mechanism shall remain operational in ambient air temperatures down to BST.
	.2 — for Baltic service temperatures (BST) colder than -23°C, i.e. design temperatures colder than t_D = -10°C, steel grade material for lifeboat and rescue boat davits fabricated from plated structure, shall be according to Sec.6 [4], considering class II. — for equipment or parts of equipment fabricated from forged or cast material, the impact test temperature and energy shall fulfil the requirements in Sec.6 [6.2] or Sec.6 [6.3].

8 Safety of navigation

Navigation requirements, listed in Table 12, shall be complied with, as applicable.

Table 12 Requirements for safety of navigation

General functional requirements	*Prescriptive requirements*
.1 Navigational equipment functionality: The navigational equipment and systems shall be designed, constructed, and installed to retain their functionality under the expected environmental conditions in the area of operation.	.1 vessels shall comply with SOLAS regulation V/22.1.9.4, irrespective of the date of construction and the size and, depending on the bridge configuration, a clear view astern.
	.2 Means to prevent the accumulation of ice on antennas required for navigation and communication shall be provided. See DNV-CG-0308 Sec.3 [1]
.2 Vessels shall have the ability to visually detect ice when operating in darkness.	.1 Vessels shall be equipped with two remotely rotatable, narrow-beam search lights controllable from the bridge to provide lighting over an arc of 360 degrees, or other means to visually detect. Ice searchlights shall be fitted with the following: — means for securing the starter function at low temperatures — anti-condensation function of the searchlight housing — anti-icing protection of the rotation mechanism, if the light is rotatable. The luminous intensity of the focused position of the ice searchlight shall be sufficient to provide an illumination of 5.6 lux at a distance of at least 1000 meters from the foremost part of the vessel or twice the vessels's stop distance at full speed, whichever is greater, with an atmospheric transmission of 0.8.
Specific functional requirements	*Prescriptive requirements*
.3 Intended to operate in low air temperatures: The navigational equipment and systems shall be designed, constructed, and installed to retain their functionality under the expected environmental conditions in the area of operation.	.1 Relevant navigation equipment located outside or in unheated compartments, if not certified for BST, shall be tested and documented to be functional in an ambient air temperature down to BST. **Guidance note 1:** As part of the testing documentation, it should be proven that the equipment is tested as per IEC 60945 clause 8.4.2, with respect to BST, and carried out by an accredited laboratory, see MSC.1/Circ.1612 Module A.1. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e--- **Guidance note 2:** See [2.3] for alternative solution. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

9 Communication

9.1 Vessel communication

Vessel communication requirements, listed in Table 13, shall be complied with, as applicable.

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Table 13 Requirements for vessel communication

General functional requirements	*Prescriptive requirements*	
.1 Vessel communication equipment shall be designed, and installed to retain their functionality under the expected environmental conditions in the area of operation.	.1 — external antennae used for mandatory ship-to ship and/or ship-to-shore communication shall be provided with anti-icing and/or de-icing systems **Guidance note:** Antennae may be heated or placed in heated domes to protect them from snow and ice accumulation. Whip type antennae do normally not require heating arrangements. Where relevant equipment requires antennae that cannot be heated, provision shall be made for easy access for manual de-icing. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---	
Specific functional requirements	*Prescriptive requirements*	
.2 Intended to operate in low air temperatures:	.1 Communication equipment on board shall have the capabilities for ship-to-ship and ship-to-shore communication, taking into account the limitations of communications systems in the anticipated low air temperature	.1 Relevant communication equipment located outside or in unheated compartments, if not certified for BST, shall be tested and documented to be functional in an ambient air temperature down to BST. **Guidance note 1:** As part of the testing documentation, it should be proven that the equipment is tested as per IEC 60945 clause 8.4.2, with respect to BST, and carried out by an accredited laboratory, see MSC.1/Circ.1612 Module A.1 ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e--- **Guidance note 2:** See [2.3] for alternative solution. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
	.2 All mandatory two-way portable radio communication equipment shall be operable at the Baltic service temperature.	.1 Exposed portable radio communication equipment shall be tested and documented to be functional in an ambient air temperature down to BST. For testing and alternative solutions, see items .2.1.1 in this table.

9.2 Survival craft and rescue boat communication capabilities

Survival craft and rescue boat communication requirements, listed in Table 14, shall be complied with, as applicable.

Table 14 Requirements for survival craft and rescue boat communications capabilities

Specific functional requirements	*Prescriptive rules*
.1 Intended to operate in low air temperatures: For vessels intended to operate in low air temperature, all survival craft shall maintain capability for transmitting signals for location and for communication.	.1 Exposed survival craft and rescue boat communication equipment, if not certified for BST, shall be tested and documented to be functional in an ambient air temperature down to BST. **Guidance note 1:** As part of the testing documentation, it should be proven that the equipment is tested as per IEC 60945 clause 8.4.2, with respect to BST, and carried out by an accredited laboratory, see MSC.1/Circ.1612 Module A.1 ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e--- **Guidance note 2:** See DNV-CG-0308 Sec.5 [10] for alternative solution. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

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SECTION 5 OPERATIONS IN POLAR WATERS - POLAR

1 General

1.1 Introduction

The International Code for Ships Operating in Polar Waters (IMO Polar Code), which entered into force on 1. January 2017, provides for safe operation and protection of environment in polar waters by addressing risks and hazards identified for the area and period of operation, and not adequately mitigated by other instruments of the organization. The code includes a set of ship specific requirements and operational regulations to mitigate the additional risks that may be experienced in polar waters.

1.2 Objective

1.2.1 The additional class notation **Polar** establishes requirements to cover all IMO Polar Code design specific regulations.

1.2.2 The additional class notation **Polar** represents the Society's interpretations of the design specific regulations in the IMO Polar Code that shall be complied with to achieve the Polar ship certificate.

1.2.3 The additional class notation **Polar** can be assigned to the design as a stand-alone notation without a Polar ship certificate, indicating full readiness of the design for a possible upgrade for operation within polar waters.

1.3 Scope

1.3.1 The additional class notation **Polar** is part of the process of preparing the design for compliance with IMO Polar Code, as illustrated by Figure 1, and thus acting as Polar ship certificate ready for vessel intended to operate in polar waters (IMO Polar Code).

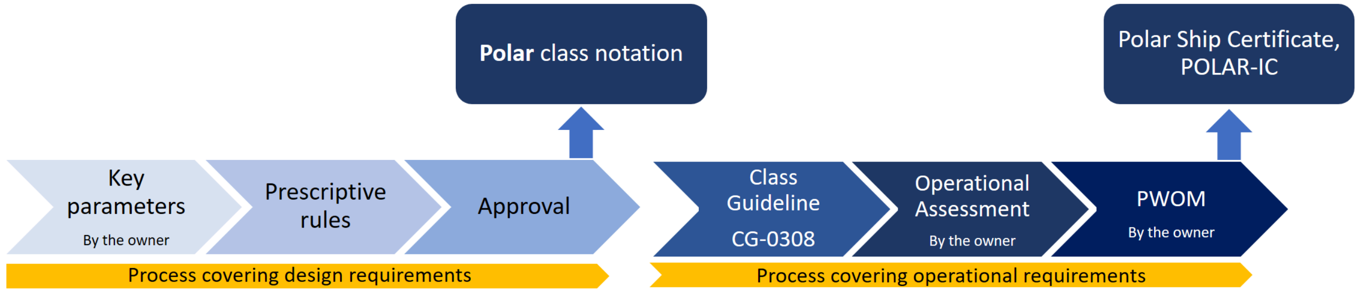

Figure 1 Process to Polar ship certificate, POLAR-IC

1.3.2 The class notation **Polar** covers all the design specific technical and functional requirements enforced by the IMO Polar Code.

1.3.3 Operational requirements, including instructions and procedures for safe operation in polar waters, are not part of the requirements under **Polar** class notation but covered in DNV-CG-0308 for development of an operational assessment and polar water operational manual for the purpose of acquiring the polar ship certificate **POLAR-IC**, see Figure 1.

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1.4 Application

1.4.1 The additional class notation **Polar** applies to ships intended for operations in polar waters as defined in Figure 2 and Figure 3.

1.4.2 For ships in operation and constructed before 1 January 2017, the following requirements are not applicable:

- Table 10 item .2
- Table 15 item .2
- Table 17 item .4.1 and Table 18 item .9.1.

1.5 Structure of the rules

1.5.1 The rules in this section consist of functional and prescriptive requirements.

The functional requirements provide the rationale and intent behind each prescriptive requirement.

The prescriptive requirements provide a set of generally acceptable solutions to meet the corresponding functional requirements.

1.5.2 All general and specific requirements applicable for qualifier **C**, are automatically applicable for qualifiers **B** and **A**, given that the same set of identified hazards is applicable.

1.6 Class notations

1.6.1 Vessels built in compliance with the requirements as specified in this section may be assigned the additional class notation **Polar** with associated qualifiers listed in Sec.1 Table 1.

1.6.2 Polar service temperature (PST) shall be set at least 10°C below the lowest mean daily low temperature (LMDLT) for the intended area and season of operation in polar waters. The qualifier **PST** shall reflect the short term ambient temperature by which the systems and equipment required by the IMO Polar Code shall be fully functional.

Guidance note:

Examples of the class notation:

- **POLAR(B)**
- **POLAR(C, -25°C)**
- **POLAR(A, -30°C)**.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

1.7 Required additional class notations

The additional class notation **DAT** is mandatory for polar service temperatures **PST** colder than -23°C.

The associated design temperature t_D, as defined in Sec.1 Table 7, shall be equal to or colder than LMDLT +3°C.

1.8 Definitions and abbreviations

1.8.1 Terminology and definitions

For general definitions, see Sec.1 [9].

In addition, Table 1 lists definitions of terms used in this section.

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Table 1 Definition of terms

Term	*Definition*
medium first-year ice	first-year ice of 70 cm to 120 cm thickness, see WMO
thin first-year ice	first-year ice of 30 cm to 70 cm thickness, see WMO
grey ice	young ice of 10 cm to 15 cm thickness that is less elastic than Nilas It often breaks from swells.
grey white	young ice of 15 cm to 30 cm thickness
ice free waters	no ice present If ice of any kind is present, this term shall not be used, see WMO.
open waters	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, see WMO.
ice of land origin	ice formed on land or in an ice shelf, found floating in water, see WMO
old ice	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 see WMO.
sea ice	any form of ice found at sea which has originated from the freezing of seawater, see WMO
escort	any ship with superior ice capability in transit with another ship
escorted operation	any operation in which a ship's movement is facilitated through the intervention of an escort
habitable environment	ventilated environment that will protect against hypothermia
maximum expected time of rescue	time adopted for the design of equipment and system that provide survival support. It shall never be less than 5 days
machinery installations	equipment and machinery and its associated piping and cabling, which is necessary for the safe operation of the ship
mean daily low temperature	mean value of the daily low temperature for each day of the year over a minimum 10 years period A data set acceptable to the administration may be used if 10 years of data is not available.
polar service temperature	temperature specified for a ship intended to operate in low air temperature, which shall be set at least 10 °C below the lowest MDLT (LMDLT) for the intended area and season of operation in polar waters
ship intended to operate in low air temperature	ship which is intended to undertake voyages to or through areas where the polar service temperature (PST) is colder than -20^{o}C
high latitude	latitudes over 80 degrees
upper ice waterline	as defined in Sec.3 and Sec.7

Table 2 lists abbreviations used in this section.

Table 2 Abbreviations

Abbreviation	*Description*
GSE	group survival equipment, see DNV-CG-0308 Sec.5 Table 9

Abbreviation	*Description*
LSA	life saving appliances
LMDLT	lowest mean daily low temperature
OA	operational assessment, see DNV-CG-0308 Sec.4
PSE	personal survival equipment, see DNV-CG-0308 Sec.5 Table 9
PST	polar service temperature
PWOM	polar water operational manual, see DNV-CG-0308 Sec.5
UWL	upper ice waterline
WMO	World Meteorological Organization

1.8.2 Figure 2 and Figure 3 represent the Antarctic area and Arctic waters, as defined in SOLAS regulations XIV/1.2 and XIV/1.3, respectively, and MARPOL Annex I, regulations 1.11.7 and 46.2m Annex II, regulations 13.8.1 and 21.2, Annex IV, regulations 17.2 and 17.3, and Annex V, regulations 1.14.7 and 13.2.

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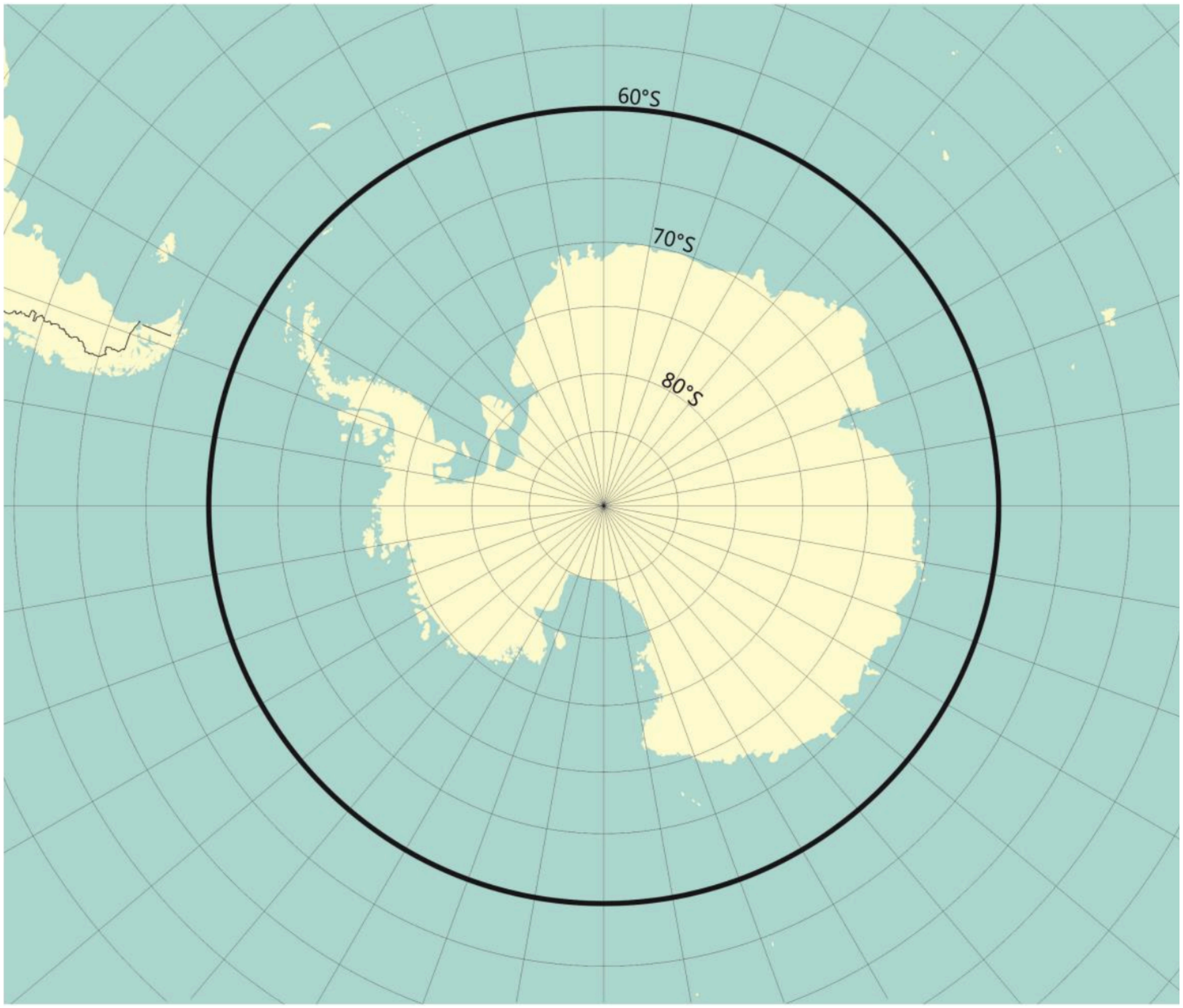

Figure 2 Maximum extent of Antarctic area application

Figure 3 Maximum extent of Arctic waters application

1.8.3 Other references

Documents referenced in this section are listed in Table 3 and Table 4.

Table 3 DNV references

Document code	*Title*
DNV-CG-0308	IMO Polar Code

Table 4 Other references

Document code	*Title*
WOM	Sea Ice Nomenclature
STCW	The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, as amended
SOLAS regulation XIV	Measure for safety of ships operating in polar water

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Document code	*Title*
SOLAS regulations II-1	Subdivision and stability
SOLAS regulations IV	Radiocommunication
SOLAS regulations V	Safety of navigation
MARPOL Annex I	Prevention of pollution by oil
MARPOL Annex II	Control of pollution by noxious liquid substances
MARPOL Annex IV	Prevention of pollution by sewage from ships
MARPOL Annex V	Prevention of pollution by garbage from ships
LSA Code	International Life-saving appliance Code (MSC.48(66))
MSC.1/Circ. 1612 Module A.1	Guidance for navigation and communication equipment intended for use on ships operating in polar waters
IEC 60945	Maritime navigation and radiocommunication equipment and systems-General requirements-Methods of testing and required test results

2 Documentation requirements

2.1 General

Documentation shall be submitted as required by Table 5.

Table 5 Documentation requirements

Object	*Documentation type*	*Additional description*	*Info*	*Qualifier*
Winterization plan	Z030 - Winterization arrangement plan	Including anti-icing, anti-freezing and de-icing systems. See also [2.2]	FI	**A** **B** **C** **PST**
Heat balance calculation	Z265 - Calculation report	For anti-freezing systems used in fresh water and ballast water tanks, indicating heating capacities required and provided.	FI	**PST**
Navigation	Z030 - Navigation bridge arrangement plan	Including ice searchlights and their total area of coverage (360°).	AP	**A** **B** **C**
Stability	B050 - Preliminary stability manual	Including loading conditions with ice accretion.	AP	**A** **B** **C**

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Object	*Documentation type*	*Additional description*	*Info*	*Qualifier*
	B120 - Final stability manual	Including loading conditions with ice accretion.	AP	**A** **B** **C**
	B070 - Preliminary damage stability calculation	Including loading conditions with ice accretion.	AP	**A** **B** **C**
		Ice-related damages.	AP	**A** **B**
	B130 - Final damage stability calculation	Including loading conditions with ice accretion.	AP	**A** **B** **C**
		Ice-related damages.	AP	**A** **B**
Design arrangement and parameters	Z010 - General arrangement plan	General arrangement should include key parameters listed in [3.1].	FI	**A** **B** **C** **PST**
Fire and safety	G040 - Fire control plan		FI	**A** **B** **C** **PST**
	G050 - Safety plan	Arrangement drawing showing escape routes, muster stations, embarkation areas, LSA, PSE/GSE, survival crafts with launching appliances and access, etc.	FI	**A** **B** **C** **PST**
AP = for approval, FI = for information				

For general requirements to documentation, including definition of the info codes, see DNV-CG-0550 Sec.6.

For a definition of the documentation types, see DNV-CG-0550 Sec.5.

2.2 Winterization plan

2.2.1 General

A winterization plan is requested for information for class notation **Polar** and shall include descriptions and arrangements of all the winterization measures for protecting the relevant exposed structures, systems, and equipment.

2.2.2 Expected content in winterization plans

The plan shall include descriptions and relevant arrangements of the following systems or functions when such systems or functions are available:

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- anti-icing systems
- anti-freezing systems
- de-icing systems
- type of hydraulic fluid and/or measures for heating of hydraulic systems.

For more information regarding anti-icing, anti-freezing, and de-icing systems, see DNV-CG-0308 Sec.3.

2.2.3 Additional content for ship intended to operate in low air temperature

For vessels intended to operate in low air temperatures, the winterization plan shall when applicable include:

- special procedures intended to compensate for additional testing to extend the coverage of a TAC
- procedures used as alternative to systems used for anti-icing and/or anti-freezing.

Guidance note:

To acquire a Polar ship certificate, acceptance by the flag administration for application of low air temperature, defined as PST, will be required.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3 Design environmental conditions

3.1 Key parameters

The requirements in this section are based on the anticipated range of operation and environmental conditions specified for the vessel, such as:

- operation in low air temperature: the anticipated lowest mean daily low temperature (LMDLT) in the area and during the period of operation shall be specified
- operation in ice: ice conditions shall be specified as listed in Table 6
- operation in high latitudes
- potential for abandonment onto ice or land.

3.2 Ice condition

Typical environmental conditions and appropriate class notations for qualifiers **A**, **B**, and **C** are listed in Table 6.

Table 6 Typical design environmental conditions for POLAR

Qualifier	*Ice conditions*	*Design ice condition*	*Ice class*	*Ice concentration*	*Decision support system*
A	Other ice conditions 1)	Up to heavy multi year ice	**PC(2)** and **PC(1)** 2)	$\geq 1/10$	Polaris or equivalent required
		Up to light multi year ice, less than 2.5 m thick	**PC(3)** 2)		
		Up to second year ice	**PC(4)** 2)		
		Up to thick first year ice	**PC(5)** 2)		

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Qualifier	*Ice conditions*	*Design ice condition*	*Ice class*	*Ice concentration*	*Decision support system*
B	Other ice conditions1)	Up to medium first year ice which may include old ice conditions	**PC(6)**2)		
		Up to medium first year ice less than 1 m thick which may include old ice conditions	**PC(7)**2)		
C	Other ice conditions less severe than those included in categories **A** and **B**.1)	Up to medium first year ice less than 1 m thick	**Ice(1A*)**2)		
		Up to thin first year ice 2nd stage	**Ice(1A)**2)		
		Up to thin first year ice 1st stage	**Ice(1B)**2)		
		Up to grey white ice	**Ice(1C)**2)		
		Grey ice			
		New ice			
	Open waters	Large area of freely navigable water in which sea ice is present	**Ice-C** and none2)	$< 1/10$	No decision support required
	Ice free	No ice		0	

1) For ice classed vessels planning to operate in other ice conditions, proper crew training according to DNV-CG-0308 Sec.6 shall be in place together with the use of an appropriate decision support system, such as Polaris, the Canada's Arctic Ice Regime Shipping System, and/or the Russian Ice Certificate as described in the rules of navigation on the water area of the Northern Sea Route.

2) Ice classed vessels may be permitted to operate in other ice conditions higher than its full ice capacity provided the risk index outcome from the decision support system used onboard is found to be positive.

4 Ship structure

Ship structure requirements, listed in Table 7 and Table 8, shall be complied with, as applicable.

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Table 7 Polar(C) requirements for ship structure

General functional requirements	*Prescriptive requirements*
.1 Scantlings of ice strengthened category C ships shall be approved by the administration, or a recognized organization accepted by it, taking into account acceptable standards adequate for the ice types and concentrations encountered in the area of operation. (IMO Polar Code Pt. I-A Ch.3 Reg. 3.3.2.3)	.1 Vessels built in compliance with the requirements in this section and that are assigned an ice class notation **Ice(1C)** to **Ice(1A*)** (see Sec.3), may be assigned the class notation **Polar(C, PST)** or **Polar(C)**, as applicable.
.2 Category C ship need not to be ice strengthened if, in the opinion of the administration, the ship's structure is adequate for its intended operation. (IMO Polar Code Pt. I-A Ch.3 Reg. 3.3.2.4)	.1 Vessels built in compliance with the requirements in this section and that are assigned a class notation **Ice-C** , see Sec.2, or no ice class notation, may be assigned the class notation **Polar(C, PST)** or **Polar(C)**, as applicable.

Specific functional requirements	*Prescriptive requirements*
.3 Intended to operate in low air temperature: Materials used shall be suitable for operation at the ships polar service temperature. (IMO Polar Code Pt. I-A Ch.3 Req.3.2.1)	.1 For ships intended to operate in areas with low air temperatures, i.e. LMDLT < -13°C and PST < -23°C, material of hull exposed structure shall be according to Sec.6 [1.4.3].

Table 8 Polar(A), Polar(B) requirements for ship structure

General functional requirements	*Prescriptive requirements*
.4 Scantlings of category A ships shall be approved by the administration, or a recognized organization accepted by it, taking into account standards acceptable to the organization or other standards offering an equivalent level of safety. (IMO Polar Code Pt. I-A Ch.3 Reg. 3.3.2.1)	.1 Vessels built in compliance with the requirements in this section and that are assigned an ice class notation **PC(1)** to **PC(5)**, see Sec.7, may be assigned the class notation **Polar(A, PST)** or **Polar(A)**, as applicable.
.5 Scantlings of category B ships shall be approved by the administration, or a recognized organization accepted by it, taking into account standards acceptable to the organization or other standards offering an equivalent level of safety. (IMO Polar Code Pt. I-A Ch.3 Reg. 3.3.2.2)	.1 Vessels built in compliance with the requirements in this section and that are assigned an ice class notation **PC(6)** and **PC(7)**, see Sec.7, may be assigned the class notation **Polar(B, PST)** or **Polar(B)**, as applicable.
.6 MARPOL (IMO Polar Code Pt. II-A Ch.1 Req. 1.2)	.1 For ships with an aggregate oil fuel capacity of less than 600 m^3, all oil fuel tanks shall be separated from the outer shell by a distance of not less than 0.76 m. This provision does not apply to small oil fuel tanks with a maximum individual capacity not greater than 30 m^3.
	.2 For ships other than oil tankers, all cargo tanks constructed and utilized to carry oil shall be separated from the outer shell by a distance of not less than 0.76 m.

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	.3 Oil tankers of less than 5,000 tonnes deadweight, the entire cargo tank length shall be protected.	.1 Double bottom tanks or spaces complying with the applicable requirements of regulation 19.6.1 of MARPOL Annex I.
		.2 Wing tanks or spaces arranged in accordance with regulation 19.3.1 of MARPOL Annex I and complying with the applicable requirements for distance referred to in regulation 19.6.2 of MARPOL Annex I.
	.4 All oil residue (sludge) tanks and oily bilge water holding tanks shall be separated from the outer shell by a distance of not less than 0.76 m. This provision does not apply to small tanks with a maximum individual capacity not greater than 30 m^3.	

5 Subdivision and stability

Subdivision and stability requirements, listed in Table 9 and Table 10, shall be complied with, as applicable.

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Table 9 Polar(A), Polar(B), and Polar(C) requirements for subdivision and stability

General functional requirements		*Prescriptive requirements*
.1 Stability in intact and damage conditions	.1 For ships operating in areas and during periods where ice accretion is likely to occur, the following icing allowance shall be made in the stability calculations. (IMO Polar Code Pt. I-A Ch.4 Reg. 4.3.1.1)	.1 For ships with class notation **Polar(A)**, **Polar(B)** and **Polar(C)** the following icing allowance shall be made in the stability calculations: — 30 kg/m^2 on exposed weather decks and gangways. — 7.5 kg/m^2 for the projected lateral area of each side of the ship above the water plane. — 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 shall be computed by increasing the total projected area of continuous surfaces by: — 5% of the total projected area, including both sides of the ship. — 10% of the static vertical moments of this area. **Guidance note:** For ships with open deck areas which are protected from sea spray by a deck or other structure above, the area of such may be excluded from the calculations. Examples: balconies, area below helideck. In general, it is sufficient to include the exposed horizontal projected areas. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
		.2 The presented loading conditions with icing allowances shall include the most critical loading conditions (departure-arrival) with respect to stability.

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General functional requirements		*Prescriptive requirements*
	.2 Ships operating in areas and during periods where ice accretion is likely to occur shall be equipped with such means for removing ice as the administration 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. (IMO Polar Code Pt. I-A Ch.4 Reg. 4.3.1.2)	.1 See DNV-CG-0308 Sec.3 [1.4].

Table 10 Polar(A), Polar(B) requirements for subdivision and stability

General functional requirements		*Prescriptive requirements*
.2 Stability in damage conditions: Ships shall be able to withstand flooding resulting from hull penetration due to ice impact. The residual stability following ice damage shall be such that the factor si, as defined in SOLAS regulations II-1/7-2.2 and II-1/7-2.3, is equal to one for all loading conditions used to calculate the attained subdivision index in SOLAS regulation II-1/7 However, for cargo ships that comply with subdivision and damage stability regulations in another instrument developed by the organization, as provided by SOLAS regulation II-1/4.1, the residual stability criteria of that instrument shall be met for each loading condition. (IMO Polar Code Pt. I-A Ch.4 Reg. 4.3.2.1)		.1 The factor S_{mom} of SOLAS Reg. II-1/7-2.4 is not required to be applied when calculating the residual stability after ice damage. The draught and trim of the loading conditions to be used for calculation of ice damage shall be taken from the loading conditions used to calculate the attained subdivision index in SOLAS Reg. II-1/7. GM values used to define the limit curve may be selected to obtain S_i=1.
		.2 In general, the regulatory loading conditions that include icing allowance as specified in item 1.1.1 in Table 9, need not comply with the damage stability requirements of the Polar code. These loading conditions should, however, comply with any other damage stability instrument as applicable to the ship. Alternatively, for such damage stability assessment, the loading conditions need not consider the icing allowance in Table 9 item 1.1.1 if this is not realistic for the intended operation.
.3 The ice damage extents to be assumed when demonstrating compliance with damage stability calculations shall be such that: (IMO Polar Code Pt. I-A Ch.4 Reg. 4.3.2.2)	.1 The longitudinal extent is 4.5% of the upper ice waterline length if centred forward of the maximum breadth on the upper ice waterline, and 1.5% of upper ice waterline length otherwise, and shall be assumed at any longitudinal position along the ship's length.	.1 The full extent of the damages shall be assumed to be confined within any vertical position between the keel and 120% of the UIWL draught. See DNV-CG-0308 Sec.5 [4].

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	.2 The transverse penetration extent is 760 mm, measured normal to the shell over the full extent of the damage.	
	.3 The vertical extent is the lesser of 20% of the upper ice waterline draught or the longitudinal extent, and shall be assumed at any vertical position between the keel and 120% of the upper ice waterline draught.	

6 Watertight and weathertight integrity

Watertight and weathertight integrity requirements, listed in Table 11, shall be complied with, as applicable.

Table 11 Polar(A), Polar(B), and Polar(C) requirements for watertight and weathertight integrity

General functional requirements	*Prescriptive requirements*
.1 For ships operating in areas and during periods where ice accretion is likely to occur, means shall be provided to remove or prevent ice and snow accretion around hatches and doors. (IMO Polar Code Pt. I-A Ch.5 Reg. 5.3.1)	.1 All doors and hatches along the defined escape routes shall be provided with anti-icing measures, see DNV-CG-0308 Sec.5 [5].

7 Machinery installations

Machinery installations requirements, listed in Table 12 and Table 13, shall be complied with, as applicable.

Table 12 Polar(A), Polar(B), and Polar(C) requirements for machinery installations

General functional requirements	*Prescriptive requirements*
.1 Machinery installations and associated equipment shall be fully functional under and shall be protected against ice accretion and/or snow accumulation. (IMO Polar Code Pt. I-A Ch.6 Reg. 6.3.1.1)	.1 See DNV-CG-0308 Sec.5 [5].
	.2 Machinery shall be protected from the harmful effects of ingestion or accumulation of ice or snow. Where continuous operation is necessary, the air intakes for machinery shall be located on both sides of the ship. Alternatively, means shall be provided to purge the system of accumulated icing and/or snow.
.2 Means shall 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. (IMO Polar Code Pt. I-A Ch.6 Reg. 6.3.2.2)	.1 If combustion air is taken from outside engine room, the engine manufacture temperature limitations on combustion air shall not be warmer than PST. Alternatively, means for air intake heating shall be provided.

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.3 Machinery installations and associated equipment shall be protected against freezing and increased viscosity of liquids. (IMO Polar Code Pt. I-A Ch.6 Reg. 6.3.1.2)	.1 Hydraulic fluid shall either be of a type that maintains an acceptable viscosity in temperatures down to PST, or the hydraulic system shall have heating/circulation arrangements to keep fluids at an appropriate temperature. Type of hydraulic fluid and /or measures for heating of hydraulic system shall be documented in the winterization plan. See DNV-CG-0308 Sec.5 [6].

Specific functional requirements		
.4 Intended to operate in low air temperature.	.1 Exposed machinery and electrical installation and appliances shall function at PST. (IMO Polar Code Pt. I-A Ch.6 Reg. 6.3.2.1)	
	.2 Materials of exposed machinery and foundations shall be approved by the administration, or a recognized organization accepted by it, taking into account standards acceptable to the organization or other standards offering an equivalent level of safety based on the PST. (IMO Polar Code Pt. I-A Ch.6 Reg. 6.3.2.3)	.1 For polar service temperatures colder than -23°C, i.e. design temperatures colder than t_d = -10°C, steel grades material for equipment or parts of equipment fabricated from plated structure, shall be selected as follows, according to Sec.6 [4]. i) Class II — anchoring and mooring equipment — emergency towing arrangement (tankers) ii) Class I. — cargo securing devices — mast with derrick having load greater than 3 tons — others not specified as class II , unless upgraded or downgraded on a case-by-case basis due to special considerations of loading rate, level and type of stress, stress concentrations and load transfer points and/or consequences of failure. Foundation and main supporting structure for heavy machinery are covered by [1.7].

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	.3 Ballast and fresh water tanks shall be fully functional. (IMO Polar Code Pt. I-A Ch.6 Reg. 6.3.1)	.1 For ballast and freshwater tanks, partially or entirely exposed, heat balance calculation shall be carried out, unless recognized anti-freezing measures, as listed in DNV-CG-0308 Sec.3 [2], are implemented. **Guidance note:** If the heat balance calculation shows a significant loss of heat in the tank, additional heat sources such as heating coils should be provided. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
.5 Open waters or other ice conditions less severe than these included in category A and B.	.1 Seawater supplies for machinery systems shall be designed to prevent ingestion of ice, or otherwise arranged to ensure functionality. (IMO Polar Code Pt. I-A Ch.6 Reg. 6.3.1.3)	.1 The sea cooling water inlet for main and auxiliary engines shall be arranged so that blockage of strums and strainers by ice is prevented: — a ship with an ice class notation shall comply with the requirements in either Sec.2 [3.3], Sec.3 [16.2].

Table 13 Polar(A), Polar(B) requirements for machinery installations

Specific functional requirements	
.6 Other ice condition Seawater supplies for machinery systems shall be designed to prevent ingestion of ice, or otherwise arranged to ensure functionality. (IMO Polar Code Pt. I-A Ch.6 Reg. 6.3.1.3)	.1 The sea cooling water inlet and discharge for main and auxiliary engines shall be arranged so that blockage of strums and strainers by ice is prevented: — a ship with an ice class notation shall comply with the requirements in Sec.7 [18].

8 Fire safety protection

Fire safety requirements, listed in Table 14, shall be complied with, as applicable.

Table 14 Polar(A), Polar(B), and Polar(C) requirements for fire safety and protection

General functional requirements	*Prescriptive requirements*
.1 Isolation and pressure/vacuum valves in exposed locations shall be protected from ice accretion and remain accessible at all time. (IMO Polar Code Pt. I-A Ch.7 Reg. 7.3.1.1)	.1 See DNV-CG-0308 Sec.5 [7].

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.2 Local equipment and machinery controls shall be arranged so as to avoid freezing, snow accumulation and ice accretion and their location to remain accessible at all time. (IMO Polar Code Pt. I-A Ch.7 Reg. 7.2.1.2)	.1 Fire pumps including emergency fire pumps, water mist and water spray pumps shall be located in compartments maintained above freezing.
	.2 The fire main shall be arranged so that exposed sections can be isolated and means of draining of exposed sections shall be provided. Fire hoses and nozzles are not required to be connected to the fire main at all times.
	.3 Firefighter's outfits shall be stored in warm locations on the ship.

Specific functional requirements		
.3 Intended to operate in low air temperature	.1 All components of fire safety systems and appliances shall be designed to ensure availability and effectiveness under the polar service temperature. (IMO Polar Code Pt. I-A Ch.7 Reg. 7.2.2.1)	.1 Portable and semi-portable extinguishers shall be located in positions protected from freezing temperatures, as far as practical. Locations subject to freezing shall be provided with extinguishers capable of operation under PST.
	.2 Materials used in exposed fire safety systems shall be suitable for operation at the polar service temperature. (IMO Polar Code Pt. I-A Ch.7 Reg. 7.2.2.2)	.1 Materials of exposed fire safety systems shall be approved by the administration, or a recognized organization accepted by it, taking into account standards acceptable to the organization or other standards offering an equivalent level of safety based on PST.
.4 Other ice conditions Local equipment and machinery controls shall provide functionality when navigating in waters with other ice conditions as defined in Table 6.		.1 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 shall be also capable of being cleared of ice accumulation. (IMO Polar Code Pt. I-A Ch.7 Reg. 7.3.2.4)

9 Life-saving appliances and arrangements

9.1 Escape

Escape requirements, listed in Table 15, shall be complied with, as applicable.

Table 15 Polar(A), Polar(B), and Polar(C) requirements for life-saving appliances and arrangements

General functional requirements	*Prescriptive requirements*

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.1 For ships exposed to ice accretion, means shall be provided to remove or prevent ice and snow accretion from escape routes, muster stations, embarkation areas, survival craft, its launching appliances and access to survival craft. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.3.1.1)	.1 See DNV-CG-0308 Sec.1 [3].
.2 Exposed escape routes shall be arranged so as not to hinder passage by persons wearing suitable polar clothing. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.3.1.2)	.1 Exposed escape exits and doors shall be provided with anti-icing protection. See DNV-CG-0308 Sec.3 [1]. .2 Exposed escape ways shall be provided with anti-icing protection securing a minimum ice free width of 700 mm. DNV-CG-0308 Sec.3 [1].

9.2 Survival

Survival requirements, listed in Table 16, shall be complied with, as applicable.

Table 16 Polar(A), Polar(B), and Polar(C) requirements for life-saving appliances and arrangements

General functional requirements	*Prescriptive requirements*
.1 Adequate thermal protection shall be provided for all persons on board, taking into account the intended voyage, the anticipated weather conditions (cold and wind), and the potential for immersion in polar water, where applicable. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.2.3.1)	.1 For passenger ships, a proper sized immersion suit or a thermal protective aid shall be provided for each person on board.
	.2 Crew responsible for handling survival crafts shall have immersion suits.
	.3 Where immersion suits are required, they shall be of the insulated type. **Guidance note:** See IMO LSA Code 2.3.2 for thermal performance requirements for immersion suits. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
.2 Taking into account the presence of any hazards identified, resources shall be provided to support survival following abandoning ship, whether to the water, to ice or to land, for the maximum expected time of rescue. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.2.3.3)	.1 No lifeboat shall be of any type other than partially or totally enclosed type.
	.2 Lifeboats and rescue boats shall maintain positive metacentric height (GM) when loaded as required by paragraph 4.4.5.1 of the LSA Code and with an additional ice load of 30 kg/m^2 on exposed horizontal surfaces and 7.5 kg/m^2 for the projected lateral area of each side of the lifeboat. (MSC.1/Circ.1614, 26 June 2019)

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.3 Personal survival equipment in combination with life-saving appliances or group survival equipment that provide sufficient thermal insulation to maintain the core temperature of persons. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.3.3.3.2)	.1 Minimum requirement for personal survival equipment (PSE) shall be: — protective polar clothing (hat, gloves, socks, face and neck protection) — skin protection cream — thermal protective aid — sunglasses — drinking mug — emergency food — weatherproof carrying bags. The PSE shall be packet in individual bags to be stowed in easily accessible locations. **Guidance note:** PSE bags are recommended to be located in the same location as life jackets. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
.4 Personal survival equipment that provide sufficient protection to prevent frostbite of all extremities. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.3.3.3.3)	

Specific functional requirements		
.5 Extended periods of darkness:	.1 Searchlights suitable for continuous use to facilitate identification of ice shall be provided for each lifeboat. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.3.3.2)	.1 Lifeboat searchlight shall have source of power with capacity enough for continuous use in ice infested waters for the maximum expected time of rescue. (MSC.1/Circ.1614, 26 June 2019)
.6 High latitude:	.1 Taking into account the presence of any hazards identified, resources shall be provided to support survival following abandoning ship, whether to the water, to ice or to land, for the maximum expected time of rescue. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.2.3.3)	.1 Lifeboats and rescue boats on ships proceeding to latitudes over 80°N shall be fitted with non-magnetic means for determining heading. It shall be possible to supply the means with power from two independent batteries. (MSC.1/Circ.1614, 26 June 2019)
.7 Potential for abandonment onto ice or land	.1 Group survival equipment shall be carried, unless an equivalent level of functionality for survival is provided by the ship's normal life-saving appliances. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.3.3.3.3.1)	.1 For abandonment on to ice and/or land, minimum group survival equipment shall contain the following for the number of persons on board: — tents or storm shelter. When abandonment onto ice, liferafts can be used as shelter as applicable — thermal protective aids or similar — foam sleeping mats — at least 2 shovels — sanitation — stove and fuel — emergency food — flashlights — waterproof and windproof matches — water containers and water purification tablets.

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		.2 When required, personal and group survival equipment sufficient for 110% of the persons on board shall be stowed in easily accessible locations, as close as practical to the muster or embarkation stations.
		.3 Unless the group survival equipment is carried in the survival craft, means shall be provided to launch the containers to water, ice or land without damage to the container or its contents. Means to launch such containers shall be independent of the ship power system. (MSC.1/Circ.1614, 26 June 2019)
	.2 Containers for group survival equipment shall be designed to be easily movable over the ice and be floatable. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.3.3.3.3.3)	.1 The container for group survival equipment when fully loaded shall have a size, shape and mass that enables it to be towed through icy water, and also allows two crew members to pull it out of water and tow it on ice or on land. (MSC.1/Circ.1614, 26 June 2019)
	.3 Group survival equipment, if carried in addition to persons, in the survival craft, the survival craft and launching appliances shall have sufficient capacity to accommodate the additional equipment. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.3.3.3.3.5)	.1 In addition to number of persons the survival craft is certified for, the survival craft shall have space and weight capacity to accommodate the GSE equipment. **Guidance note:** The seating capacity of each survival craft should be adjusted taking into account polar clothing, additional equipment including all persons carrying their intended personal survival equipment and space for occupants to stand and move in turns. (MSC.1/Circ.1614, 26 June 2019) ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

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.8 Intended to operate in low air temperature:	.1 Survival systems and equipment shall be fully operational at the polar service temperature during the maximum expected rescue time. (IMO Polar Code Pt. I-A Ch.1 Req. 1.4.3)	.1 Means shall be provided to avoid icing or dew on the windows of the lifeboat steering position, in order to maintain a proper lookout. (MSC.1/Circ.1614, 26 June 2019)
		.2 — Securing and launching systems for lifeboats and life rafts shall be documented to be operable in ambient air temperatures down to PST. — Lifeboat engines shall be fitted with a heater. — Lifeboat engine fuel oil shall be suitable for operation under ambient air temperatures down to PST without waxing or gelling.
		.3 — For polar service temperatures colder than -23°C, i.e. design temperatures colder than t_d = -10°C, steel grade material for lifeboat and rescue boat davits fabricated from plated structure, shall be according to Sec.6 [4], considering class II. — For equipment or parts of equipment fabricated from forged or cast material, the impact test temperature and energy shall fulfil the requirements in Sec.6 [6.2] or Sec.6 [6.3].
	.2 Taking into account the presence of any hazards identified, resources shall be provided to support survival following abandoning ship, whether to the water, to ice or to land, for the maximum expected time of rescue. (IMO Polar Code Pt. I-A Ch.8 Reg. 8.2.3.3)	.1 Life-saving appliances shall provide a habitable environment and shall provide protection of persons from the effects of cold and wind. see DNV-CG-0308 Sec.5 [8.3].

10 Safety of navigation

Navigation requirements, listed in Table 17 and Table 18, shall be complied with, as applicable.

Table 17 Polar(A), Polar(B), and Polar(C) requirements for safety of navigation

General functional requirements	*Prescriptive requirements*

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.1 Navigational equipment functionality: The navigational equipment and systems shall be designed, constructed, and installed to retain their functionality under the expected environmental conditions in the area of operation. (IMO Polar Code Pt. I-A Ch.9 Req. 9.2.2.1)	.1 Ships shall comply with SOLAS regulation V/22.1.9.4, irrespective of the date of construction and the size and, depending on the bridge configuration, a clear view astern.
	.2 Means to prevent the accumulation of ice on antennas required for navigation and communication shall be provided. See DNV-CG-0308 Sec.3 [1.3].
.2 Ships shall have two non-magnetic means to determine and display their heading. Both means shall be independent and shall be connected to the ship's main and emergency source of power. (IMO Polar Code Pt. I-A Ch.9 Req. 9.3.2.2.1)	.1 Acceptable two non-magnetic means to determine and display heading can be either two gyro compasses or a combination of a gyro compass with GNSS. Both means shall be independent and shall be connected to the ship's main and emergency source of power.
.3 Ships shall have means of receiving and displaying current information on ice conditions in the area of operation. (IMO Polar Code Pt. I-A Ch.9 Req. 9.2.1)	.1 Ship shall have means to receive daily updated ice information (Ice maps).

Specific functional requirements	*Prescriptive requirements*
.4 Navigational equipment functionality for ships with ice class notation: The navigational equipment and systems shall be designed, constructed, and installed to retain their functionality under the expected environmental conditions in the area of operation.	.1 Ships shall have either two independent echo-sounding devices or one echo-sounding device with two separate independent transducers. (IMO Polar Code Pt. I-A Ch.9 Req. 9.3.2.1.1)
	.2 Where equipment required by SOLAS chapter V or this chapter have sensors that project below the hull, such sensors shall be protected against ice. (IMO Polar Code Pt. I-A Ch.9 Req. 9.3.2.1.4.1)
.5 High latitude: Systems for providing reference headings and position fixing shall be suitable for the intended areas. (IMO Polar Code Pt. I-A Ch.9 Req. 9.3.2.2.2)	.1 Ships shall be fitted with at least one GNSS compass or equivalent, which shall be connected to the ship's main and emergency source of power.
.6 Darkness: Ships, with the exception of those solely operating in areas with 24 hours daylight, shall be equipped with two remotely rotatable, narrow-beam search lights controllable from the bridge to provide lighting over an arc of 360 degrees, or other means to visually detect ice. (IMO Polar Code Pt. I-A Ch.9 Req. 9.3.3.1)	.1 In addition, to function in the design environmental conditions, ice searchlights shall be fitted with the following: — means for securing the starter function at low temperatures — anti-condensation function of the searchlight housing — anti-icing protection of the rotation mechanism, if the light is rotatable. The luminous intensity of the focussed position of the ice searchlight shall be sufficient to provide an illumination of sufficient to provide an illumination of 5.6 lux at a distance of at least 1000 metres from the foremost part of the ship or twice the ship’s stop distance at ful sped, whichever is greater, with an atmospheric transmission of 0.8.

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.7 Intended to operate in low air temperature. The navigational equipment and systems shall be designed, constructed, and installed to retain their functionality under the expected polar service temperature. (IMO Polar Code Pt. I-A Ch.1 Req. 1.4.3)	.1 Relevant navigation equipment located outside or in unheated compartments, if not certified for PST, shall be tested and documented to be functional in an ambient air temperature down to PST. **Guidance note 1:** As part of the testing documentation, it should be proven that the equipment is tested as per IEC 60945 clause 8.4.2, with respect to PST, and carried out by an accredited laboratory, see MSC.1/Circ.1612 Module A.1 ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e--- **Guidance note 2:** See Sec.4 [2.3] for alternative solution. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Table 18 Polar(A), Polar(B) requirements for safety of navigation

General functional requirements	*Prescriptive requirements*
.8 Navigational equipment functionality: The navigational equipment and systems shall be designed, constructed, and installed to retain their functionality under the expected environmental conditions.	.1 The bridge wings shall be enclosed or designed to protect navigational equipment and operating personnel. (IMO Polar Code Pt. I-A Ch.9 Req. 9.3.2.1.4.2)

11 Communication

11.1 Ships communication

Ships communication requirements, listed in Table 19, shall be complied with, as applicable.

Table 19 Polar(A), Polar(B), and Polar(C) requirements for ships communication

General functional requirements	*Prescriptive requirements*
.1 Two-way on-scene and SAR coordination communication capability in ships shall include equipment for voice communications with aircraft on 121.5 MHz and 123.1 MHz. (IMO Polar Code Pt. I-A Ch.10 Req. 10.3.1.3.2)	.1 A fixed or portable aeronautical VHF shall be confirmed provided onboard. If not type approved, minimum requirements of performance standard shall be demonstrated.
.2 Appropriate communication equipment to enable telemedical assistance in polar areas shall be provided. The equipment shall provide for two-way voice and data communication with a telemedical assistance service (TMAS). (IMO Polar Code Pt. I-A Ch.10 Req. 10.3.1.4)	.1 A voice and imagery data communication system as supported by an official shore based medical facility and with proper coverage through all intended areas of the voyage. **Guidance note:** This may be complied with by using systems such as: different Inmarsat SES equipment, IRIDIUM, VSAT, MF/HF, etc. depending on agreement with shore medical facility and proper coverage on the intended areas of voyage. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Specific functional requirements	*Prescriptive requirements*

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.3 Icebreaker and escort: Suitable means of communications shall be provided where escort and convoy operations are expected. (IMO Polar Code Pt. I-A Ch.10 Req. 10.3.1.2)		.1 Ships intended to provide icebreaking escort shall be equipped with a sound signalling system mounted to face astern to give necessary signals to the following ships.
.4 High latitude: Communication equipment on board shall have the capabilities for ship-to-ship and ship-to-shore communication, taking into account the limitations of communications systems in high latitudes. (IMO Polar Code Pt. I-A Ch.10 Req. 10.3.1.1)		.1 Standard geostationary satellite communication equipment, GMDSS, is expected to function properly within latitudes up to 70 degree. For operation at higher latitude, special communication equipment shall be provided. **Guidance note:** IRIDIUM as a voice and/or data communication equipment in high latitude may be accepted. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
.5 Intended to operate in low air temperature: (IMO Polar Code Pt. I-A Ch.10 Req. 10.3.1.1)	.1 Communication equipment on board shall have the capabilities for ship-to-ship and ship-to-shore communication, taking into account the limitations of communications systems in the anticipated low temperature.	.1 Relevant communication equipment located outside or in unheated compartments, if not certified for PST, shall be tested and documented to be functional in an ambient air temperature down to PST. **Guidance note 1:** As part of the testing documentation, it should be proven that the equipment is tested as per IEC 60945 clause 8.4.2, with respect to PST, and carried out by an accredited laboratory, see MSC.1/Circ.1612 Module A.1 ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e--- **Guidance note 2:** See Sec.4 [2.3] for alternative solution. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
	.2 All two-way portable radio communication equipment shall be operable at the polar service temperature.	.1 Exposed portable radio communication equipment shall be tested and documented to be functional in an ambient air temperature down to PST. For testing and alternative solutions, see items .5.1.1 .

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11.2 Survival craft and rescue boat communication capabilities

Survival craft and rescue boat communication requirements, listed in Table 20, shall be complied with, as applicable.

Table 20 Polar(A), Polar(B), and Polar(C) requirements for survival craft and rescue boat communication

Specific functional requirements			*Prescriptive requirements*
.1 Intended to operate in low air temperature: (IMO Polar Code Pt. I-A Ch.10 Req. 10.3.2)	.1 Exposed survival craft and rescue boat communication equipment, such as : — EPIRB — Radar transponder — Fixed and/or portable life-saving VHF radio		.1 If not certified for PST, shall be tested and documented to be functional in an ambient air temperature down to PST. **Guidance note 1:** As part of the testing documentation, it should be proven that the equipment is tested as per IEC 60945 clause 8.4.2, with respect to PST, and carried out by an accredited laboratory, see MSC.1/Circ.1612 Module A.1 ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e--- **Guidance note 2:** See Sec.4 [2.3] for alternative solution. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
	.2 All rescue boats and lifeboats shall:	.1 For distress alerting, carry one device for transmitting ship to shore alerts.	.1 — generally, every lifeboat and rescue boat shall carry 1 EPIRB. However, procedures on how to use and activate EPIRB for distress alerting during the maximum expected time of rescue shall be well described in the PWOM — in order to avoid confusion in search and rescue operations due to multiple EPIRB activation, the PWOM shall also include instructions on optimal use of the available EPIRB units **Guidance note:** It is not required to transmit distress alerting signal continuously during the maximum expected time of rescue. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
		.2 In order to be located, carry one device for transmitting signals for location.	.1 Every lifeboat and rescue boat shall carry minimum 1 radar transponder (SART) or minimum 1 AIS-SART.

	.3 All rescue boats and lifeboats, whenever released for evacuation, shall:	.1 For on-scene communications, carry one device for transmitting and receiving on-scene communications.	.1 Fixed and/or portable life-saving VHF radio shall be provided on every lifeboat and rescue boat. These apparatuses may also be used for compliance with SOLAS Regs. III/6.2.1 and IV/4 if clearly addressed in written procedures).
	.4 All other survival craft shall:	.1 In order to be located, carry one device for transmitting signals for location.	.1 See item .1.2.1.1 in this table.
		.2 device for transmitting and receiving on-scene communications.	.1 See item .1.2.2.1 in this table.

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SECTION 6 MATERIAL REQUIREMENT FOR LOW AIR TEMPERATURE - DAT-B AND DAT

1 General

1.1 Objective

The objective of this section is to provide the basis for selection of material classes and steel grades for vessels that will operate in low air temperatures.

1.2 Scope

The scope of this section covers the criteria for the class notations **DAT-B** and **DAT** and their requirements for selection of materials based on the design temperature.

1.3 Application

This section is applicable for all vessels that will operate in low air temperatures, including vessels with the additional class notations **Polar(A, PST)**, **Polar(B, PST)**, **Polar(C, PST)** and **Winterized(BST)**.

1.4 Class notations

1.4.1 General

For general information about the class notations **DAT-B** or **DAT**, see Sec.1 Table 1.

1.4.2 DAT-B

The additional class notation applies to vessels designed to operate for longer periods in areas with lowest mean daily average temperatures, LMDAT, colder than -10°C.

Guidance note:

The additional class notation **DAT-B** covers the material requirements given in IACS UR S6.2.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

1.4.3 DAT

The additional class notation applies to vessels designed to operate in polar waters according to IMO Polar Code, in areas with LMDAT colder than -10°C and polar service temperatures, PST, colder than -23°C.

1.5 Documentation requirements

Documentation shall be submitted as required by Sec.1 [8].

For general requirements to documentation, including definition of the info codes, see DNV-CG-0550 Sec.6.

For a full definition of the documentation types, see DNV-CG-0550 Sec.5.

1.6 Definitions

For definitions, see Sec.1 [9].

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2 Technical requirements for DAT-B

2.1 Material classes

For vessels with the additional class notation **DAT-B**, the material classes listed in Table 1 apply.

2.2 Material grades

For vessels with the additional class notation **DAT-B**, the material classes listed in Table 1 apply.

3 Technical requirements for DAT

3.1 Material classes

For vessels with the additional class notation **DAT**, the material classes listed in Table 1 and Table 2 apply.

3.2 Material grades

The steel grades shall be according to Table 3, based on the design temperature, t_D, defined for the vessel.

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4 Selection of material class for vessels with class notation DAT-B

Structural members listed in Table 1 shall be categorized with material class as follow:

Table 1 Material classes of strength members in general

Structural member category	*Structural member*		*Class*	
			Within 0.4 L amidships 10)	*Elsewhere*
Secondary	*A1.*	Deck plating exposed to weather, other than that belonging to the primary or special category	I	
	A2.	Side plating above water ballast water line, WBL		
	A3.	Transverse bulkhead plating above the LWBL, as defined in Sec.1 [9.2] 8)		
	A4.	Cargo tank boundary plating exposed to cold cargo 9)		
Primary	*B1.*	Strength deck plating, excluding that belonging to the special category	II 7)	I
	B2.	Continuous longitudinal members above strength deck, excluding hatch coamings		
	B3.	Uppermost strake in longitudinal bulkhead above the LWBL as defined in Sec.1 [9.2] 8)		
	B4.	Vertical strake (hatch side girder) and uppermost sloped strake in top wing tank 8)		
Special	*C1.*	Sheer strake at strength deck 1), 2)	III	II 6)
	C2.	Stringer plate in strength deck 1), 2)		
	C3.	Deck strake at longitudinal bulkhead, excluding deck plating in way of inner-hull longitudinal bulkhead of double-hull ships 1)		
	C4.	Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configurations 3)		
	C5.	Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers combination carriers and other ships with similar hatch opening configurations 4)		
	C6.	Longitudinal hatch coamings of length greater than 0.15 *L* 5)		
	C7.	End brackets of longitudinal cargo hatch coamings/deck house transition 5)		
Other	*D1.*	Fore ship substructure for vessels with class notation **Icebreaker** 10)	II	
	D2.	Aft ship substructure for vessels with class notation **DAV** and equipped with podded propulsors or azimuth thrusters		

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Structural member category	*Structural member*	*Class*	
		Within 0.4 L amidships 10)	*Elsewhere*
	1) Single strakes required to be of class III or of grade E/EH shall have strake width not less than (800 + 5 L) mm, and need not be taken greater than 1 800 mm, unless limited by the geometry of the vessel's design. 2) Shall not be less than grade E/EH within 0.4 L amidships in ships with L>250 m. 3) Minimum class III within cargo region. 4) Class III within 0.6 L amidships and class II elsewhere in the cargo region. 5) Shall not be less than grade D/DH. 6) May be class I outside 0.6 L amidships. 7) May be class I if as built midship section modulus is greater than 1.5 times the required gross midship section modulus, according to Pt.3 Ch.5 Sec.2 [1]. 8) Applicable to plating attached to hull envelope plating exposed to low air temperature. At least one strake shall be considered in the same way as exposed plating and the strake width shall be minimum 600 mm. 9) For cargo tank boundary plating exposed to cold cargo for ships other than liquified gas carriers, see Pt.3 Ch.3 Sec.1 [2.4.2]. 10) Material class requirements for structural members within 0.4 L shall apply for structural members within 0.2 L aft of amidships and 0.3 L forward of amidships for vessel with class notation **Icebreaker**.		

5 Selection of material class for vessels with class notation DAT

In addition to material class requirements provided in [4] for **DAT-B**, structural members listed in Table 2 shall be categorized with material class as follow:

Table 2 Additional material class requirements for DAT

Structural member		*Class*
E.1	Stern frame	II
E.2	Rudder	
E.3	Rudder horn	
E.4	Propeller nozzles	
E.5	Shaft brackets	
E.6	Foundation and main supporting structure for heavy machinery and equipment 1), 2)	
E.7	Crane pedestal and main supporting structure 1), 2)	
E.8	Main supporting structure for helideck sub-structure 2)	
E.9	Frame for windlasses, emergency towing and chain stopper, when equipment is welded to foundation or deck, i.e. not applicable when equipment is bolted to foundation or deck	

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Structural member	*Class*
F.10 Cargo hatch covers [3)]	I

1) List of equipment not to be operated in polar waters shall be explicitly mentioned in the polar waters operational manual (PWOM) as required by the IMO Polar code. For such equipment the additional material class requirements may be irrelevant.
2) Main supporting structures are primary load bearing members such as plates, girders, web frames/bulkheads, and pillars.
3) Only for hatch covers intended for carrying cargo.

6 Selection of steel grades

6.1 Plating materials for various structural categories

Plating materials for various structural categories as defined in [4] and [5], shall not be of lower grades than obtained from Table 3, using the specified design temperature, t_D.

Plating materials of non-exposed members, except as defined in note 8) of Table 1 shall not be of lower grade than obtained according to Pt.3 Ch.3 Sec.1 Table 9.

Table 3 Material grade requirements for classes I, II, and III at low temperatures

Class I										
As-built thickness [mm]	-11°C to -15°C		-16°C to -25°C		-26°C to -35°C		-36°C to -45°C		-46°C to -55°C	
	NS	HT	NS	HT	NS	HT	NS	HT	NS	HT
$t \le 10$	A	AH	A	AH	B	AH	D	DH	D	DH
$10 < t \le 15$	A	AH	B	AH	D	DH	D	DH	D	DH
$15 < t \le 20$	A	AH	B	AH	D	DH	D	DH	E	EH
$20 < t \le 25$	B	AH	D	DH	D	DH	D	DH	E	EH
$25 < t \le 30$	B	AH	D	DH	D	DH	E	EH	E	EH
$30 < t \le 35$	D	DH	D	DH	D	DH	E	EH	E	EH
$35 < t \le 45$	D	DH	D	DH	E	EH	E	EH	Ø	FH
$45 < t \le 50$	D	DH	E	EH	E	EH	Ø	FH	Ø	FH
$50 < t \le 60$	D	DH	E	EH	E	EH	Ø	FH	Ø	FH
$60 < t \le 65$	E	EH	E	EH	Ø	FH	Ø	FH	Ø	Ø
$65 < t \le 70$	E	EH	E	EH	Ø	FH	Ø	Ø	Ø	Ø
$70 < t \le 75$	E	EH	Ø	FH	Ø	FH	Ø	Ø	Ø	Ø
$75 < t \le 80$	E	EH	Ø	FH	Ø	Ø	Ø	Ø	Ø	Ø
Ø = not applicable										

Class II										
As-built thickness [mm]	-11°C to -15°C		-16°C to -25°C		-26°C to -35°C		-36°C to -45°C		-46°C to -55°C	
	NS	HT	NS	HT	NS	HT	NS	HT	NS	HT
t ≤ 10	A	AH	B	AH	D	DH	D	DH	E	EH
10 < *t* ≤ 20	B	AH	D	DH	D	DH	E	EH	E	EH
20 < *t* ≤ 30	D	DH	D	DH	E	EH	E	EH	Ø	FH
30 < *t* ≤ 40	D	DH	E	EH	E	EH	Ø	FH	Ø	FH
40 < *t* ≤ 45	E	EH	E	EH	Ø	FH	Ø	FH	Ø	Ø
45 < *t* ≤ 50	E	EH	E	EH	Ø	FH	Ø	FH	Ø	Ø
50 < *t* ≤ 60	E	EH	E	EH	Ø	FH	Ø	FH	Ø	Ø
60 < *t* ≤ 65	E	EH	Ø	FH	Ø	FH	Ø	Ø	Ø	Ø
65 < *t* ≤ 70	E	EH	Ø	FH	Ø	Ø	Ø	Ø	Ø	Ø
70 < *t* ≤ 75	Ø	FH	Ø	FH	Ø	Ø	Ø	Ø	Ø	Ø
75 < *t* ≤ 80	Ø	FH	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
Ø = not applicable										

Class III										
As-built thickness [mm]	-11°C to -15°C		-16°C to -25°C		-26°C to -35°C		-36°C to -45°C		-46°C to -55°C	
	NS	HT	NS	HT	NS	HT	NS	HT	NS	HT
t ≤ 10	B	AH	D	DH	D	DH	E	EH	E	EH
10 < *t* ≤ 20	D	DH	D	DH	E	EH	E	EH	Ø	FH
20 < *t* ≤ 25	D	DH	E	EH	E	EH	E	FH	Ø	FH
25 < *t* ≤ 30	D	DH	E	EH	E	EH	Ø	FH	Ø	FH
30 < *t* ≤ 35	E	EH	E	EH	Ø	FH	Ø	FH	Ø	Ø
35 < *t* ≤ 40	E	EH	E	EH	Ø	FH	Ø	FH	Ø	Ø
40 < *t* ≤ 50	E	EH	Ø	FH	Ø	FH	Ø	Ø	Ø	Ø
50 < *t* ≤ 60	E	EH	Ø	FH	Ø	FH	Ø	Ø	Ø	Ø
60 < *t* ≤ 65	Ø	FH	Ø	FH	Ø	Ø	Ø	Ø	Ø	Ø
65 < *t* ≤ 70	Ø	FH	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
70 < *t* ≤ 75	Ø	FH	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
75 < *t* ≤ 80	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø
Ø = not applicable										

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6.2 Forged materials

Forged materials in exposed hull structural members, according to [4] and [5], with design temperature, t_D, colder than -10°C, shall fulfil the material requirements given in Table 4.

Table 4 Charpy V-notch impact toughness test requirements for forged materials

Structural category	Test temperature [°C]	*Minimum average energy [J]*
Secondary and those included in [5]	t_D-5	27
Primary and Special	t_D-10	27

Guidance note:

Forged material can be used in structures exposed to design temperature, t_D, colder than -10°C, where plate thickness is beyond the validity range of Table 3.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.3 Cast materials

Cast materials used in exposed hull structural members, and with a design temperature, colder than -10°C, shall be Charpy V-notch impact tested at 5°C below t_D.

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SECTION 7 POLAR CLASS - PC

1 General

1.1 Introduction

The additional class notation **PC** sets requirements for ships constructed of steel, intended for navigation in ice-infested polar waters. The requirements for the additional class notation **PC** are, in general, equivalent to the IACS *Unified Requirements for Polar Ships* (UR I1, UR I2 and UR I3).

1.2 Scope

The scope for the additional class notation **PC** considers hull structure, main propulsion, steering gear, emergency and essential auxiliary systems essential for the safety of the ship and the survivability of the crew.

These rules do not consider aspects related to the operation of on-board equipment in cold climates. It is recommended that ships intended to operate in cold climate environments for longer periods comply with the requirements as given in Sec.4.

1.3 Application

1.3.1 The additional class notation **PC** applies to steel ships complying with the requirements in this section, as listed in Sec.1 Table 1. If the hull and machinery are constructed such as to comply with the requirements of different polar classes, then the ship shall be assigned the lower of these classes in the classification certificate. Compliance of the hull or machinery with the requirements of a higher polar class is also to be indicated in the classification certificate or an appendix thereto.

Ships designed for ice breaking for the purpose of escort and ice management, and which are assigned a polar class notation **PC(1)** to **PC(7)**, may be given the ship type notation **Icebreaker**, as given in Pt.5 Ch.10 Sec.10.

1.3.2 For ships which are assigned a polar class notation, the hull form and propulsion power shall be such that the ship can operate independently and at continuous speed in a representative ice condition, as defined in Sec.1 Table 1 for the corresponding polar class. For the ships and ship-shaped units which are not intentionally designed to operate independently in ice, such operational intent or limitations shall be explicitly stated in appendix to the classification certificate.

1.3.3 For ships which are assigned a polar class notation **PC(1)** through **PC(5)**, bows with vertical sides, and bulbous bows shall generally be avoided. Bow angle should in general be within range specified in [4.1.5].

1.3.4 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 condition shall be stated in appendix to the classification certificate.

1.4 Class notations

1.4.1 Vessels built in compliance with the requirements of this section may be assigned the additional class notations **PC** with the associated qualifier as described in Sec.1 Table 1.

1.4.2 It is the responsibility of the owner to select an appropriate polar class. The descriptions in Sec.1 Table 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.

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1.4.3 The polar class notation is used throughout the IACS *Unified Requirements for Polar Ships* to convey the differences between classes with respect to operational capability and strength.

1.5 Definitions

For definitions, see Sec.1 [9].

2 Documentation requirements

Documentation shall be submitted as required by Table 1.

Table 1 Documentation requirements

Object	*Documentation type*	*Additional description*	*Info*
Technical information	Z100 - Specification	Main propulsion machinery, steering, emergency and essential auxiliaries: description, location, protection against freezing, ice and snow, and operational capability in intended environment. Operational limitations, if any.	FI
Damage stability	B030 - Internal watertight integrity plan		FI
	B070 - Preliminary damage stability calculation		AP
	B130 - Final damage stability calculation		AP
Propulsion torque and thrust transmission arrangement	C040 - Design analysis	Ice load response simulation.	AP
Propeller arrangements	C040 - Design analysis	Finite element analysis of blade stresses introduced by ice loads.	AP
External environment	Z100 - Specification	Details of the environmental conditions and the required ice class for the machinery, if different from ship's ice class.	FI
AP = for approval, FI = for information			

For general requirements to documentation, including definition of the info codes, see DNV-CG-0550 Sec.6.

For a full definition of the documentation types, see DNV-CG-0550 Sec.5.

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3 Design principles

3.1 Design temperature for structure and equipment

3.1.1 Applicable design temperature, t_D, for the operation of the ship in ice infested waters shall be given in the documentation submitted for approval. See Sec.1 Table 4 and Table 1.

3.1.2 Unless a lower design temperature is specified, a design temperature for material selection, t_D, of -35°C for **PC(1)** to **PC(5)** and -25°C for **PC(6)** to **PC(7)** shall be applied.

3.2 Hull areas

3.2.1 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 ice belt regions. The extent of each hull area is illustrated in Figure 1.

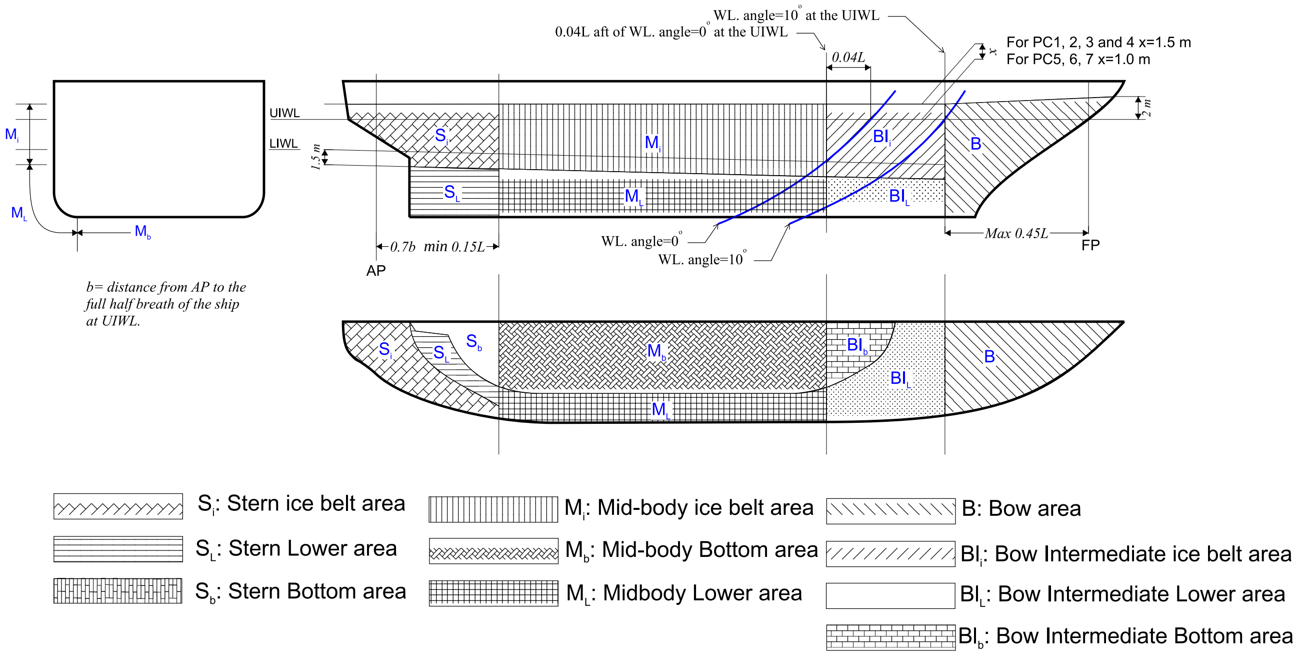

Figure 1 Hull area extents

3.2.2 The upper ice waterline (UIWL) and lower ice waterline (LIWL) are as defined in Sec.1 [9.2].

3.2.3 Figure 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.

3.2.4 Figure 1 notwithstanding, the aft boundary of the bow region need not be more than 0.45 L aft of the forward perpendicular (F.P.).

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

3.2.6 If a ship is intended to operate astern in ice regions, the aft section of the ship shall be designed using the bow and bow intermediate hull area requirements as given in [4.7].

3.3 System design

3.3.1 Systems subject to damage by freezing shall be drainable.

3.3.2 Ships classed **PC(1)** to **PC(5)** inclusive shall have means provided to ensure sufficient ship operation in the case of propeller damage including CP-mechanism, i.e. pitch control mechanism.

Sufficient ship operation means that the ship must be able to reach safe harbour (safe location) where repair can be undertaken in case of propeller damage. This may be achieved either by a temporary repair at sea, or by towing assuming assistance is available (condition for approval).

3.3.3 Means shall be provided to free a stuck propeller by turning it in reverse direction. This means that a plant intended for unidirectional rotation shall be equipped at least with a sufficient turning gear that is capable of turning the propeller in reverse direction.

3.3.4 Propellers shall be fully submerged at the ship's LIWL.

3.4 Propulsion power

Ships shall have sufficient propulsion power and sufficient manoeuvrability for operation in the intended area.

Guidance note:

1) The maximum continuous engine output of propulsion machinery, in KW, should not be less than:

$$P = 1.5 c_s c_p B_{UI} \left(0.1 CF_{DIS} + 2.7\right)\left[1 + 1.6 T_{UI} + 27\left(0.1 \frac{\left(0.1 CF_{DIS} + 2.7\right)}{T_{UI}^{0.25}}\right)^{0.5}\right]$$

where:

c_s = 0.9+γ/200, minimum 1.0 but shall not exceed 1.2

c_p = 1.0 for controllable pitch propeller

= 1.1 for fixed pitch propeller

CF_{DIS}= displacement class factor from Table 2

B_{UI} = moulded breadth corresponding to the upper ice waterline (UIWL) [m]

T_{UI} = draught at to the upper ice waterline (UIWL) [m]

γ = buttock angle at the upper ice waterline (UIWL) in degree, see Figure 2.

2) When the vessel is provided with special means for improving performance in ice, e.g. air bubbling system, the input rating of machinery used for such purpose may be added to the actual rating of propulsion machinery. The propeller rating is, however, not to be less than 85% of that calculated according to 1).

3) When the vessel is provided with nozzle, a reduction of calculated engine output corresponding to increase of thrust in ice conditions should be considered. the reduction is, however, not to exceed 20% of engine output according to 1) or 2).

4) Additional reduction of engine output according to 1) may be considered for a vessel having design features for improving performance in ice. Such features shall be documented, either by means of model testing or full scale measurements.

5) It is strongly recommended to use model test for better prediction of ship performance in ice.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

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4 Design ice loads – hull

4.1 General

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

4.1.2 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.

4.1.3 Within the bow area of polar class ships, and within the bow intermediate ice belt area of polar class **PC(6)** and **PC(7)**, 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.

4.1.4 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.

4.1.5 Design ice forces, calculated according to [4.3.3], are applicable for bow forms where the buttock angle γ at the stem is positive and less than 80 degrees, and the normal frame angle β' at the center of the foremost sub-region, as defined in [4.3.1], is greater than 10 degrees.

4.1.6 Design ice forces calculated according to [4.3.4] are applicable for ships which are assigned the polar class **PC(6)** or **PC(7)** and have bow form with vertical sides. This includes bows where the normal frame angles β' at considered sub-regions, as defined in [4.3.1], are between 0 and 10 deg.

4.1.7 For ships which are assigned the polar class **PC(6)** or **PC(7)**, and equipped with bulbous bows, the design ice forces in the vicinity of the bulb shall be determined according to [4.3.4]. In addition, the design ice forces are not to be taken less than those given in [4.3.3] assuming *fa* = 0.6 and *AR* = 1.3. The design ice forces for the remaining part of the bow shall be specially considered.

4.1.8 For ships with bow forms other than those defined in [4.1.5] to [4.1.7], design forces shall be specially considered.

4.1.9 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, as given in [4.1.10] to [4.1.12], which shall be considered as alternative to the design accelerations given in Pt.3 Ch.4 Sec.3.

4.1.10 Maximum longitudinal impact acceleration, in m/s^2, at any point along the hull girder, to be taken as:

$$a_\ell = \left(\frac{F_{IB}}{\Delta_{UI}}\right)\left(1.1\tan\left(\gamma+\varphi\right)+7\frac{H}{L_{UI}}\right)$$

4.1.11 Combined vertical impact acceleration, in m/s^2, at any point along the hull girder, to be taken as:

$$a_v = \left(\frac{F_{IB}}{\Delta_{UI}}\right)F_x$$

where:

F_x = 1.3 at F.P.
= 0.2 at midships

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= 0.4 at A.P.
= 1.3 at A.P. for ships conducting ice breaking astern.

Intermediate values to be interpolated linearly.

4.1.12 Combined transverse impact acceleration, in m/s^2, at any point along hull girder, to be taken as:

$$a_t = 3F_{Bow}\frac{F_x}{\Delta_{UI}}$$

where:

F_x = 1.5 at F.P.
= 0.25 at midships
= 0.5 at A.P.
= 1.5 at A.P. for ships conducting ice breaking astern.

Intermediate values to be interpolated linearly.

where:

L_{UI} = ship length as defined in Pt.3 Ch.1, measured in m on the upper ice waterline (UIWL), see Sec.1 [9.2]
φ = maximum friction angle between steel and ice, normally taken as 10°, in degrees
γ = bow stem angle at waterline, in degrees
Δ_{UI} = displacement at UIWL [kt]
H = vertical distance from UIWL to the point being considered [m]
F_{IB} = vertical impact force, defined in [6.2] [MN]
F_{Bow} = as defined in [4.5.1] [MN].

4.2 Glancing impact load characteristics

The parameters defining the glancing impact load characteristics are reflected in the class factors listed in Table 2 and Table 3.

Table 2 Class factors to be used in [4.3.3]

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)
PC(1)	17.69	68.60	2.01	250	7.46
PC(2)	9.89	46.80	1.75	210	5.46
PC(3)	6.06	21.17	1.53	180	4.17
PC(4)	4.50	13.48	1.42	130	3.15
PC(5)	3.10	9.00	1.31	70	2.50
PC(6)	2.40	5.49	1.17	40	2.37
PC(7)	1.80	4.06	1.11	22	1.81

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Table 3 Class factors to be used in [4.3.4]

Polar class	*Crushing failure class factor (CF_{CV})*	*Line load class factor (CF_{QV})*	*Pressure class factor (CF_{PV})*
PC(6)	3.43	2.82	0.65
PC(7)	2.60	2.33	0.65

4.3 Bow area

4.3.1 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 Figure 2.

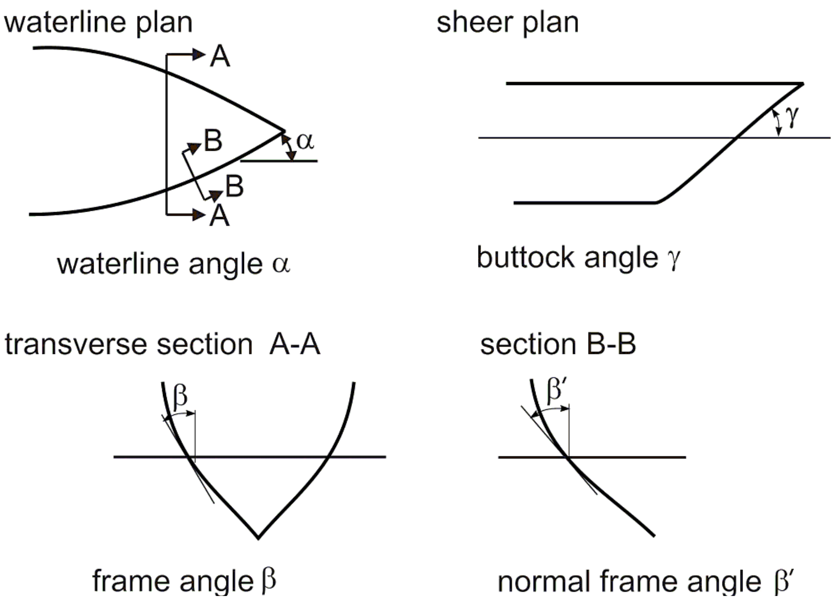

Figure 2 Definition of hull angles

β' = normal frame angle at upper ice waterline, in degrees

α = upper ice waterline angle, in degrees

γ = buttock angle at upper ice waterline (angle of buttock line measured from horizontal), in degrees

$\tan(\beta)$ = $\tan(\alpha)/\tan(\gamma)$

$\tan(\beta')$ = $\tan(\beta)\cos(\alpha)$.

4.3.2 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 shall be calculated with respect to the mid-length position of each sub-region (each maximum of F, Q and P shall be used in the calculation of the ice load parameters P_{avg}, b and w).

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4.3.3 The bow area load characteristics for bow forms defined in [4.1.5] are determined as follows:

a) Shape coefficient, fa_i, shall be taken as:

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

where:

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

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

$fa_{i,3}$ = 0.60

i = sub-region considered

L_{UI} = ship length as defined in Pt.3 Ch.1, measured in [m] on the upper ice waterline (UIWL), see Sec.1 [9.2]

x = ship length as defined in Pt.3 Ch.1, measured in [m] on the upper ice waterline (UIWL), see Sec.1 [9.2]

α = distance from the forward perpendicular (FE) to station under consideration, in m

β' = normal frame angle, in degrees, see Figure 2

Δ_{UI} = ship displacement, in kt, at UIWL, not to be taken less than 5 kt

CF_C = crushing failure class factor from Table 2

CF_F = flexural failure class factor from Table 2.

b) Force [MN]:

F_i = $fa_i \cdot CF_C \cdot \Delta_{UI}{}^{0.64}$

where:

i = sub-region considered

fa_i = shape coefficient of sub-region i

CF_F = crushing failure class factor from Table 2

Δ_{UI} = ship displacement, in kt, at UIWL, not to be taken less than 5 kt.

c) Load patch aspect ratio, AR:

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

where:

i = sub-region considered

β' = normal frame angle of sub-region i, in degrees.

d) Line load [MN/m]:

Q_i = $F_i^{0.61} \cdot CF_D\ /\ AR_i^{0.35}$

where:

i = sub-region considered

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F_i = force of sub-region i [MN]

CF_D = load patch dimensions class factor from Table 2

AR_i = load patch aspect ratio of sub-region i.

e) Pressure [MPa]:

$$P_i = F_i^{0.22} \cdot CF_D^{\,2} \cdot AR_i^{0.3}$$

where:

i = sub-region considered

F_i = force of sub-region i [MN]

CF_D = load patch dimensions class factor from Table 2

AR_i = load patch aspect ratio of sub-region i.

4.3.4 The bow area characteristics for bow forms defined in [4.1.6] are determined as follows:

a) Shape coefficient, fa_i, shall be taken as:

$$fa_i = \alpha_i / 30$$

b) Force, F_i [MN]:

$$F_i = fa_i \cdot CF_{CV} \cdot \Delta_{UI}^{0.47}$$

c) Line load, Q_i [MN/m]:

$$Q_i = F_i^{0.22} \cdot CF_{QV}$$

d) Pressure, P_i [MPa]:

$$P_i = F^{0.56} \cdot CF_{PV}$$

where:

i = sub-region considered

α = waterline angle [deg], see Figure 2

Δ_{UI} = ship displacement [kt], as defined in [4.3.3]

CF_{CV} = crushing failure class factor from Table 3

CF_{QV} = line load class factor from Table 3

CF_{PV} = pressure class factor from Table 3.

4.4 Hull areas other than the bow

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, in MN:

$$F_{NonBow} = 0.36 \cdot CF_C \cdot DF$$

b) Line load, in MN/m:

$$Q_{NonBow} = 0.639 \cdot F_{NonBow}^{\,0.61} \cdot CF_D$$

where:

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CF_C = crushing force class factor from Table 2

CF_D = load patch dimensions class factor from Table 2

DF = ship displacement factor

= $\Delta_{UI}^{0.64}$ if $\Delta_{UI} \leq CF_{DIS}$

= $CF_{DIS}^{0.64} + 0.10\ (\Delta_{UI} - CF_{DIS})$ if $\Delta_{UI} > CF_{DIS}$

Δ_{UI} = ship displacement, in kt at UIWL, not to be taken less than 10 kt

CF_{DIS} = displacement class factor from Table 2.

4.5 Design load patch

4.5.1 In the bow area for all PC-classes, and the bow intermediate ice belt area for ships with class notation **PC(6)** and **PC(7)**, the design load patch, in m, has dimensions of width, w_{Bow}, and height, b_{Bow}, defined as follows:

$$w_{Bow} = F_{Bow} / Q_{Bow}$$
$$b_{Bow} = Q_{Bow} / P_{Bow}$$

where:

F_{Bow} = maximum force F_i in the bow area, see [4.3.3] b) [MN]

Q_{Bow} = maximum line load Q_i in the bow area, see [4.3.3] d) [MN/m]

P_{Bow} = maximum pressure P_i in the bow area, see [4.3.3] e) [MPa].

4.5.2 In hull areas other than those covered by [4.5.1], the design load patch, in m, has dimensions of width, w_{NonBow}, and height, b_{NonBow}, defined as follows:

$$w_{NonBow} = F_{NonBow} / Q_{NonBow}$$
$$b_{NonBow} = w_{NonBow} / 3.6$$

where:

F_{NonBow} = ice force as given by [4.4] [MN]

Q_{NonBow} = ice line load as given by [4.4] [MN/m].

4.6 Pressure within the design load patch

4.6.1 The average pressure within a design load patch, in MPa, is determined as follows:

$$P_{avg} = F / (b \cdot w)$$

where:

F = F_{Bow} or F_{NonBow}, see [4.5.1] and [4.5.2] as appropriate for the hull area under consideration [MN]

b = b_{Bow} or b_{NonBow}, see [4.5.1] and [4.5.2] as appropriate for the hull area under consideration [m]

w = w_{Bow} or w_{NonBow} , see [4.5.1] and [4.5.2] as appropriate for the hull area under consideration [m].

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4.6.2 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 4 are used to account for the pressure concentration on localized structural members.

Table 4 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 [1]	$PPF_t = (1.6 - s) \geq 1.0$
	With no load distributing stringers [1]	$PPF_t = (1.8 - s) \geq 1.2$
Frames in bottom structures		$PPF_s = 1.0$
Load carrying stringers Side longitudinals Web frames		$PPF_s = 1$, 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]

[1] A reduced PPF_t value can be used if:

- the load distributing stringer is located at or close to the middle of span of the transverse frames
- web height is not less than the 80% of the transverse frames
- net web thickness is not less than the net web thickness of the transverse frames.

4.7 Hull area factors

4.7.1 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 5.

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

4.7.3 Due to their increased manoeuvrability, ships having propulsion arrangements with azimuting thruster(s) or podded propellers shall have specially considered stern ice belt (S_i) and stern lower (S_l) hull area factors according to Table 6. The fore boundary of the stern region shall be at least 0.04 *L* forward of the section where the parallel ship side at the upper ice waterline (UIWL) ends.

Table 5 Hull area factors (AF)

Hull area		*Area*	*Polar class*						
			PC(1)	***PC(2)***	***PC(3)***	***PC(4)***	***PC(5)***	***PC(6)***	***PC(7)***
Bow (B)	All	B	1.00	1.00	1.00	1.00	1.00	1.00	1.00

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Hull area		*Area*	*Polar class*						
			PC(1)	***PC(2)***	***PC(3)***	***PC(4)***	***PC(5)***	***PC(6)***	***PC(7)***
Bow intermediate (BI)	Ice belt	BI_i	0.90	0.85	0.85	0.80	0.80	1.00 1)	1.00 1)
	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)	Ice belt	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	2)	2)	2)	2)
Stern (S)	Ice belt	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	2)	2)

1) See [4.1.3].

2) Indicates that strengthening for ice loads is not necessary.

Table 6 Hull area factors (AF) for ships with thrusters/podded propulsion

Hull area		*Area*	*Polar class*						
			PC(1)	***PC(2)***	***PC(3)***	***PC(4)***	***PC(5)***	***PC(6)***	***PC(7)***
Bow (B)	All	B	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bow intermediate (BI)	Ice belt	BI_i	0.90	0.85	0.85	0.80	0.80	1.00 1)	1.00 1)
	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)	Ice belt	M_i	0.70	0.65	0.55	0.55	0.50	0.45	0.45
	Lower	M_l	0.55	0.45	0.40	0.35	0.30	0.25	0.25
	Bottom	M_b	0.30	0.30	0.25	2)	2)	2)	2)
Stern (S)	Ice belt	S_i	0.90	0.85	0.80	0.75	0.65	0.55	0.50
	Lower	S_l	0.60	0.55	0.50	0.45	0.40	0.40	0.40
	Bottom	S_b	0.35	0.30	0.30	0.25	0.15	2)	2)

1) See [4.1.3].

2) Indicates that strengthening for ice loads is not necessary.

4.8 Ice compression load amidships

4.8.1 All ships shall withstand line loads acting simultaneously in the horizontal plane at the water level on both sides of the hull. These loads are assumed to arise when a ship is trapped between moving ice floes. The parameter for ice thickness CF_m is given in Table 7 and will be stated in the appendix to the classification certificate.

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Table 7 Ice compression class factors

Polar class	CF_m
PC(1)	3.0
PC(2)	2.5
PC(3)	2.0
PC(4)	1.6
PC(5)	1.2
PC(6)	0.7
PC(7)	0.5

4.8.2 The design line load shall be applied parallel to the midbody region and at locations, within the ice belt, where capacity of structural members under combined effect of bending and shear is minimized.

The design line load shall not be combined with any other loads.

4.8.3 The design line loads [kN/m], shall be taken as:

$$q = \frac{165}{\sin\beta_f}\left(CF_m\right)^{1.5}$$

For vertical side shells with $\beta_f < 10$ degrees, the design line loads [kN/m], may be taken as:

$$q = 950\left(CF_m\right)^{1.5}$$

where:

CF_m = ice compression class factor
β_f = angle of outboard flare at the water level, in degrees.

The stresses, in N/mm^2, resulting from bending moments and shearing forces shall not be greater than the following permissible values:

Normal stress	$= 0.67R_{eH}$
Shear stress	$= 0.67\tau_{eH}$
von Mises stress	$= 0.75R_{eH}$

5 Local strength requirements

5.1 Shell plate requirements

5.1.1 The required minimum gross shell plate thickness, in mm, is given by:

$$t_{gr} = t + t_s$$

where:

t = net plate thickness required to resist ice loads according to [5.1.2] [mm]

t_s = corrosion and abrasion allowance according to [10.1] [mm].

5.1.2 The thickness of shell plating required to resist the design ice load, *t*, depends on the orientation of the framing.

In the case of transversely-framed plating (Ω ≥ 70 deg), and bottom plating regardless of frame orientation, i.e. plating in hull areas B_{Ib}, M_b and S_b, the net thickness, in mm, is given by:

$$t = 500s\sqrt{\frac{AF \cdot PPF_p \cdot P_{avg}}{R_{eH}}} \cdot \frac{1}{1 + \frac{s}{2b}}$$

In the case of longitudinally-framed plating (Ω ≤ 20°), when $b \geq s$, the net thickness, in mm, is given by:

$$t = 500s\sqrt{\frac{AF \cdot PPF_p \cdot P_{avg}}{R_{eH}}} \cdot \frac{1}{1 + \frac{s}{2\,\ell}}$$

In the case of longitudinally-framed plating (Ω ≤ 20°), when $b < s$, the net thickness, in mm, is given by:

$$t = 500s\sqrt{\frac{AF \cdot PPF_p \cdot P_{avg}}{R_{eH}}} \cdot \sqrt{2\frac{b}{s} - \left(\frac{b}{s}\right)^2} \cdot \frac{1}{1 + \frac{s}{2\,\ell}}$$

In the case of obliquely-framed plating (70° > Ω > 20°), linear interpolation shall be used

where:

Ω = smallest angle between the chord of the waterline and the line of the first level framing as illustrated in Figure 3 [degrees]

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

AF = hull area factor from Table 5 and Table 6

PPF_p = peak pressure factor from Table 5

P_{avg} = average patch pressure as given in [4.6] [MPa]

b = height of design load patch [m], where $b \leq (\ell - s/4)$ in the case of transversely framed plating

ℓ = full length between frame supports, as given in Pt.3 Ch.3 Sec.7 [m].

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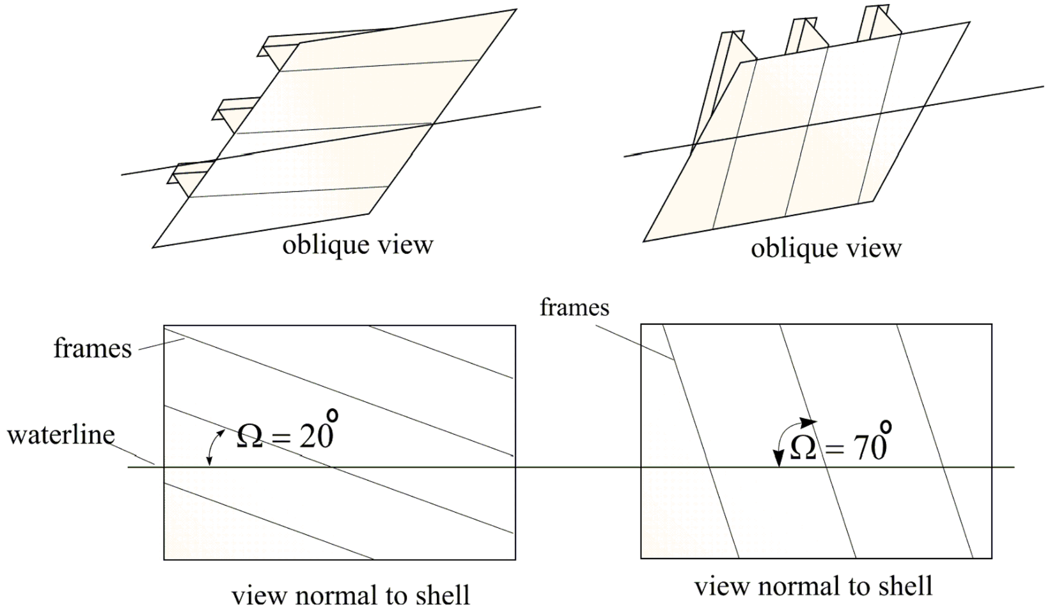

Figure 3 Shell framing angle Ω

5.2 Framing general

5.2.1 Framing members of polar class ships shall be designed to withstand the ice loads defined in [4].

5.2.2 The term framing member refers to transverse and longitudinal local frames (stiffeners), load-carrying stringers and web frames in the areas of the hull exposed to ice pressure, see Figure 1.

5.2.3 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 should be assumed unless the connection can be demonstrated to provide significant rotational restraint. Fixity shall be ensured at the support of any framing which terminates within an ice-strengthened area.

5.2.4 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, shall be in accordance with [5.9] and Pt.3 Ch.3 Sec.5 [3], Pt.3 Ch.3 Sec.5 [4], Pt.3 Ch.3 Sec.6 [2] and Pt.3 Ch.6 Sec.7, as applicable.

5.2.5 The design span of framing members shall generally be determined according to Pt.3 Ch.3 Sec.7 [1]. However, the span length is only to be reduced in accordance with Pt.3 Ch.3 Sec.7 [1] provided the end brackets fitted are flanged or the free edge length in mm is equal to or less than 600 $t_b / R_{eH}^{0.5}$.

t_b = net thickness of bracket [mm].

5.2.6 Load-carrying stringers and web frames are generally to be of symmetrical cross-section. When the flange is arranged to be unsymmetrical, an effective tripping support shall be provided at the middle of each span length.

5.2.7 When calculating the section modulus and shear area of a framing member, net thickness of the web, flange (if fitted) and of the attached shell plating shall be used. The shear area of a framing member may

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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.

5.2.8 The actual net effective shear area of a framing member [cm^2], is given by:

$$A_w = \frac{h \cdot t_w \cdot \sin\varphi_w}{100}$$

where:

h = height of stiffener [mm], see Figure 4

t_w = net web thickness [mm]

= $t_{w\text{-}as\text{-}built}$-$t_s$

$t_{w\text{-}as\text{-}built}$ = as built web thickness [mm], see Figure 4

t_s = corrosion addition [mm], as given in [10.1.4], to be subtracted from the web and flange thickness

φ_w = smallest angle between shell plate and stiffener web [degrees], measured at the midspan of the stiffener, see Figure 4. The angle φ_w may be taken as 90 degrees provided the smallest angle is not less than 75 degrees.

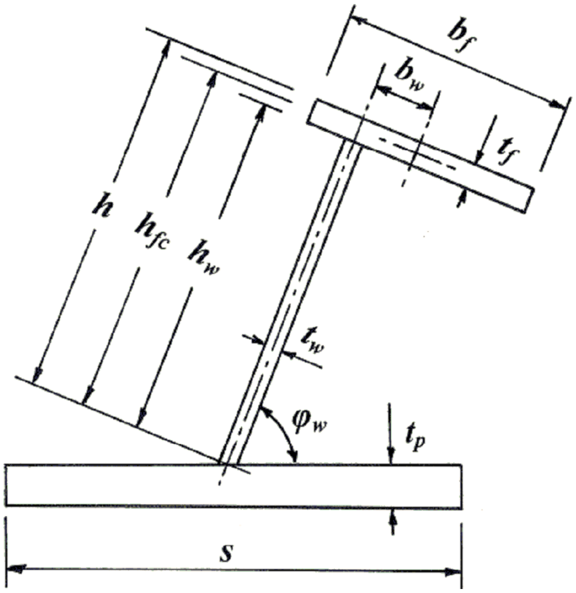

Figure 4 Stiffener geometry

5.2.9 When the cross-sectional area of the attached plate flange, A_{pn}, exceeds the cross-sectional area of the local frame, $(A_{fn}+h_w \cdot t_w/100)$, the actual net effective plastic section modulus [cm^3], of a transverse or longitudinal frame (stiffeners), is given by:

$$Z_p = A_p \cdot \frac{t_p}{20} + \frac{h_w^2 \cdot t_w \cdot \sin\varphi_w}{2000} + A_f \cdot \frac{h_{fc} \cdot \sin\varphi_w - b_w \cdot \cos\varphi_w}{10}$$

where:

h, t_w, and φ_w are as given in [5.2.7] and s as given in [5.1.2].

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A_p = net cross-sectional area of the fitted shell plate, ($t_{pn} \cdot s \cdot 10$) [cm^2]

t_p = fitted net shell plate thickness [mm] (shall comply with *t* as required by [5.1.2])

h_w = height of local frame web [mm], see Figure 4

A_f = 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 Figure 4

b_w = distance from mid thickness plane of local frame web to the centre of the flange area [mm], see Figure 4.

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 above the attached shell plate, in mm, given by:

$$z_{na} = \frac{100A_f + h_w t_w - 1000 t_p s}{2t_w}$$

and the net effective plastic section modulus, of a transverse or longitudinal frame (stiffeners) in cm^3, is given by:

$$Z_p = t_p \cdot s \cdot \left(z_{na} + \frac{t_p}{2}\right) \cdot \sin\varphi_w + \frac{\left(\left(h_w - z_{na}\right)^2 + z_{na}^2\right) \cdot t_w \cdot \sin\varphi_w}{2000} + \frac{A_f \cdot \left(\left(h_{fc} - z_{na}\right) \cdot \sin\varphi_w - b_w \cdot \cos\varphi_w\right)}{10}$$

5.2.10 In the case of oblique framing arrangement 70° > Ω > 20°, where Ω is defined as given in [5.1.2], linear interpolation shall be used.

5.3 Framing – transversely framed side structures and bottom structures

5.3.1 Local frames in bottom structure (i.e. hull areas B_{Ib}, M_b and S_b) and transverse local frames (stiffeners) in side structure shall 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 patch load that causes the development of a plastic hinge mechanism.

For bottom structure the patch load shall be applied with the dimension (*b*) parallel with the frame direction.

5.3.2 The actual net effective shear area of the frame, in cm^2, as defined in [5.2.8], shall comply with the following condition: $A_w \geq A_t$, where:

$$A_t = \frac{100^2 \cdot 0.5 \cdot LL \cdot s \cdot \left(AF \cdot PPF_t \cdot P_{avg}\right)}{0.577 R_{eH}}$$

where:

LL = length of loaded portion of span
= lesser of *a* and *b* [m]

a = frame span as defined in [5.2.5] [m]

b = height of design ice load patch as given in [4.5] [m]

s = spacing of local frame [m]

AF = hull area factor from Table 5, Table 6 and Table 7

PPF_t = peak pressure factor from Table 5

P_{avg} = average pressure within load patch as given in [4.6] [MPa] .

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5.3.3 The actual net effective plastic section modulus of the plate/stiffener combination, in cm^3, as defined in [5.2.9], shall comply with the following condition: $Z_p \geq Z_{pt}$, where Z_{pt} shall be the greater calculated on the basis of two load conditions: a) ice load acting at the midspan of the transverse frame, and b) the ice load acting near a support. The A_1 parameter reflects the two conditions:

$$Z_{pt} = \frac{100^3 \cdot LL \cdot Y \cdot s \cdot AF \cdot PPF_t \cdot P_{avg} \cdot a \cdot A_1}{4R_{eH}}$$

where:

AF, PPF_t, P_{avg}, LL, b, s, and a are as given in [5.3.2].

Y = $1 - 0.5 \cdot \frac{LL}{a}$

A_1 = maximum of:

A_{1A} = $\frac{1}{\left(1 + \frac{j}{2} + k_w \cdot \frac{j}{2} \cdot \left(\sqrt{\left(1 - a_1{}^2\right)} - 1\right)\right)}$

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

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 = $\frac{A_t}{A_w}$

A_t = minimum shear area of the local frame as given in [5.3.2] [cm^2]

A_w = effective net shear area of the local frame (calculated according to [5.2.8] [cm^2]

k_w = $\frac{1}{\left(1 + 2 \cdot \frac{A_f}{A_w}\right)}$

with A_f as given in [5.2.9]

k_z = $\frac{z_p}{Z_p}$

in general

0.0 when the frame is arranged with end bracket

z_p = sum of the individual plastic section modulus of flange and shell plate as fitted [cm^3]

= $\left(\frac{b_f \cdot t_f{}^2}{4} + \frac{b_{eff} \cdot t_p{}^2}{4}\right) \cdot \frac{1}{1000}$

b_f = flange breadth [mm], see Figure 4

t_f = net flange thickness [mm]

= $t_{f\text{-}as\text{-}built} - t_s$ (t_s as given in [5.2.8])

$t_{f\text{-}as\text{-}built}$ = as-built flange thickness [mm], see Figure 4

t_p = the fitted net shell plate thickness [mm] (not to be less than t_{net} as given in [5.1.2])

b_{eff} = effective width of shell plate flange mm

= 500 s

Z_p = net effective plastic section modulus of the local frame (calculated according to [5.2.9]) [cm^3].

5.3.4 The scantlings of the frame shall meet the structural stability requirements of [5.6].

5.4 Framing – longitudinal local frames in side structure

5.4.1 Longitudinal local frames in side structure shall 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.

5.4.2 The actual net effective shear area of the frame, in cm^2, as defined in [5.2.8], shall comply with the following condition:

$$A_w \geq A_L$$

$$A_L = \frac{100^2 \cdot 0.5 \cdot b_1 \cdot a \cdot AF \cdot PPF_s \cdot P_{avg}}{0.577 \cdot R_{eH}}$$

where:

AF = hull area factor from Table 5, Table 6 or Table 7

PPF_s = peak pressure factor from Table 5

P_{avg} = average pressure within load patch as given in [4.6] [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 given by [4.5.1] or [4.5.2] [m]

s = spacing of longitudinal frames [m]

b_2 = corrected load height [m]

= $b\,(1 - 0.25 \cdot b')$ if $b' < 2$

= s if $b' \geq 2$

a = longitudinal design span as given in [5.2.5] [m].

5.4.3 The actual net effective plastic section modulus of the plate/stiffener combination, in cm^3, as defined in [5.2.9], shall comply with the following condition:

$$Z_P \geq Z_{PL}$$

$$Z_{PL} = \frac{100^3 \cdot b_1 \cdot a^2 \cdot A_4 \cdot \left(AF \cdot PPF_s \cdot P_{avg}\right)}{8 \cdot R_{eH}}$$

where:

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AF, PPF_s, P_{avg}, b_1, and a are as given in [5.4.2].

A_4 = $\frac{1}{(2 + k_{wl} \cdot (\sqrt{(1 - {a_4}^2)} - 1)}$

a_4 = $\frac{A_L}{A_w}$

A_L = minimum shear area for longitudinal as given in [5.4.2] [cm^2]

A_w = net effective shear area of longitudinal (calculated according to [5.2.8]) [cm^2]

$k_{w\ell}$ = $\frac{1}{\left(1 + 2 \cdot \frac{A_f}{A_w}\right)}$ with A_f as given in [5.2.9].

5.4.4 The scantlings of the longitudinals shall meet the structural stability requirements of [5.6].

5.5 Framing – web frames and load carrying stringers

5.5.1 Web frames and load-carrying stringers shall be designed to withstand the ice load patch as defined in [4.5]. The load patch shall be applied at locations where the capacity of these members under the combined effects of bending and shear is minimized.

5.5.2 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 outlined in [8] shall normally be used.

5.5.3 The scantlings of web frames and load-carrying stringers shall meet the structural stability requirements of [5.6].

5.6 Framing – structural stability

5.6.1 To prevent local buckling in the web, the ratio of web height, h_w, to net web thickness, t_w, of any framing member (stiffener) shall not exceed:

for flat bar sections:

$$h_w / t_w \leq 282 / (R_{eH})^{0.5}$$

for bulb, tee and angle sections:

$$h_w / t_w \leq 805 / (R_{eH})^{0.5}$$

where:

h_w = web height, in mm

t_w = net web thickness, in mm.

5.6.2 Load carrying stringers or web frames, are required to have their webs effectively stiffened. The minimum net web thickness for these framing members, in mm, is given by:

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$$t_w = 2.63 \cdot 10^{-3} \cdot c_1 \cdot \sqrt{\frac{R_{eH}}{5.34 + 4\left(\frac{c_1}{c_2}\right)^2}}$$

where:

c_1 = $h_w - 0.8 \cdot h$ [mm]

h_w = web height of stringer/web frame, in mm, see Figure 5

h = height of framing member penetrating the member under consideration (0 if no such framing member) [mm], see Figure 5

c_2 = spacing between supporting structure oriented perpendicular to the member under consideration [mm], see Figure 5.

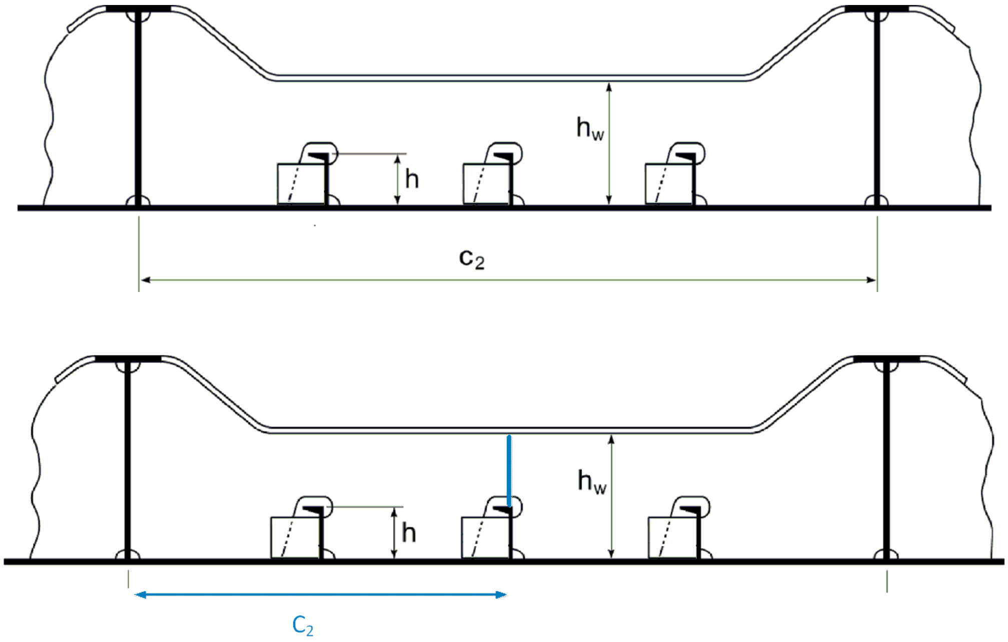

Figure 5 Parameter definition for web stiffening

5.6.3 In addition, the following shall be satisfied:

$$t_w \geq 0.35 \cdot t_p \cdot (R_{eH} / 235)^{0.5}$$

where:

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

t_w = net thickness of the web [mm]

t_p = net thickness of the shell plate in way of the framing member [mm].

5.6.4 To prevent local flange buckling of welded profiles, the following shall be satisfied:

— the flange width, b_f in mm, shall not be less than 5 × t_w

- the flange outstand, $b_{f\text{-}out}$, as defined in Pt.3 Ch.8 Sec.2, in mm, shall meet the following requirement:

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

where:

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

5.7 Plated structures

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

- web height of adjacent parallel web frame or stringer
- 2.5 times the depth of framing that intersects the plated structure.

5.7.2 The thickness of the plating and the scantlings of attached stiffeners shall be consistent with the end connection requirements for supported framing as given in [5.9].

5.7.3 Plated structures subjected to direct ice loads, as defined in [4], shall be considered with respect to the buckling requirements in Pt.3 Ch.8.

5.8 Stem and stern frames

5.8.1 For **PC(6)** or **PC(7)** ships requiring **1A***/**1A** equivalency, the stem and stern requirements of the Finnish-Swedish Ice Class Rules may need to be additionally considered.

5.8.2 When the ship has a sharp edged stem, the thickness of the stem side plate within a breadth not less than 0.7 *s*, where *s* denotes the spacing of stiffening members, in m, shall not be less than 1.2 *t*, where *t* denotes the required net shell plate thickness, in mm, for the bow area, as given in [5.1].

The stem reinforcement shall be extending vertically from a line 1.5 m below the LIWL to the horizontal line x m above the UIWL, see Figure 6.

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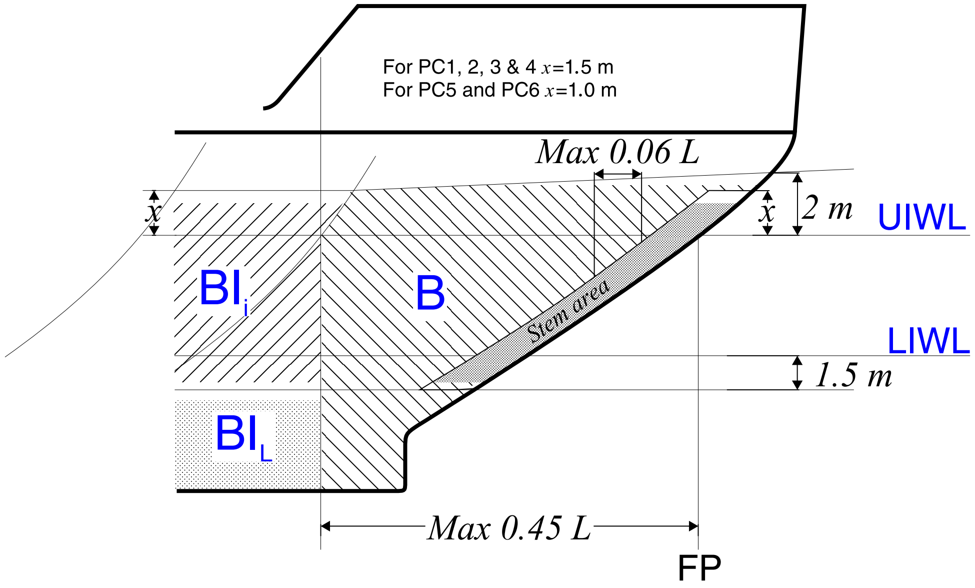

Figure 6 Stem reinforcement

5.8.3 In ships with class notation **PC(3)** to **PC(1)**, intended to operate under harsh ice condition, and of type and size that may cause excessive beaching to occur, a forward ice knife may be required fitted. This requirement will be based on consideration of design speed, stability, and freeboard.

5.9 End connections for framing members

5.9.1 The end connection for framing members (stiffeners) exposed to ice loads, to supports, e.g. stringers, web frames, decks or bulkheads, shall be related to the response of the member when subjected to ice loads. The connection area is generally obtained through support members such as collar plate, lugs, end brackets, or web stiffener.

The total net connection area of support members, in cm^2, is given as:

$$a_c = \sum_n 0.01 k_\tau \, t_i \, h_i$$

where:

h_i = effective dimension of connection area of member #*i* [mm]
t_i = net thickness of connection area #*i* [mm]
k_τ = 1.0 for members where critical stress response is shear
= 1.5 for members where critical stress response is normal stress
n = number of support members.

5.9.2 The net end connection area fitted, a_c, shall generally not be less than a_0, in cm^2, given as:

for longitudinal local frames

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$$a_0 = \frac{100^2 \cdot \left(AF \cdot PPF_s \cdot P_{avg}\right) \cdot b_1 \cdot \left(w - s\right) \cdot \left(a - \frac{w}{2}\right)}{0.577 \cdot R_{eH} \cdot \eta \cdot a \cdot \sin\varphi_w}$$

for transverse local frames

$$a_0 = \frac{100^2 \cdot \left(AF \cdot PPF_t \cdot P_{avg}\right) \cdot s \cdot b \cdot \left(a - \frac{b+s}{2}\right)}{0.577 \cdot R_{eH} \cdot \eta \cdot a \cdot \sin\varphi_w}$$

where:

AF = hull area factor from Table 5, Table 6 or Table 7
PPF = peak pressure factor from Table 5
P_{avg} = average pressure within load patch as given in [4.6.1] [MPa]
LH = load height, given as the smaller of *b* and (*a*-*s*) [m]
LL = load length, given as the smaller of *w* and (*a*-*s*) [m]
a = span of member as given in [5.2.5] [m]
s = spacing of frames (stiffeners) [m]
b, w = as given in [4.6.1]
b_1 = as given in [5.4.2]
η = permissible usage factor
= 0.9
φ_w = smallest angle between shell plate and the web of the stringer or web frame as applicable, in degrees, measured at the intersection with the stiffener. The angle φ_w may be taken as 90 degrees provided the smallest angle is not less than 75 degrees.

5.9.3 For end connections of local supporting members (stiffeners), the leg thickness in mm of double fillet welds for the connection member *i*, to the web frame or load carrying stringer is given as the smaller of:

$$t_{leg} = \frac{\left(t_i - t_c\right) \cdot a_0 \cdot R_{eH}}{320 a_c \cdot f_{yd}} + 0.7 t_s$$

$$= 0.7\, t_i$$

where:

a_c = as given in [5.9.1]
a_o = as given in [5.9.2]
t_i = as built thickness of connection member *i* [mm]
f_{yd} = as given in Pt.3 Ch.13 Sec.1 [2.5.2]
t_s = corrosion addition/abrasion addition as given in [10.1.4] [mm].

The throat thickness not be less than as given in Pt.3 Ch.13 Sec.1 [2.5].

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6 Longitudinal strength

6.1 Application

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

6.1.2 Intentional ramming is not considered as a design scenario for ships which are designed with a vertical or bulbous bow, see [1.3.4]. Hence the longitudinal strength requirements given in [6] shall not be considered for ships with stem angle γ_{stem} equal or larger than 80 degrees.

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

6.2 Design vertical ice force at the bow

The design vertical ice force at the bow [MN], shall be taken as:

$$F_{IB} = \text{minimum}\ (F_{IB,1}, F_{IB,2})$$

where:

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

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

K_I = indentation parameter = K_f / K_h.

a) For the case of a blunt bow form:

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

b) For the case of wedge bow form (α_{stem} < 80 deg), e_b = 1 and the above simplifies to:

$$K_f = (\tan(\alpha_{stem}) / \tan^2(\gamma_{stem}))^{0.9}$$

$$K_h = 0.01 \cdot A_{wp}\ \text{[MN/m]}.$$

CF_L = longitudinal strength class factor from Table 2

e_b = bow shape exponent which best describes the water plane, see Figure 7 and Figure 8
= 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, in degrees, (buttock angle as per Figure 2 measured on the centerline)

α_{stem} = hull waterline angle to be measured at stem (centre line) at the UIWL, see Figure 2, in degrees

C = $1 / (2 \cdot (L_B / B_{UI})^{eb})$

B_{UI} = moulded breadth corresponding to the upper ice waterline (UIWL) [m]

L_B = bow length used in the equation $y = B_{UI} / 2 \cdot (x/L_B)^{eb}$ measured from the stem to the full half breath of the ship at the UIWL, in m, see Figure 7 and Figure 8

Δ_{UI} = ship displacement, in kt, at UIWL, not to be taken less than 10 kt
A_{wp} = ship water plane area [m^2]
CF_F = flexural failure class factor from Table 2.

Draught dependent quantities shall, where applicable, be determined at the waterline corresponding to the loading condition under consideration.

6.3 Design vertical shear force

6.3.1 The design vertical ice shear force along the hull girder [MN], shall be taken as:

$$F_I = C_f \cdot F_{IB}$$

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_{UI} and 0.6 L_{UI} from aft
C_f = 1.0 between 0.9 L_{UI} from aft and the forward end of L_{UI}

b) negative shear force

C_f = 0.0 at the aft end of L_{UI}
C_f = – 0.5 between 0.2 L_{UI} and 0.6 L_{UI} from aft
C_f = 0.0 between 0.8 L_{UI} from aft and the forward end of L_{UI}

where L_{UI} is ship length, in m, as defined in [6.4.1].

Intermediate values shall be determined by linear interpolation.

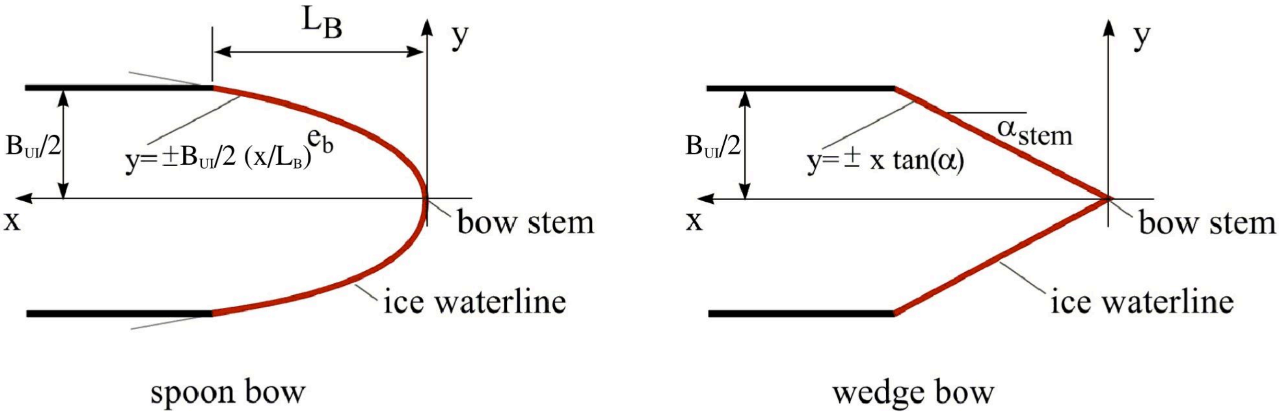

Figure 7 Bow shape definition

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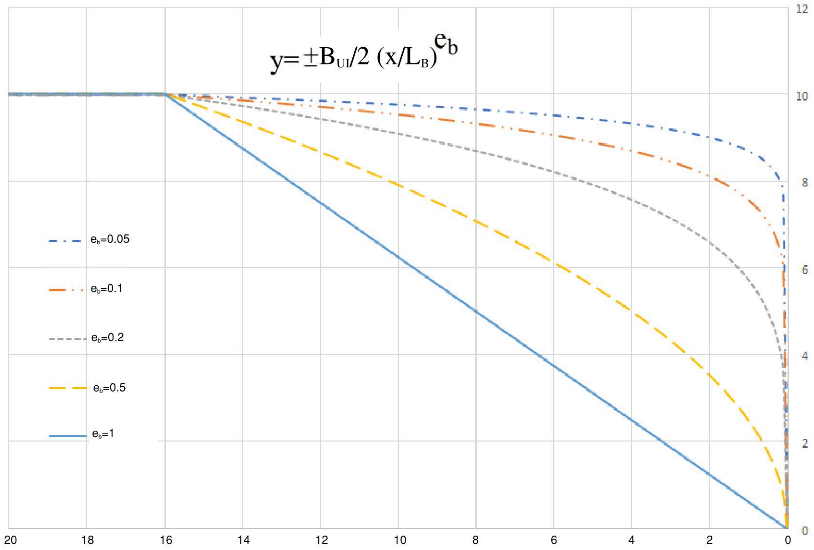

Figure 8 Illustration of e_b effect on the bow shape for B_{UI} = 20 and L_B = 16

6.3.2 The applied vertical shear stress, τ_a, shall be determined along the hull girder in a similar manner as in Pt.3 Ch.5 Sec.1 by substituting the design vertical ice shear force for the design vertical wave shear force.

6.4 Design vertical ice bending moment

6.4.1 The design vertical ice bending moment along the hull girder [MNm], shall be taken as:

$$M_I = 0.1 \cdot C_m \cdot L_{UI} \cdot \sin^{-0.2}(\gamma_{stem}) \cdot F_{IB}$$

where:

γ_{stem} is as given in [6.2].

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_{UI}

C_m = 1.0 between 0.5 L_{UI} and 0.7 L_{UI} from aft

C_m = 0.3 at 0.95 L_{UI} from aft

C_m = 0.0 at the forward end of L_{UI}

L_{UI} = ship length as defined in Pt.3 Ch.1 Sec.4, but measured on the upper ice waterline (UIWL) [m].

Intermediate values shall be determined by linear interpolation.

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

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6.4.2 The applied vertical bending stress, σ_a, shall be determined along the hull girder in a similar manner as in Pt.3 Ch.5 Sec.1 by substituting the design vertical ice bending moment for the design vertical wave bending moment. The ship still water bending moment shall be taken as the maximum sagging moment.

6.5 Longitudinal strength criteria

The strength criteria provided in Table 8 shall be satisfied. The design stress shall not exceed the permissible stress.

Table 8 Longitudinal strength criteria

Failure mode	*Applied stress*	*Permissible stress when $R_{eH} / R_m \leq 0.7$*	*Permissible stress when $R_{eH} / R_m > 0.7$*
Tension	σ_a	$\eta \cdot R_{eH}$	$\eta \cdot 0.41 \ (R_m + R_{eH})$
Shear	τ_a	$\eta \cdot \tau_{eH}$	$\eta \cdot 0.41 \ (R_m + R_{eH}) / (3)^{0.5}$
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} = specified minimum yield stress of the material [N/mm^2]
R_m = specified minimum tensile strength of material [N/mm^2]
σ_c = critical buckling stress in compression, according to Pt.3 Ch.8 [N/mm^2]
τ_c = critical buckling stress in shear, according to Pt.3 Ch.8 [N/mm^2]
η = 0.8.

7 Appendages

7.1 General

7.1.1 All appendages shall be designed to withstand forces appropriate for the location of their attachment to the hull structure or their position within a hull area. For appendages of type or arrangement other than as considered in the following, the load definition and response criteria are subject to special consideration.

7.1.2 Stern frames, rudders and propeller nozzles shall be designed according to the rules given in Pt.3 Ch.14 Sec.1.

7.1.3 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.

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7.1.4 Additional requirements for ice reinforced ships are given in the following. For ships with rudders which are not located behind the propeller, special consideration will be made with respect to the longitudinal ice load.

7.2 Rudders

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

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

7.2.3 Ice horns shall, in general, be fitted to protect the rudder in centre position and 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
- 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 CF_D [m], below LIWL, where CF_D shall be taken as given in Table 2 and need not to be extended more than 25% of rudder height, H, below the upper edge of the rudder. See Figure 9. Alternatively, an equivalent arrangement shall be arranged.

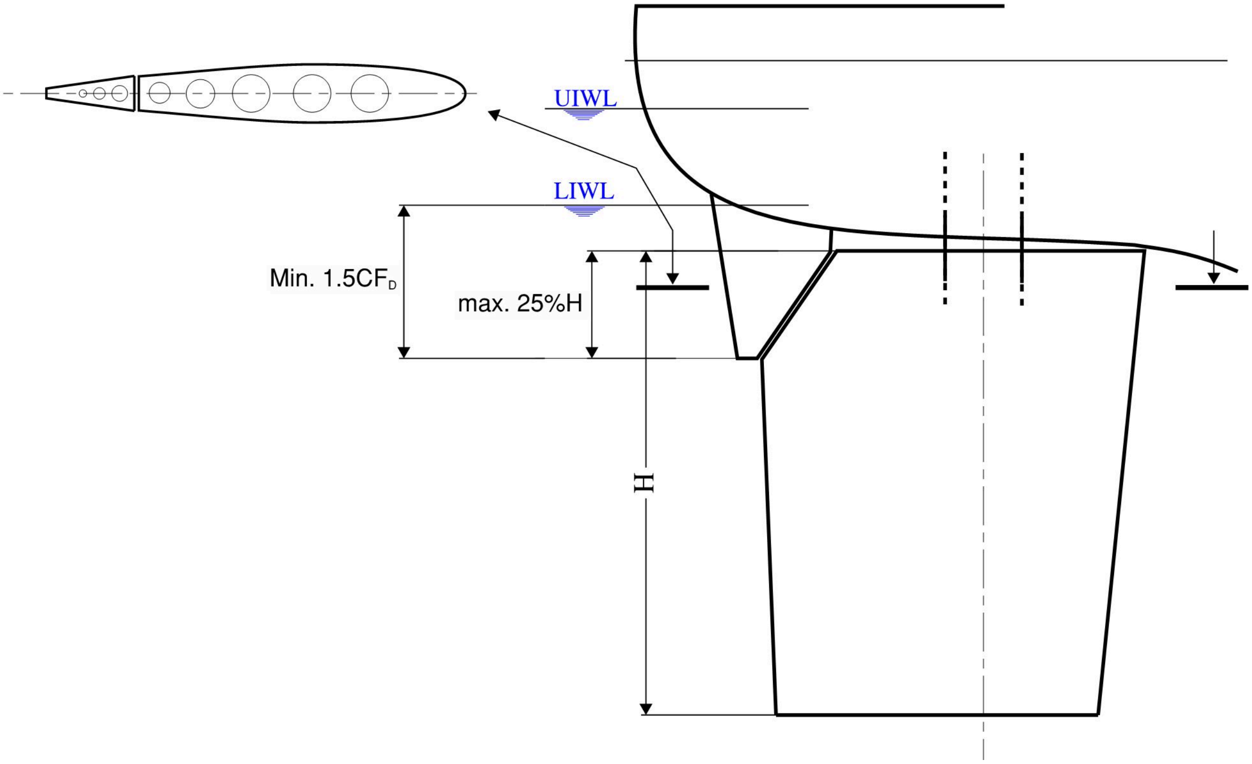

Figure 9 Ice horn arrangement

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

- ice formation

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— specified design temperature.

7.3 Ice forces on rudder

7.3.1 The ice force due to ice, F, acting on the uppermost part of the rudder, the ice horn and rudder horn included, shall be assessed on a case-by-case basis based on the Society's current practice, see DNV-CG-0041 Sec.8 [1.3].

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

7.3.2 The ice force due to ice, F_R, acting on the rudder shall be assessed on a case-by-case basis based on the Society's current practice.

The rudder force, F_R [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.

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

$$M = F_R \cdot h_s$$

h_s = vertical distance from the centre of the ice load patch to the rudder section in question [m].

The rudder force, F_R, gives rise to a rudder torque, Q_R, and a bending moment in the rudder stock, M, 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, Q_R and M with respect to the structure under consideration shall be applied in a direct calculation of the rudder structure.

The design value of Q_R is given by:

Q_R = $F_R\,(0.6\,\ell_r - X_F)$ [kNm]
= $0.15\,F_R\,\ell_r$ minimum
X_F = longitudinal distance [m], from the leading edge of the rudder to the axis of the rudder stock
ℓ_r = length of rudder profile [m]
H = rudder height [m].

Guidance note:

Ice force on rudder, ice horn and rudder horn should be determined considering ice load formulation and load cases described in DNV-CG-0041 Sec.8.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.4 Rudder scantlings

7.4.1 Scantlings of rudder, rudder stock, rudder horn and rudder stoppers, as applicable, shall be calculated for the force, F, given in [7.3.1] 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 [N/mm^2].

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7.4.2 The scantlings of rudders, rudder stocks and shafts, pintles, rudder horns and rudder actuators shall be calculated from the formulae given in Pt.3 Ch.14 Sec.1, inserting the rudder torque Q_R, bending moments M and rudder force C_R as given in [7.3.2].

7.4.3 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:

Q_R = Q_{RO}

Q_{RO} = steering gear relief torque [kNm].

7.4.4 For rudder plating the ice load thickness shall be calculated as given in [5.1] for the stern area or lower stern area as applicable.

7.5 Ice loads on propeller nozzles

The transverse ice force, F and the longitudinal ice force, F, acting on the nozzle shall be assessed on a case-by-case basis based on the Society's current practice.

For the determination of F, 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 [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 [m].

Guidance note:

Ice loads F acting on nozzles should be determined considering ice load formulation and load cases described in DNV-CG-0041 Sec.8.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.6 Propeller nozzle scantlings

The scantlings of the propeller nozzle and its supports in the hull shall be calculated for the ice loads given in [7.5]. 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 [5.1] using the design ice pressure as given for the stern area, lower stern area as applicable.

7.7 Podded propulsors and azimuth thrusters

7.7.1 Ships operating in ice and equipped with podded propulsors or azimuth thrusters shall be designed according to operational mode and purpose stated in the design specification. If not given, it shall be assumed that the ship may operate longer periods in ice using astern running mode as part of its operational profile. When limitations are given, this information shall also be stated in the appendix to the classification certificate.

7.7.2 Ramming astern is not anticipated.

7.7.3 Documentation of both local and global strength capacity of the pod/thruster shall be submitted for class assessment. Recognized structural idealization and calculation methods shall be applied.

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7.7.4 Ice loads on pod/thruster body shall be assessed on a case-by-case basis based on the Society's current practice.

Guidance note:

1) Ice loads on pod/thruster body should be determined considering ice load formulation and load cases described in DNV-CG-0041 Sec.7.
2) Ice load on bow tunnel thruster grid should be assessed considering ice load and load cases described in DNV-CG-0041 Sec.8.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.7.5 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.

8 Direct calculations

8.1 General

8.1.1 Direct calculations shall not be utilized as an alternative to the analytical procedures prescribed for shell plating and local frames.

8.1.2 Direct calculations shall be used for load carrying stringers and web frames forming a part of a grillage system.

8.1.3 Where direct calculation is used to check the strength of structural systems, the load patch specified in [4.5] shall not be combined with any other load. The load patch shall be applied at locations where the capacity of these members under the combined effects of bending and shear is minimized. Special attention shall be paid to lightening holes and cut-outs within the ice reinforced area.

8.1.4 The strength evaluation of the web frames and load carrying stringers may be performed based on linear or non-linear analysis. Recognized structural idealization and calculation methods shall be in accordance with Pt.3 Ch.7 Sec.1. In the strength evaluation, the guidance given in [8.2] and [8.3] may generally be considered.

8.2 Linear finite element analysis

If the structure is evaluated based on linear calculation methods, the following shall be considered:

1) Web plates and flanges elements in compression and shear to fulfil relevant buckling criteria as specified in Pt.3 Ch.8.
2) Nominal shear stresses in member web plates shall be less than:

$$\frac{R_{eH}}{\sqrt{3}}$$

3) Nominal von Mises stresses in member flanges shall be less than 1.15 R_{eH}.

8.3 Non-linear finite element analysis

8.3.1 Permanent set analyses

8.3.1.1 General

Non-linear finite element analysis should be carried out according to procedures provided in DNV-CG-0127 Sec.6. Acceptance criteria for each analysis shall be as described in [8.3.1.2] through [8.3.1.4].

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8.3.1.2 Permanent set analysis (in plane deformation)

For permanent set analysis, as specified in DNV-CG-0127 Sec.6 [9.2.1], permanent in plane local deflection of the member, after loading up to $P_D.CF_P$ and unloading, shall be $\delta_p \leq 0.3\,\%\ l$

where:

- l =web frame span. Web frame span shall be taken as the greater of spans of members sharing the same maximum permanent deflection, as illustrated by Figure 10 case 3, and shall, in any case, not be taken less than 3000 mm.

  See IACS Rec.47 *Shipbuilding and Repair Quality Standard*.

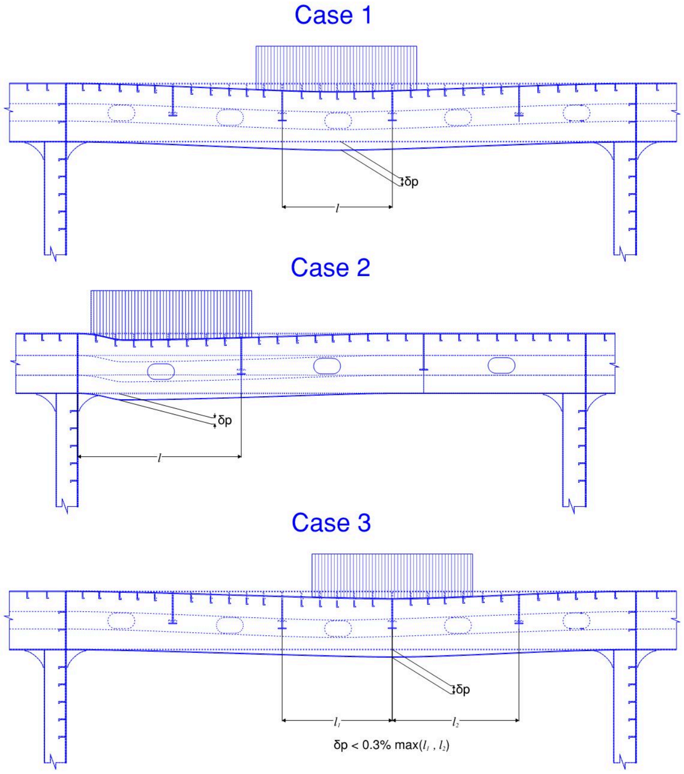

Figure 10 Permanent in plane defection

8.3.1.3 Permanent set analysis (out-of-plane deformation)

For permanent set analysis, as specified in DNV-CG-0127 Sec.6 [9.2.1], permanent buckling/out-of-plane deformations shall not be greater than the values listed in Table 9 and shall in any case not be greater than the maximum allowable deformations according to IACS Rec.47.

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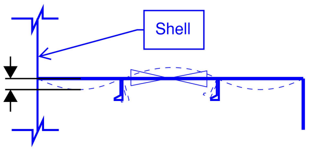
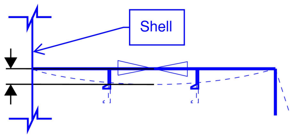
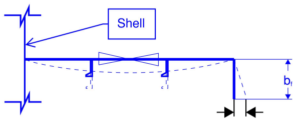
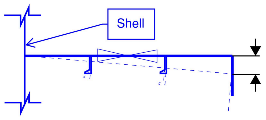
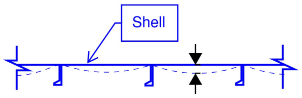
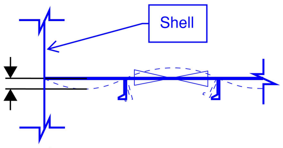
Table 9 Maximum allowable permanent out-of-plane deformation

Item	*Description*	*Max. out of plane deformation*
Stringers and web girders		8 mm
		
		3 mm per 100 mm of flange breadth b_f
		25 mm per 10 m of length of the span
Shell plating 1)		8 mm
Decks and transverse bulkheads		

1) The acceptance criteria applies only for out of plane permanent deflection due to overall shell structure response to ice load, and shall not apply for the case where an ice patch land directly on a shell plate filed, as this case is already covered by the prescriptive rules under [5.1].

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8.3.1.4 Overload capacity analysis

Slope of load-deflection curve shall be positive up to 150% of design ice load, P_D, see DNV-CG-0127 Sec.6 Figure 5.

9 Welding

9.1 General

9.1.1 All welding within ice-strengthened areas shall be of the double continuous type.

9.1.2 Continuity of strength shall be ensured at all structural connections.

9.2 Minimum weld requirements

9.2.1 The weld connection of local frames (stiffeners) and load carrying stringers and web frames supporting local frames to shell shall be as given in Pt.3 Ch.13 Sec.1 [2.5] with the weld factor, f_{weld}, given as:

f_{weld} = $0.31 r_w$, minimum 0.25, for middle 60% of span
= $0.52 f_{tr} . r_w$, minimum 0.35, at ends

f_{tr} = 1.4 for transverse frames
= 1.0 in general

r_w = ratio of required net web area over fitted net web area for the considered number

$$r_w = \frac{A}{A_w}$$

A = minimum shear area of the local frame as given in [5.3.2] and [5.4.2]
A_w = effective net shear area of the local frame according to [5.2.8].

9.2.2 Weld throat thickness need not be greater than 0.50 × as built thickness of the abutting plate.

10 Materials and corrosion protection

10.1 Corrosion/abrasion additions and steel renewal

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

10.1.2 Type approved abrasion resistant coatings, listed in DNV-CP-0293, may be accepted as effective protection against corrosion and ice-induced abrasion.

Guidance note:

Abrasion resistant coatings which are not type approved according to DNV-CP-0293, may be accepted based on adequate documentation of satisfactory service experience and laboratory tests.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

10.1.3 The values of corrosion/abrasion additions, t_s, to be used in determining the shell plate thickness are listed in Table 10.

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Table 10 Corrosion/abrasion additions for shell plating

Hull area	*t_s [mm]*					
	With effective protection			*Without effective protection*		
	PC(1) PC(2) PC(3)	***PC(4) PC(5)***	***PC(6) PC(7)***	***PC(1) PC(2) PC(3)***	***PC(4) PC(5)***	***PC(6) PC(7)***
Bow: bow intermediate ice belt	3.5	2.5	2.0	7.0	5.0	4.0
Bow intermediate lower: midbody and stern ice belt	2.5	2.0	2.0	5.0	4.0	3.0
Midbody and stern lower: bottom	2.0	2.0	2.0	4.0	3.0	2.5

10.1.4 Polar class ships shall 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.

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

10.2 Hull materials

10.2.1 Steel grades of plating for hull structures shall be not less than those given in Table 12 based on the as-built thickness, the **PC** class notation assigned to the ship and the material class of structural members given in [10.2.2].

10.2.2 Material classes specified in Pt.3 Ch.3 Sec.1 are applicable to polar class ships regardless of the ship's length. In addition, material classes for weather and sea exposed structural members and for members attached to the weather and sea exposed shell plating of polar class ships are given in Table 11. Where the material classes in Table 11 and those in Pt.3 Ch.3 Sec.1 differ, the higher material class shall be applied.

Table 11 Material classes for structural members of polar ships

Structural members	*Material class*
Shell plating within the bow and bow intermediate ice belt hull areas (B, BI_i)	II
All weather and sea exposed SECONDARY and PRIMARY, as defined in Pt.3 Ch.3 Sec.1 Table 3, structural members outside 0.4 *L* 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 Pt.3 Ch.3 Sec.1 Table 3, structural members within 0.2 *L* from FP	II

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10.2.3 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 Figure 11, shall be obtained from Pt.3 Ch.3 Sec.1 based on the material class for structural members in Table 11 above, regardless of qualifier.

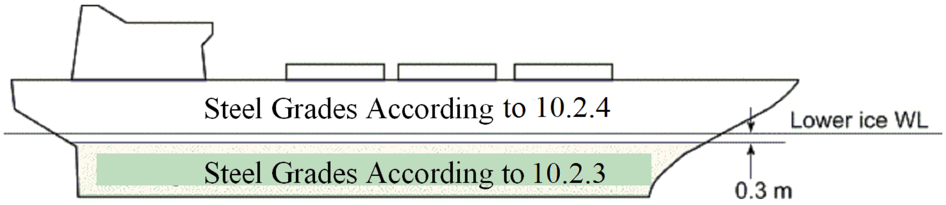

Figure 11 Steel grade requirements for submerged and weather exposed shell plating

Table 12 Steel grades for weather exposed plating 1)

Thickness t [mm]	*Material class I*				*Material class II*				*Material class III*					
	PC(1) *through* ***(5)***		***PC(6)*** *and* ***(7)***		***PC(1)*** *through* ***(5)***		***PC(6)*** *and* ***(7)***		***PC(1)*** *through* ***(3)***		***PC(4)*** *and* ***(5)***		***PC(6)*** *and* ***(7)***	
	MS	*HT*	*MS*	*HT*	*MS*	*HT*	*MS*	*HT*	*MS*	*HT*	*MS*	*HT*	*MS*	*HT*
$t \le 10$	B	AH	B	AH	B	AH	B	AH	E	EH	E	EH	B	AH
$10 < t \le 15$	B	AH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
$15 < t \le 20$	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
$20 < t \le 25$	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
$25 < t \le 30$	D	DH	B	AH	E	EH 2)	D	DH	E	EH	E	EH	E	EH
$30 < t \le 35$	D	DH	B	AH	E	EH	D	DH	E	EH	E	EH	E	EH
$35 < t \le 40$	D	DH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
$40 < t \le 45$	E	EH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
$45 < t \le 50$	E	EH	D	DH	E	EH	D	DH	F	FH	F	FH	E	EH

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.

10.2.4 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 Figure 11, shall be not less than given in Table 12.

10.2.5 Forged or cast materials in structural members exposed to design temperatures lower than -10°C, shall fulfil requirements given in Sec.6 [6.2] and Sec.6 [6.3]. The test temperature of components in forged or cast materials fully exposed to ambient air shall, if the design temperature has not been specified, for notations **PC(1)** to **PC(5)** be taken as -20ºC and for notations **PC(6)** and **PC(7)** as -10ºC.

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10.3 Materials for machinery components

10.3.1 General

Materials shall be of an approved ductile material. Ferritic nodular cast iron may be used for parts other than bolts. For nodular cast iron an averaged impact energy value of 10 J at testing temperature is regarded as equivalent to the Charpy V test requirements defined below.

Charpy V impact tests are not required for bronze and austenitic steel.

10.3.2 Materials exposed to seawater

Materials exposed to seawater, such as propeller blades, propeller hubs and cast thruster bodies, shall have an elongation not less than 15% on a test specimen according to IACS UR W2.

Charpy V-notch impact testing shall be carried out on three specimens at minus 10 ºC, and the average energy value shall not be less than 20 J. However, Charpy V impact test requirements of IACS UR W7 or UR W27 as applicable for ships with ice class notation, shall also be applied to ships covered by this rule section.

This requirement applies to components such as but not limited to blade bolts, CP-mechanisms, shaft bolts, propeller shaft, strut-pod connecting bolts, etc. This requirement does not apply to surface hardened components, such as bearings and gear teeth or sea water cooling lines (heat exchangers, pipes, valves, fittings, etc.).

For a definition of structural boundaries exposed to seawater temperature, see Figure 11.

10.3.3 Materials exposed to low air temperature

Materials of exposed machinery and foundations shall be manufactured from steel or other approved ductile material. An average impact energy value of 20 J taken from three Charpy V tests shall be obtained at 10 ºC below the lowest design temperature. This requirement does not apply to surface hardened components, such as bearings and gear teeth.

For a definition of structural boundaries exposed to air temperature, see Figure 11.

11 Definitions, machinery and systems

11.1 Definitions of symbols

Table 13 Definitions of symbols

Symbol	*Unit*	*Definition*
c	m	chord length of blade section
$c_{0.7}$	m	chord length of blade section at 0.7R propeller radius
CP	-	controllable pitch
D	m	propeller diameter
d	m	external diameter of propeller hub (at propeller plane)
d_p	m	required diameter of propeller shaft
d_{pin}	mm	diameter of shear pin
D_{limit}	m	limit value for propeller diameter
EAR	-	expanded blade area ratio
F_b	kN	maximum backward blade force for the ship’s service life

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Symbol	*Unit*	*Definition*
F_{ex}	kN	ultimate blade load resulting from blade failure through plastic bending
F_f	kN	maximum forward blade force for the ship’s service life
F_{ice}	kN	ice load
$(F_{ice})_{max}$	kN	maximum ice load for the ship’s service life
FP	-	fixed pitch
h_0	m	depth of the propeller centreline from lower ice waterline (*LIWL*)
H_{ice}	m	Ice block dimension for propeller load definition
I	kgm^2	equivalent mass moment of inertia of all parts on 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 S-N curve in log/log scale
M_{BL}	kNm	blade bending moment
MCR	-	maximum continuous rating
N	-	number of ice load cycles
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 ice impacts per propeller revolution per ice class
N_{ice}	-	total number of ice load cycles on propeller blade for the ship’s service life
N_R	-	reference number of ice load cycles 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
PCD	m	pitch circle diameter
$Q(\varphi)$	kNm	torque
Q_{Amax}	kNm	maximum response torque amplitude as a simulation result
Q_{emax}	kNm	maximum engine torque
$Q_F(\varphi)$	kNm	ice torque excitation for frequency domain calculations
Q_{fr}	kNm	friction torque in pitching mechanism, reduction of spindle torque
Q_{max}	kNm	maximum torque on the propeller resulting from propeller/ice interaction
Q_{motor}	kNm	electric motor peak torque

Symbol	Unit	Definition
Q_n	kNm	nominal torque at MCR in free running condition
$Q_r(t)$	kNm	response torque along the propeller shaft line
Q_{peak}	kNm	maximum of the response torque $Q_r(t)$
Q_{smax}	kNm	maximum spindle torque of the blade for the ship's service life
Q_{sex}	kNm	extreme spindle torque corresponding to the blade failure load F_{ex}
Q_{vib}	kNm	vibratory torque at considered component, taken from frequency domain open water TVC
R	m	propeller radius
S	-	safety factor
S_{fat}	-	safety factor for fatigue
S_{ice}	-	ice strength index for blade ice force
r	m	blade section radius
T	kN	Hydrodynamic propeller thrust in bollard condition
T_b	kN	maximum backward propeller ice thrust for the ship's service life
T_f	kN	maximum forward propeller ice thrust for the ship's service life
T_n	kN	propeller thrust at MCR in free running condition
T_r	kN	maximum response thrust along the shaft line
T_{Kmax}	kNm	maximum torque capacity of flexible coupling
T_{Kmax1}	kNm	T_{Kmax} at $N = 5 \times 10^4$ load cycles
T_{Kmax2}	kNm	T_{Kmax} at $N = 1$ load cycle
T_{KV}	kNm	vibratory torque amplitude at $N = 10^6$ load cycles
ΔT_{Kmax}	kNm	maximum range of T_{Kmax} at $N = 5 \times 10^4$ load cycles
t	m	maximum blade section thickness
Z	-	number of propeller blades
z_{pin}	-	number of shear pins
α_i	deg	duration of propeller blade/ice interaction expressed in rotation angle
γ_ε	-	reduction factor for fatigue, scatter and test specimen size effect
γ_v	-	reduction factor for fatigue, variable amplitude loading effect
γ_m	-	reduction factor for fatigue, mean stress effect
ρ	-	reduction factor for fatigue correlating the maximum stress amplitude to the equivalent fatigue stress for 10^8 stress cycles
$\sigma_{0.2}$	MPa	proof yield strength (at 0.2% plastic strain) of material
σ_{exp}	MPa	mean fatigue strength of blade material at 10^8 cycles to failure in sea water
σ_{fat}	MPa	equivalent fatigue ice load stress amplitude for 108 stress cycles

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Symbol	*Unit*	*Definition*
σ_{fl}	MPa	characteristic fatigue strength for blade material
σ_{ref1}	MPa	reference stress for blade failure load
σ_{ref2}	MPa	reference stress for blade fatigue evaluation
σ_{st}	MPa	maximum stress resulting from F_b or F_f
σ_u	MPa	ultimate tensile strength of blade material
$(\sigma_{ice})_{bmax}$	MPa	principal stress caused by the maximum backward propeller ice load
$(\sigma_{ice})_{fmax}$	MPa	principal stress caused by the maximum forward propeller ice load
$(\sigma_{ice})_{Amax}$	MPa	maximum ice load stress amplitude at the considered location on the blade
σ_{mean}	MPa	mean stress
$(\sigma_{ice})_A(N)$	MPa	blade stress amplitude distribution

11.2 Definitions of loads

Table 14 Definition of loads

Symbol	*Definition*	*Use of the load in design process*
F_b	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 Figure 12.	Design force for strength calculation of the propeller blade.
F_f	Maximum lifetime forward 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.	Design force for calculation of strength of the propeller blade.
Q_{smax}	Maximum lifetime spindle torque on a propeller blade resulting from propeller/ice interaction, including hydrodynamic 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.
T_b	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.	Used for estimation of the response thrust T_r and T_b can be used as an estimate of excitation for axial vibration calculations. However, axial vibration calculations are not required in the rules.
T_f	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.	Used for estimation of the response thrust T_r and T_f can be used as an estimate of excitation for axial vibration calculations. However, axial vibration calculations are not required in the rules.

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Symbol	*Definition*	*Use of the load in design process*
Q_{max}	Maximum ice-induced torque resulting from propeller/ice interaction on one propeller blade, including hydrodynamic loads on that blade.	Used for estimation of the response torque Q_r 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 $0.8R$	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_{sex}	Maximum spindle torque resulting from blade failure load	Used to ensure pyramid strength principle for the pitching mechanism
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.

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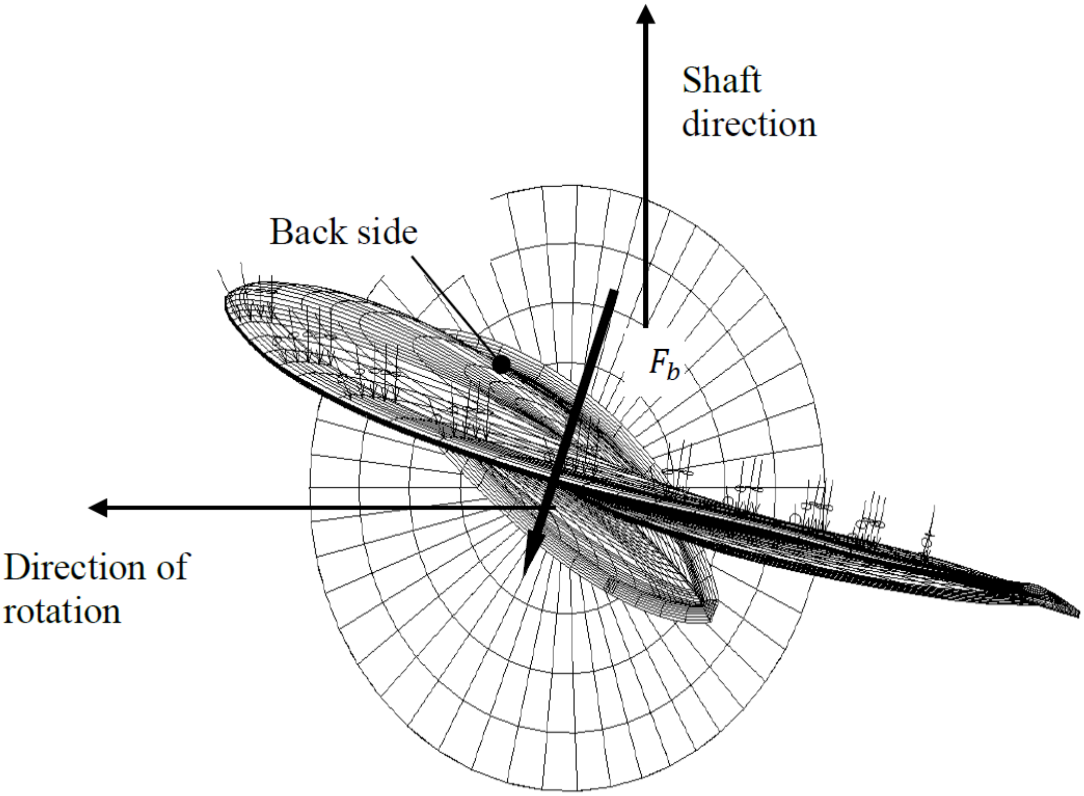

Figure 12 Direction of the backward blade force resultant taken perpendicular to the chord line at radius 0.7*R*. Ice contact pressure at leading edge is shown with small arrows

12 Design ice loads – machinery

12.1 General

12.1.1 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-mounted propellers shall receive special consideration. The given loads are expected, single occurrence, maximum values for the whole ship's service life for normal operational conditions, including loads resulting from directional change of rotation where applicable. These loads do not cover off-design operational conditions, for example when a stopped propeller is dragged through ice. These rules also cover loads due to propeller/ice interaction for azimuth and fixed thrusters with geared transmission or integrated electric motor (geared and podded propulsors). However, the load models of these rules do not cover propeller/ice interaction loads when ice enters the propeller of a turned azimuthing thruster from the side (radially), or when an ice block hits the propeller hub of a pulling propeller. Ice loads resulting from ice impacts on the body of thrusters are not included in this section.

12.1.2 The loads given in this section are total loads including ice-induced loads and hydrodynamic loads (unless otherwise stated) during ice interaction and shall be applied separately (unless otherwise stated) and are intended for component strength calculations only.

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12.1.3 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 a propeller interacts with an ice block while rotating ahead. F_b and F_f originate from different propeller and ice interaction phenomena, which do not act simultaneously. Hence, they shall be applied separately.

12.2 Ice class factors

The dimensions of the considered design ice block are $H_{ice} \times 2H_{ice} \times 3H_{ice}$. The design ice block and ice strength index (S_{ice}) are used for the estimation of propeller ice loads. Both H_{ice} and S_{ice} are defined for each ice class in Table 15.

Table 15 Design ice class factors

Ice class	*H_{ice} [m]*	*S_{ice} [-]*
PC(1)	4.0	1.2
PC(2)	3.5	1.1
PC(3)	3.0	1.1
PC(4)	2.5	1.1
PC(5)	2.0	1.1
PC(6)	1.75	1
PC(7)	1.5	1

12.3 Interaction loads between propeller and ice

12.3.1 Maximum backward blade force F_b for open propellers

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 $D \geq D_{limit}$:

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

where:

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

and:

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

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12.3.2 Maximum forward blade force F_f for open propellers

when $D < D_{limit}$:

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

when $D \geq D_{limit}$:

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

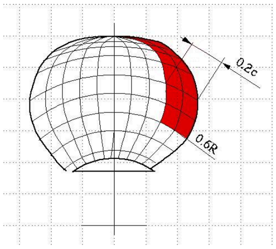
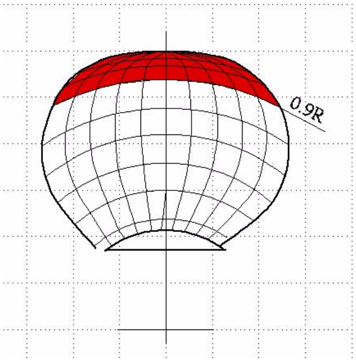
where:

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

12.3.3 Loaded area on the blade for open propellers

Load cases 1-4 shall be covered, as given in Table 16, for CP and FP propellers. In order to obtain blade ice loads for a reversing propeller, load case 5 shall also be covered for propellers where reversing is possible.

Table 16 Loaded areas and load case definitions 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 of 0.9R radius	

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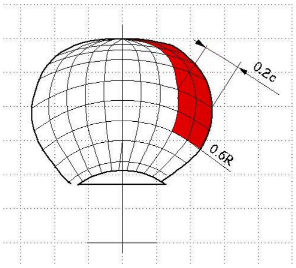
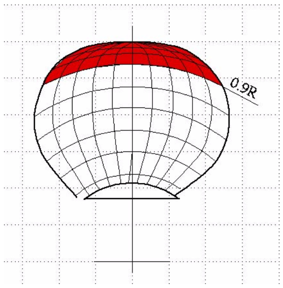
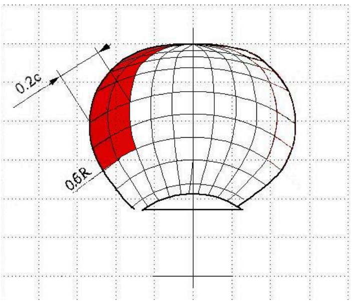
	Force	*Loaded area*	*Right handed propeller blade seen from behind*
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length	
Load case 4	50% of F_f	Uniform pressure applied on propeller face (pressure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

12.3.4 Maximum backward blade ice force F_b for ducted propellers

when $D < D_{limit}$:

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

when $D \geq D_{limit}$:

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

where:

$$D_{limit} = 4 \cdot H_{ice} \text{ [m]}$$

n shall be taken as in [12.3.1].

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12.3.5 Maximum forward blade ice 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 $D > D_{limit}$:

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

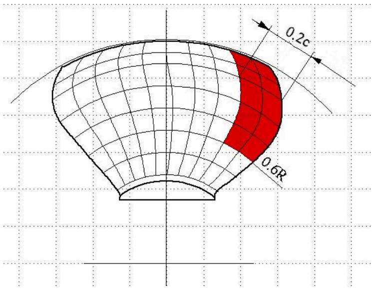
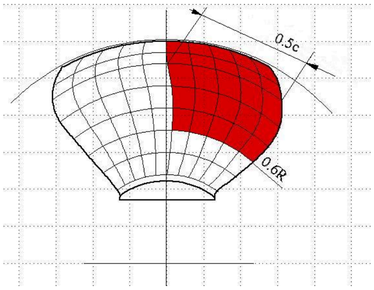
where:

$$D_{limit} = \frac{2}{1 - \frac{d}{D}} \cdot H_{ice} \text{ [m]}$$

12.3.6 Loaded area on the blade for ducted propellers

Load cases 1 and 3 shall be covered as given in Table 17 for all propellers. In order to obtain blade ice loads for a reversing propeller, load case 5 shall also be covered for propellers where reversing is possible.

Table 17 Loaded areas and load case definition for ducted propellers

	Force	*Loaded area*	*Right handed propeller blade seen from back*
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	

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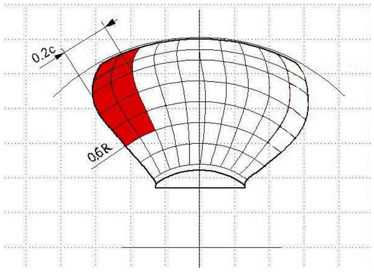
	Force	*Loaded area*	*Right handed propeller blade seen from back*
Load case 5	60% of F_b or F_f, whichever is greater	Uniform pressure applied on propeller face (pressure side) to an area from $0.6R$ to the tip and from the trailing edge to 0.2 times the chord length	

12.3.7 Maximum blade spindle torque Q_{smax} for open and ducted propellers

The spindle torque around the axis of the blade fitting Q_{smax} shall be determined both for the maximum backward blade force F_b and forward blade force F_f, which are applied as per Table 16 and Table 17. If this method gives a value which is less than the default value given by the formula below, the default value shall be used.

Default value: $Q_{\text{smax}} = 0.25 \cdot F \cdot c_{0.7}$ [kNm]

where:

F = either F_b or F_f, whichever has the greater absolute value.

The blade failure spindle torque Q_{sex} is defined under [12.4.2].

12.3.8 Load distributions for blade loads

The Weibull-type distribution (probability that F_{ice} exceeds $(F_{ice})_{max}$), as given in Figure 13 is used for the fatigue design of the blade.

$$P\left(\frac{F_{ice}}{\left(F_{ice}\right)_{max}} \geq \frac{F}{\left(F_{ice}\right)_{max}}\right) = e^{\left(-\left(\frac{F}{\left(F_{ice}\right)_{max}}\right)^{k} \cdot \ln\left(N_{ice}\right)\right)}$$

where:

k = shape parameter of the spectrum

N_{ice} = number of ice load cycles in the spectrum

F_{ice} = random variable for ice loads on the blade, $0 \leq F_{ice} \leq \left(F_{ice}\right)_{max}$

This results in a blade stress amplitude distribution:

$$\left(\sigma_{ice}\right)_A(N) = \left(\sigma_{ice}\right)_{Amax} \cdot \left(1 - \frac{\log(N)}{\log\left(N_{ice}\right)}\right)^{\frac{1}{k}}$$

where:

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$$(\sigma_{ice})_{Amax} = \frac{(\sigma_{ice})_{fmax} - (\sigma_{ice})_{bmax}}{2}$$

Shape parameter k = 0.75 shall be used for the ice force distribution of an open propeller and shape parameter k = 1.0 for that of a ducted propeller.

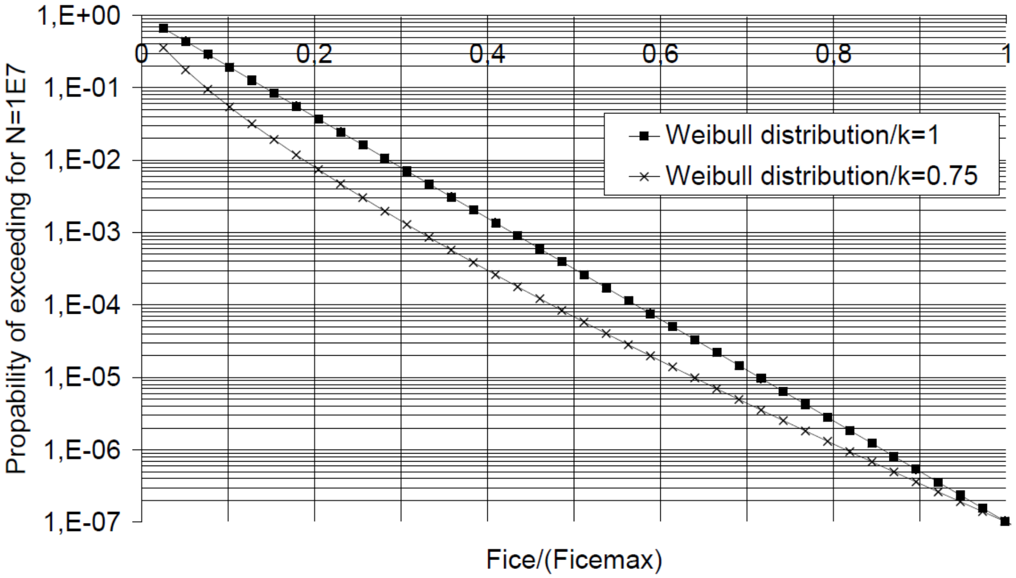

Figure 13 The Weibull-type distribution (probability that F_{ice} exceeds $(F_{ice})_{max}$) that is used for fatigue design.

12.3.9 Number of ice loads

Number of load cycles N_{ice} in the load spectrum per blade shall be determined according to the formula:

$$N_{ice} = k_1 \cdot k_2 \cdot k_3 \cdot N_{class} \cdot n$$

where:

N_{class} = reference number of impacts per propeller revolution for each ice class.

Ice class	***PC(1)***	***PC(2)***	***PC(3)***	***PC(4)***	***PC(5)***	***PC(6)***	***PC(7)***
N_{class}	21×10^6	17×10^6	15×10^6	13×10^6	11×10^6	9×10^6	6×10^6

k_1 = 1 for centre propeller
= 2 for wing propeller
= 3 for pulling propeller (wing and centre).

k_2 = $0.8 - f$ when $f < 0$
= $0.8 - 0.4 \cdot f$ when $0 \leq f \leq 1$
= $0.6 - 0.2 \cdot f$ when $1 < f \leq 2.5$

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= 0.1 when $f > 2.5$

k_3 = 1 for fixed propulsors

= 1.2 for azimuthing propulsors

where the immersion function *f* is:

$$f = \frac{h_0 - H_{ice}}{\frac{D}{2}} - 1$$

If h_0 is not known, h_0 = $D/2$.

For components that are subject to loads resulting from propeller and ice interaction with all propeller blades, the number of load cycles (N_{ice}) shall be multiplied by the number of propeller blades (Z).

12.4 Blade failure load for both open and ducted propellers

12.4.1 Bending force F_{ex}

The minimum load required resulting in blade failure through plastic bending shall be calculated iteratively along the radius of the blade from blade root to 0.5R using the equation below, with the ultimate load assumed to be acting at 0.8R in the weakest direction.

The blade failure load is:

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

where:

$$\sigma_{ref1} = 0.6 \cdot \sigma_{0.2} + 0.4 \cdot \sigma_u \text{ [MPa]}$$

and:

σ_u = minimum ultimate tensile strength specified on the drawing

$\sigma_{0.2}$ = minimum yield or 0.2% proof strength specified on the drawing

are representative values for the blade material,

and:

c = actual chord length

t = maximum thickness

r = 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.

A blade is regarded as having failed if the tip is bent by more than 10% of the propeller diameter.

12.4.2 Spindle torque Q_{sex}

The maximum spindle torque due to a blade failure load acting at 0.8R shall be determined. The force that causes blade failure typically reduces when moving from the propeller centre towards the leading and trailing

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edges. At a certain distance from the blade centre of rotation the maximum spindle torque will occur. This maximum spindle torque shall be obtained by an appropriate stress analysis or using the equation below.

$$Q_{sex} = \max\left(c_{LE0.8}; 0.8 \cdot c_{TE0.8}\right) \cdot C_{spex} \cdot F_{ex} \text{ [kNm]}$$

where:

$$C_{spex} = C_{sp} \cdot C_{fex} = 0.7 \cdot \left(1 - \left(4 \cdot \frac{EAR}{Z}\right)^3\right)$$

C_{sp} = non-dimensional parameter taking into account the spindle arm

C_{fex} = non-dimensional parameter taking into account the reduction of blade failure force at the location of maximum spindle torque.

If C_{spex} is below 0.3, a value of 0.3 shall be used.

$c_{LE0.8}$ = leading edge portion of the chord length at 0.8*R*

$c_{TE0.8}$ = trailing edge portion of the chord length at 0.8*R*.

Figure 14 illustrates the spindle torque values due to blade failure loads across the whole chord length.

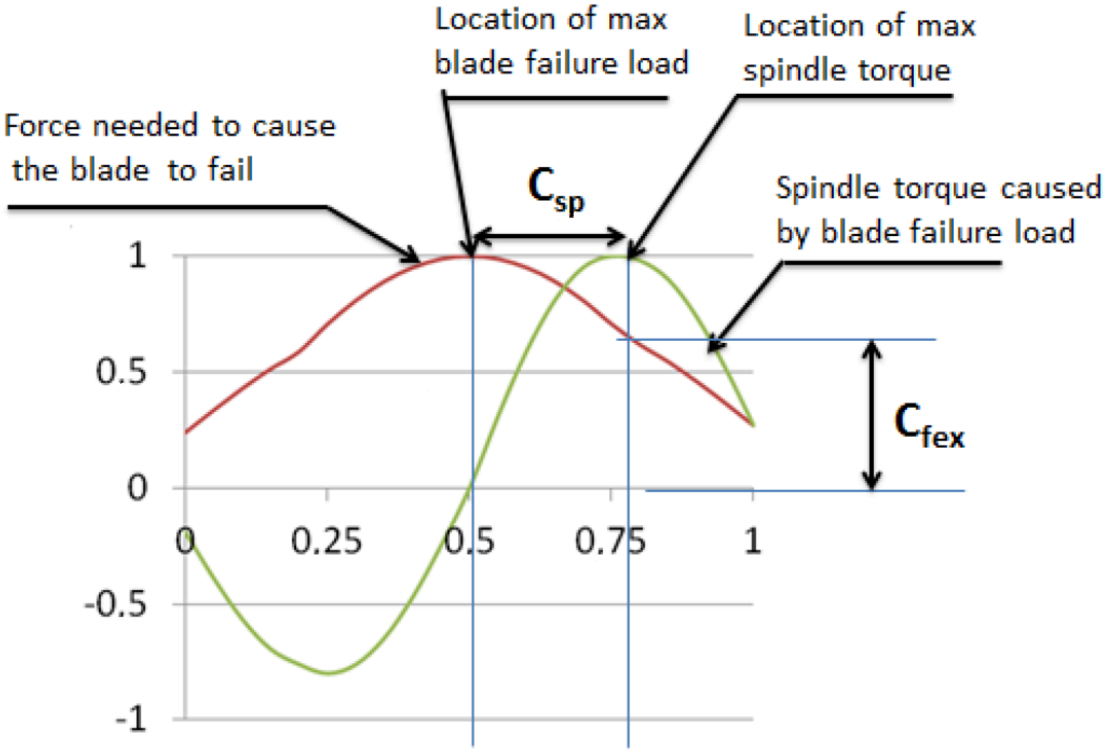

Figure 14 Schematic figure showing blade failure load and related spindle torque when the force acts at different location on the chord line at radius 0.8*R*.

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12.5 Axial design loads acting on open and ducted propellers

12.5.1 Maximum ice thrust on propeller T_f and T_b acting on open and ducted propellers

The maximum forward and backward ice thrusts are given by the following formulae:

$$T_f = 1.1 \cdot F_f \text{ [kN]}$$

$$T_b = 1.1 \cdot F_b \text{ [kN]}$$

The load models within this rule section do not include propeller/ice interaction loads where an ice block hits the propeller hub of a pulling propeller.

12.5.2 Design thrust along the propulsion shaft line for open and ducted propellers

The design thrust along the propeller shaft line shall be calculated with the formulae below. The greater value of the forward and backward directional load 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:

$$T_r = T + 2.2 \cdot T_f \text{ [kN]}$$

in backward direction:

$$T_r = 1.5 \cdot T_b \text{ [kN]}$$

If the hydrodynamic bollard thrust *T* is not known, *T* shall be taken as follows:

Table 18 Guidance for bollard thrust values

Propeller type	*T*
CP propellers (open)	1.25 T_n
CP propellers (ducted)	1.1 T_n
FP propellers driven by turbine or electric motor	T_n
FP propellers driven by diesel engine (open)	0.85 T_n
FP propellers driven by diesel engine (ducted)	0.75 T_n

Here, T_n is the nominal propeller thrust at MCR in free running open water condition.

where:

T_n = nominal propeller thrust at MCR in free running open water condition.

For pulling type propellers ice interaction loads on the propeller hub shall be considered in addition to the above.

12.6 Torsional design loads acting on open and ducted propellers

12.6.1 Design ice torque on propeller Q_{max} for open propellers

Q_{max} is the maximum torque on a propeller resulting from ice and propeller interaction.

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when D < $\mathrm{D}_{\mathrm{limit}}$:

$$Q_{\max} = k_{open} \cdot \left(1 - \tfrac{d}{D}\right) \cdot \left(\tfrac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^{3} \text{ [kNm]}$$

where:

k_{open} = 14.7 for **PC(1)** - **PC(5)**
= 10.9 for **PC(6)** - **PC(7)**

when $D \geq D_{limit}$:

$$Q_{\max} = 1.9 \cdot k_{open} \cdot \left(1 - \tfrac{d}{D}\right) \cdot H_{ice}{}^{1.1} \cdot \left(\tfrac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^{1.9} \text{ [kNm]}$$

where:

$$D_{limit} = 1.8 \cdot H_{ice}$$

and:

n = rotational propeller speed, in rev/s, in bollard condition

If not known, *n* shall be taken as shown in Table 19.

Table 19 Guidance for rotational speeds to calculate torsional loads

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

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

12.6.2 Design ice torque on propeller Q_{max} for ducted propellers

when D < D_{limit}:

$$Q_{\max} = k_{ducted} \cdot \left(1 - \tfrac{d}{D}\right) \cdot \left(\tfrac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^{3} \text{ [kNm]}$$

where:

k_{ducted} = 10.4 for **PC(1)** - **PC(5)**
= 7.7 for **PC(6)** - **PC(7)**

when $D \geq D_{limit}$:

$$Q_{\max} = 1.9 \cdot k_{ducted} \cdot \left(1 - \frac{d}{D}\right) \cdot H_{ice}{}^{1.1} \cdot \left(\frac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^{1.9} \text{ [kNm]}$$

where:

$$D_{limit} = 1.8 \cdot H_{ice}$$

n shall be taken as in [12.6.1].

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

12.6.3 Ice torque excitation for open and ducted propellers

12.6.3.1

The given excitations are used to estimate the maximum torque likely to be experienced once during the service life of the ship. The following load cases are intended to reflect the operational loads on the propulsion system when the propeller interacts with ice and the corresponding reaction of the complete system. The ice impact and system response cause 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 considerations at specific shaft speeds are performed a relevant Q_{max} may be calculated using the relevant speed.

Diesel engine plants without an elastic coupling shall be calculated at the least favourable phase angle for ice versus engine excitation, when calculated in time domain. The engine firing pulses shall be included in the calculations and their standard steady state harmonics can be used. A phase angle between ice and gas force excitation does not need to be regarded in frequency domain analysis. Misfiring does not need to be considered.

If there is a blade order resonance just above MCR speed, calculations shall cover the rotational speeds up to 105% of MCR speed.

See also guidelines for calculations given in [15].

12.6.3.2 Excitation for time domain calculation

The propeller ice torque excitation for shaft line transient dynamic analysis (time domain) is defined as 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 defined as:

$$Q(\varphi) = C_q \cdot Q_{max} \cdot \sin\left(\varphi \cdot \left(\frac{180}{\alpha_i}\right)\right)$$

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 starting when the first impact occurs.

C_q and α_i parameters are given in Table 20. α_i is the duration of propeller blade and ice interaction expressed in propeller rotation angle.

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Table 20 Ice impact magnification and duration factors for different blade numbers

Torque excitation	Propeller/ ice interaction	C_q	α_i [deg]			
			Z = 3	Z = 4	Z = 5	Z = 6
Excitation case 1	Single ice block	0.75	90	90	72	60
Excitation case 2	Single ice block	1.0	135	135	135	135
Excitation case 3	Two ice blocks (phase shift 360/(2· Z) deg.)	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, taking into account the phase shift 360 deg./Z.

At the beginning and at the end of the milling sequence (within calculated duration) linear ramp functions shall be used to increase C_q to its maximum within one propeller revolution and vice versa to decrease it to zero.

The number of propeller revolutions during a milling sequence shall be obtained from the formula:

$$N_Q = 2 \cdot H_{ice}$$

The number of impacts is $Z{\cdot}N_Q$ for blade order excitation.

Guidance note:

An illustration of all excitation cases for different blade numbers is given in Sec.3 Figure 8. The illustration is made for ice class **Ice(1A)**, which for this purpose is identical to **PC(7)**.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

The dynamic simulation shall be performed for all excitation cases starting at MCR nominal, MCR bollard condition and just above all resonance speeds (first engine and first blade harmonic), so that the resonant vibration responses can be obtained. For a fixed pitch propeller plant the dynamic simulation shall also cover bollard pull condition with a corresponding speed assuming maximum possible output of the engine.

If a speed drop occurs down to stand still of the main engine, it 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 shall be applied. In these cases, the excitation shall follow the shaft speed.

12.6.3.3 Frequency domain excitation

For frequency domain calculations, the following torque excitation may be used. The excitation has been derived so that the time domain half sine impact sequences have been assumed to be continuous and the Fourier series components for first and second blade order have been derived. The frequency domain analysis is considered as conservative compared to the time domain simulation provided there is a first blade order resonance in the considered speed range.

$$Q_{F(\varphi)} = Q_{max} \cdot \left(C_{q0} + C_{q1} \cdot \sin\left(Z \cdot E_0 \cdot \varphi + \alpha_1\right) + C_{q2} \cdot \sin\left(2 \cdot Z \cdot E_0 \cdot \varphi + \alpha_2\right)\right) \text{ [kNm]}$$

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where:

C_{q0} = mean torque component
C_{q1} = first blade order excitation amplitude
C_{q2} = second blade order excitation amplitude
E_0 = number of ice blocks in contact
Φ = angle of rotation
$\alpha_{1,2}$ = phase angle of excitation component
Z = number of blades.

Table 21 Coefficients for simplified excitation torque estimation

Torque excitation	Z = 3					
	C_{q0}	C_{q1}	α_1	C_{q2}	α_2	E_0
Excitation case 1	0.375	0.375	-90	0	0	1
Excitation case 2	0.70	0.33	-90	0.05	-45	1
Excitation case 3	0.25	0.25	-90	0	0	2
Excitation case 4	0.20	0.25	0	0.05	-90	1
Torque excitation	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	0.20	0.25	0	0.05	-90	1
Torque excitation	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	0.30	0.25	-90	0.048	-90	2
Excitation case 4	0.20	0.25	0	0.05	-90	1
Torque excitation	Z = 6					
Excitation case 1	0.45	0.375	-90	0.05	-90	1
Excitation case 2	1.435	0.10	-90	0	0	1
Excitation case 3	0.30	0.25	-90	0.048	-90	2
Excitation case 4	0.20	0.25	0	0.05	-90	1

Torsional vibration responses shall be calculated for all excitation cases.

The results of the relevant excitation cases at the most critical rotational speeds shall be used in the following way:

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- The highest response torque (between the various lumped masses in the system) is in the following referred to as peak torque Q_{peak}.
- The highest torque amplitude during a sequence of impacts shall be determined as half of the range from max to min torque and is referred to as Q_{Amax}.

An illustration of Q_{Amax} is given in Figure 15. It can be determined by:

$$Q_{\mathrm{Amax}} = \left(\frac{\max\left(Q_r(time)\right) - \min\left(Q_r(time)\right)}{2} \right) \text{ [kNm]}$$

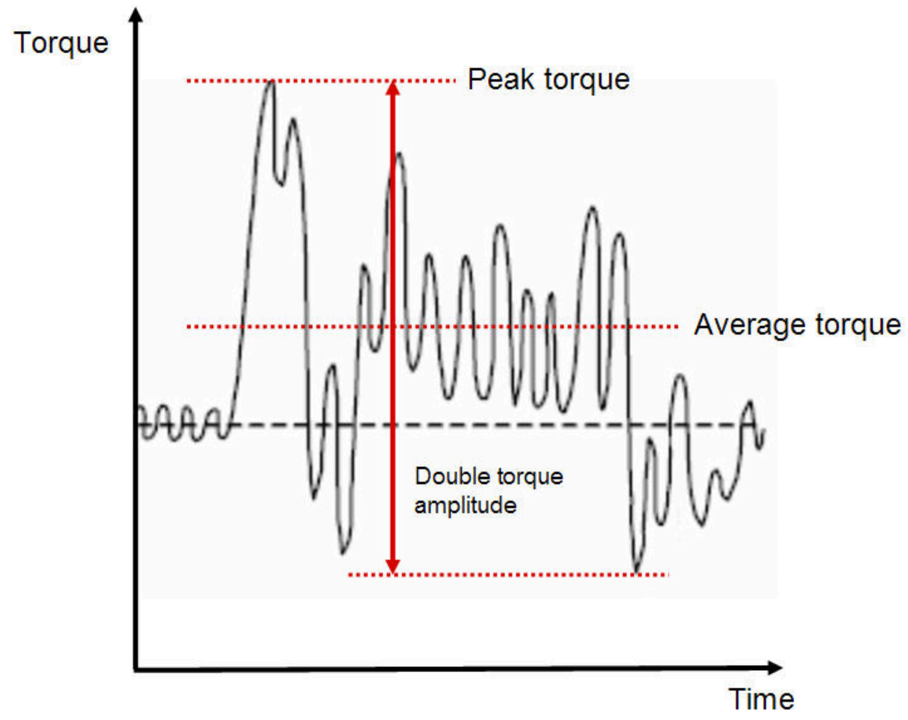

Figure 15 Illustration of different torque levels in a measured curve

12.6.4 Design torque along shaft line

12.6.4.1 Non-resonant shaft lines

If there is no relevant first order propeller torsional resonance in the range 20% (of n_n) above and 20% below the maximum operating speed in bollard condition (see Table 19), the following estimations of the maximum response torque may be used to calculate the design torque along the propeller shaft line:

$$Q_r = Q_{\mathrm{emax}} + Q_{vib} + Q_{\max} \cdot \frac{I}{I_t} \text{ [kNm]}$$

The equation above shall be applied for directly coupled two stroke Diesel engines without flexible coupling.

For all other plants:

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$$Q_r = Q_{\text{emax}} + Q_{\max} \cdot \frac{I}{I_t} \text{ [kNm]}$$

where:

I = equivalent mass moment of inertia of all parts on engine side of component under consideration
I_t = equivalent mass moment of inertia of the whole propulsion system.

All torques and inertia moments shall be reduced to the rotation speed of the component being examined.

If the maximum torque Q_{emax} is not known, it shall be taken as described in Table 22:

Table 22 Guideline for the determination of maximum motor torque

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 Q_n

where:

Q_{motor} = electric motor peak torque.

12.6.4.2 Resonant shaft lines

If there is a first blade order torsional resonance in the range 20% (of n_n) above and 20% below the maximum operating speed (bollard condition), the design torque (Q_r) of the shaft component shall be determined by means of a dynamic torsional vibration analysis of the entire propulsion line in the time domain or alternatively in the frequency domain. It is assumed that the plant is designed to avoid harmful operation in barred speed range.

12.6.5 Torsional vibration calculation

The aim of torsional vibration calculations is to estimate the torsional loads for individual shaft line components over the lifetime in order to determine scantlings for safe operation. The model can be taken from the normal lumped mass elastic torsional vibration model (frequency domain) including the damping. Standard harmonics may be used to consider the gas forces. The engine torque vs. speed curve of the actual plant shall be applied.

For time domain analysis the model shall include the ice excitation at propeller, the mean torques provided by the prime mover and the hydrodynamic mean torque produced by the propeller as well as any other relevant excitations. The calculations shall cover the variation of phase between the ice excitation and prime mover excitation. This is extremely relevant for propulsion lines with direct driven combustion engines.

For frequency domain calculations the load should be estimated as a Fourier component analysis of the continuous sequence of half sine load peaks. The first and second order blade components shall be used for excitation. The calculation shall cover the whole relevant shaft speed range. The analysis of the responses at the relevant torsional vibration resonances may be performed for open water (without ice excitation) and ice excitation separately. The resulting maximum torque can be obtained for directly coupled plants by the following superposition:

$$Q_{peak} = Q_{\text{emax}} + Q_{opw} + Q_{ice} \text{ [kNm]}$$

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where:

Q_{emax} = maximum engine torque at considered rotational speed

Q_{opw} = maximum open water response of engine excitation at considered shaft speed and determined by frequency domain analysis

Q_{ice} = calculated torque using frequency domain analysis for the relevant shaft speeds, ice excitation cases 1-4, resulting in the maximum response torque due to ice excitation.

13 Design – machinery

13.1 Design principles

The propulsion line shall be designed according to the pyramid strength principle. This means that the loss of a propeller blade shall not cause any significant damage to other propeller shaft line components.

The propulsion line components shall withstand maximum and fatigue operational loads with relevant safety margin. The loads do not need to be considered for shaft alignment or other calculations for normal operational conditions.

13.2 Fatigue design in general

The design loads shall be based on ice excitation described as a sequence of blade impacts (see [12.6.3.2]). The shaft response torque shall be determined according to [12.6.4].

The propulsion line components shall be designed to prevent accumulated fatigue failure when considering the relevant loads using the linear elastic Palmgren-Miner’s rule as defined below.

$$MDR = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \ldots + \frac{n_k}{N_k} \leq 1 \text{ or } MDR = \sum_{j=1}^{k} \frac{n_j}{N_j} \leq 1$$

where:

k = number of stress levels

$N_{1 \ldots k}$ = number of load cycles to failure of the individual stress level class

$n_{1 \ldots k}$ = accumulated number of load cycles of the case under consideration, per class

MDR = Miner's damage sum.

Guidance note:

The stress distribution can be divided into a frequency load spectrum having minimum 10 stress blocks (every 10 % of the load). Calculation with 5 stress blocks has been found to be too conservative. The maximum allowable load is limited by σ_{ref2} for propeller blades and yield strength for all other components. The load distribution (spectrum) must be in accordance with the Weibull distribution.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

13.3 Propeller blades

13.3.1 Calculation of blade stresses due to static loads

The equivalent and principal blade stresses shall be calculated for the design loads given in [12.3]. Finite element analysis (FEA) shall be used for stress analysis as part of the final approval for all propeller blades. The von Mises stresses, taken as σ_{st}, shall comply with the acceptance criterion in [13.3.2].

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Alternatively, the following simplified equation can be used in estimating the blade stresses for all propellers in the root area ($r/R < 0.5$) for final approval.

$$\sigma_{st} = C_1 \cdot \frac{M_{BL}}{100 \cdot c \cdot t^2} \text{ [MPa]}$$

where:

$$C_1 = \frac{actual\ stress}{stress\ \ obtained\ \ with\ \ beam\ \ equation}$$

If the actual value is not available, C_1 shall be taken as 1.6.

and:

M_{BL} = $\left(0.75 - \frac{r}{R}\right) \cdot R \cdot F$, for relative radius $r/R < 0.5$

F = maximum of F_b and F_f, whichever is greater.

Guidance note:

A recommended fatigue analysis method is given in DNV-CG-0041 Sec.5.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

13.3.2 Acceptability criterion for static loads

The following criterion for calculated blade stresses shall be fulfilled:

$$\frac{\sigma_{ref2}}{\sigma_{st}} \geq 1.3$$

where:

σ_{st} = calculated stress for the design loads.

Guidance note:

If FE analysis is used in assessing the stresses, von Mises stresses must be used.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

13.3.3 Fatigue design of propeller blades

13.3.3.1 General

For materials with a two slope S-N curve (see Figure 16) the fatigue calculations defined in this chapter are not required if the following criterion is fulfilled:

$$\sigma_{\exp} \geq B_1 \cdot \sigma_{ref2}{}^{B_2} \cdot \log\left(N_{ice}\right)^{B_3} \text{ [MPa]}$$

where B_1, B_2 and B_3 are coefficients for open and ducted propellers, given in Table 23.

Table 23 Coefficients to check omission from fatigue calculation

	Open propeller	*Ducted propeller*
B_1	0.00328	0.00223
B_2	1.0076	1.0071
B_3	2.101	2.471

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Where the above criterion is not fulfilled the fatigue requirements shall be defined as follows:

- 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 σ_{fat} that produces the same fatigue damage as the expected load distribution shall be calculated according to Miner's rule and the acceptability criterion for fatigue in [13.3.3.3] shall be fulfilled. The equivalent stress is normalized for 100 million cycles.
- The blade stresses at various selected load levels for fatigue analysis shall be taken proportional to the stresses calculated for maximum loads given in [12.3]. The peak principal stresses σ_f and σ_b are determined from F_f and F_b using FEA. The peak stress range $\Delta\sigma_{max}$ and the maximum stress amplitude σ_{Amax} are determined on the basis of load cases 1 and 3, and 2 and 4.

$$\Delta\sigma_{\max} = 2 \cdot \sigma_{A\max} = \left|\left(\sigma_{ice}\right)_{f\max}\right| + \left|\left(\sigma_{ice}\right)_{b\max}\right|$$

- For the calculation of equivalent stress, two types of S-N curves are available:
  - Two-slope S-N curve (slopes 4.5 and 10), see Figure 16.
  - Single-slope S-N curve (the slope can be chosen), see Figure 17.
- The type of the S-N-curve shall be selected to correspond with the material properties of the blade. If the S-N-curve is not known the two slope S-N curve shall be used.

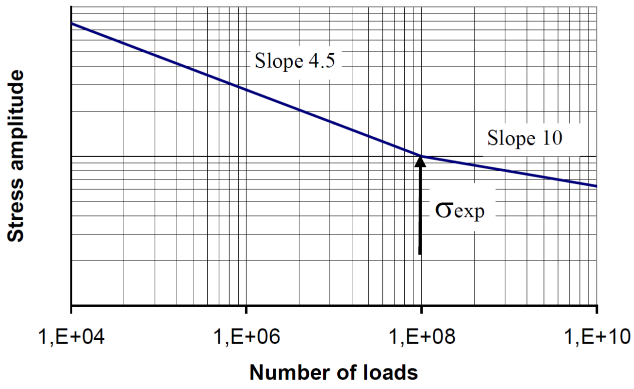

Figure 16 Two-slope S-N curve

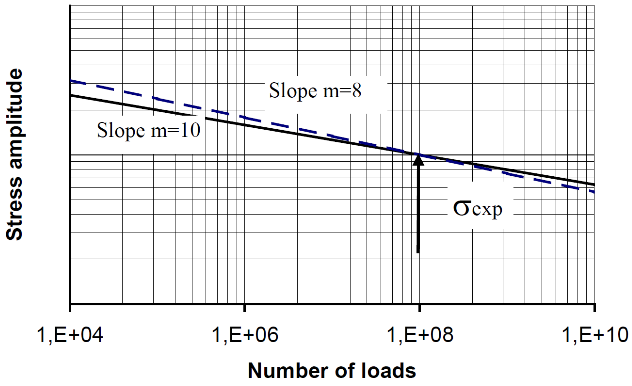

Figure 17 Single-slope S-N curve

13.3.3.2 Equivalent fatigue stress

The equivalent fatigue stress for 10^8 cycles which produces the same fatigue damage as the load distribution is:

$$\sigma_{fat} = \rho \cdot \left(\sigma_{ice}\right)_{max} \text{ [MPa]}$$

where:

$$\left(\sigma_{ice}\right)_{max} = 0.5 \cdot \left(\left(\sigma_{ice}\right)_{fmax} - \left(\sigma_{ice}\right)_{bmax}\right) \text{ [MPa]}$$

$(\sigma_{ice})_{max}$ = mean value of the principal stress amplitudes resulting from design forward and backward blade forces at the location being studied [MPa]

$(\sigma_{ice})_{fmax}$ = principal stress resulting from forward load [MPa]

$(\sigma_{ice})_{bmax}$ = principal stress resulting from backward load [MPa].

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In the calculation of $(\sigma_{ice})_{\text{max}}$, cases 1 and 3, or cases 2 and 4 are considered as pairs for $(\sigma_{ice})_{\text{fmax}}$, and $(\sigma_{ice})_{\text{bmax}}$ calculations. Case 5 is excluded from fatigue analysis.

Calculation of parameter ρ for two-slope S-N curve:

- The error of the following method to determine the parameter ρ is sufficiently small if the number of load cycles N_{ice} is in the range:

$$5 \cdot 10^6 \leq N_{ice} \leq 10^8$$

- The parameter ρ relates the maximum ice load to the distribution of ice loads according to the regression formula:

$$\rho = C_1 \cdot \left(\sigma_{ice}\right)_{max}^{\ \ C_2} \cdot \sigma_{fl}^{\ \ C_3} \cdot \log\left(N_{ice}\right)^{C_4}$$

  where σ_{fl} is the blade material fatigue strength at 10^8 load cycles, see [13.3.3.3].

  The coefficients C_1, C_2, C_3 and C_4 are given in Table 24.

Table 24 Coefficients to evaluate material fatigue strength

	Open propeller	*Ducted propeller*
C_1	0.000747	0.000534
C_2	0.0645	0.0533
C_3	-0.0565	-0.0459
C_4	2.22	2.584

Calculation of parameter ρ for single-slope S-N curve:

For materials with a single-slope S-N curve the factor ρ shall be calculated from the following formula:

$$\rho = \left(G \cdot \frac{N_{ice}}{N_R}\right)^{\frac{1}{m}} \cdot \left(\ln\left(N_{ice}\right)\right)^{-\frac{1}{k}}$$

where:

k = shape parameter of the Weibull distribution
= 1.0 for ducted propellers
= 0.75 for open propellers
N_R = reference number of load cycles (=10^8).

Values for the parameter G are given in Table 25. Linear interpolation may be used to calculate the value of G for m/k ratios other than those given in Table 25.

Table 25 Value for the parameter G for different m/k ratios

m/k	G	*m/k*	G	*m/k*	G
3	6	6.5	1871	10	$3.623 \cdot 10^6$
3.5	11.6	7	5040	10.5	$11.899 \cdot 10^6$

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m/k	G	m/k	G	m/k	G
4	24	7.5	14034	11	$39.917 \cdot 10^6$
4.5	52.3	8	40320	11.5	$136.843 \cdot 10^6$
5	120	8.5	119292	12	$479.002 \cdot 10^6$
5.5	287.9	9	362880		
6	720	9.5	$1.133 \cdot 10^6$		

Guidance note:

A more general method of determining the equivalent fatigue stress of propeller blades is described in [13.5], where the principal stresses are considered according to [12.3] using the Miner's rule. For a total number of load blocks n_{bl} > 100, both methods deliver the same result. Therefore, they are regarded as equivalent.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

13.3.3.3 Acceptability criterion for fatigue

The equivalent fatigue stress σ_{fat} at all locations on the blade shall fulfil the following acceptability criterion:

$$\frac{\sigma_{fl}}{\sigma_{fat}} \geq 1.5$$

where:

$$\sigma_{fl} = \gamma_{\epsilon 1} \cdot \gamma_{\epsilon 2} \cdot \gamma_v \cdot \gamma_m \cdot \sigma_{\text{exp}} \text{ [MPa]}$$

$\gamma_{\varepsilon 1}$ = 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
σ_{exp} = mean fatigue strength of the blade material at 10^8 cycles to failure in seawater [MPa].

Table 26 Mean fatigue strength σ_{exp} for different material types at 10^8 load cycles and stress ratio R = -1 with a survival probability of 50%

Mean fatigue strength σ_{exp} for different material types at 10^8 load cycles			
Bronze and brass (a = 0.10)		Stainless steel (a = 0.05)	
Mn-Bronze, CU1 (high tensile brass)	84 MPa	Ferritic (12Cr 1Ni)	144 MPa [1]
Mn-Ni-Bronze, CU2 (high tensile brass)	84 MPa	Martensitic (13Cr 4Ni/13Cr 6Ni)	156 MPa
Ni-Al-Bronze, CU3	120 MPa	Martensitic (16Cr 5Ni)	168 MPa
Mn-Al-Bronze, CU4	113 MPa	Austenitic (19Cr 10Ni)	132 MPa

1) This value may be used, provided a perfect galvanic protection is active. Otherwise, a reduction of about 30 MPa shall be applied.

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σ_{exp} in Table 26 has been defined from the results of constant amplitude loading fatigue tests at 10^7 load cycles and 50% survival probability and has been extended to 10^8 load cycles.

Guidance note:

Fatigue strength values and correction factors other than those given in Table 26 may be used, provided the values are determined under conditions approved by the Society.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

The S-N curve characteristics are based on two slopes, the first slope 4.5 is from 1000 to 10^8 load cycles, the second slope 10 is above 10^8 load cycles.

The maximum allowable stress for one or low number of cycles is limited to σ_{ref2}/S, with S = 1.3 for static loads.

The fatigue strength σ_{fat} is the fatigue limit at 100 million load cycles. The geometrical size factor $\gamma_{\varepsilon 2}$ is:

$$\gamma_{\epsilon 2} = 1.0 - a \cdot \ln\left(\frac{t}{0.025}\right)$$

where a is as given in Table 26 and t is the maximum blade thickness at the considered point.

The mean stress effect γ_m is:

$$\gamma_m = 1.0 - \left(\frac{1.4 \cdot \sigma_{mean}}{\sigma_u}\right)^{0.75}$$

The following values shall be used for the reduction factors if actual values are not available: $\gamma_{\varepsilon 1}$ = 0.85, γ_v = 0.75, and γ_m = 0.75.

13.4 Blade bolts, propeller hub, and CP mechanism

13.4.1 General

13.4.1.1 The blade bolts, CP mechanism, propeller boss and the fitting of the propeller to the propeller shaft shall be designed to withstand the maximum static and fatigue design loads (as applicable), as defined in [12.3] and [13.3]. The safety factor S against yielding due to static loads and against fatigue shall be greater than 1.5, if not stated otherwise. The safety factor S for loads resulting from propeller blade failure as defined in [12.4] shall be greater than 1.0 against yielding.

13.4.1.2 Provided that calculated stresses, duly considering local stress concentrations are less than yield strength, or maximum of 70% of σ_u for the respective materials, detailed fatigue analysis is not required. In all other cases components shall be analysed for cumulative fatigue. An approach similar to that used for shafting assessment may be applied, see [13.5].

13.4.2 Blade bolts

13.4.2.1 Blade bolts shall withstand the following bending moment considered around a tangent on bolt pitch circle, or any other relevant axis for non-circular joints, parallel to considered root section:

$$M_{bolt} = S \cdot F_{ex} \cdot \left(0.8 \cdot \frac{D}{2} \cdot r_{bolt}\right) \text{ [kNm]}$$

where:

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r_{bolt} = radius to the bolt plane [m]
S = safety factor (here = 1.0).

13.4.2.2 Blade bolt pre-tension shall be sufficient to avoid separation between mating surfaces when the maximum forward and backward ice loads defined in [12.3] (open and ducted propellers respectively) are applied. For conventional arrangements, the following formula may be applied:

$$d_{bb} = 41 \cdot \sqrt[2]{\frac{F_{ex} \cdot (0.8 \cdot D - d) \cdot S \cdot \alpha}{\sigma_{0.2} \cdot Z_{bb} \cdot PCD}} \text{ [mm]}$$

where:

α = 1.6 torque guided tightening
= 1.3 elongation guided
= 1.2 angle guided
= 1.1 elongated by other additional means.
d_{bb} = effective diameter of blade bolt in way of thread [mm]
Z_{bb} = number of blade bolts
S = Safety factor (here = 1.0).

13.4.3 CP mechanism

Separate means, e.g. dowel pins, shall be provided in order to withstand the spindle torque resulting from blade failure Q_{sex} [12.4.2] or ice interaction Q_{smax} [12.3.7], whichever is greater. Other components of the CP mechanism shall not be damaged by the maximum spindle torques (Q_{sex}, Q_{smax}). One third of the spindle torque is assumed to be consumed by friction, if not otherwise documented trough further analysis.

The required diameter of fitted pins d_{fp} between the blade and blade carrier can be calculated using the formula:

$$d_{fp} = 66 \cdot \sqrt{\frac{\left(Q_s - Q_{fr}\right)}{PCD \cdot z_{pin} \cdot \sigma_{0.2}}} \text{ [mm]}$$

where:

Q_s = $\max\left(S \cdot Q_{smax}; S \cdot Q_{sex}\right)$ [kNm]
S = safety factor (here = 1.3 for Q_{smax} and 1.0 for Q_{sex})
Q_{fr} = friction between connected surfaces taken as $Q_s/3$ (if not otherwise documented) [kNm].

The stress in the actuating pin can be estimated by:

$$\sigma_{vMises} = \sqrt{\left(\frac{\left(F \cdot \frac{h_{pin}}{2}\right)}{\frac{\Pi \cdot d_{pin}^{3}}{32}}\right)^{2} + 3 \cdot \left(\frac{F}{\frac{\Pi}{4} \cdot d_{pin}^{2}}\right)^{2}} \text{ [MPa]}$$

where:

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F = $\frac{Q_s - Q_{fr}}{l_m}$ [kN]
l_m = distance from pitching centre of blade to axis of pin [m]
h_{pin} = height of actuating pin [mm]
d_{pin} = diameter of actuating pin [mm]
Q_{fr} = friction torque in blade bearings acting on the blade palm and caused by the reaction forces due to F_{ex}, F_b or F_f, whichever is relevant, taken to one third of spindle torque Q_s if not known.

The blade failure spindle torque Q_{sex} shall not lead to any consequential damage.

Fatigue strength shall be considered for parts transmitting the spindle torque from the blade to a servo system considering the ice spindle torque acting on one blade with the maximum amplitude Q_{samax} defined as:

$$Q_{samax} = \frac{Q_{sb} + Q_{sf}}{2} \text{ [kNm]}$$

where:

Q_{sb} = spindle torque due to $|F_b|$ [kNm]
Q_{sf} = spindle torque due to $|F_f|$ [kNm].

13.4.4 Servo pressure

The design pressure for the servo system shall be taken as the pressure caused by Q_{smax} or Q_{sex} when not protected by relief valves on the hydraulic actuator side, reduced by relevant friction losses in bearings caused by the respective ice loads. The design pressure shall, in any case, not be less than relief valve set pressure.

13.5 Propulsion line components

13.5.1 General

The ultimate load resulting from total blade failure F_{ex} as defined in [12.4] shall consist of combined axial and bending load components, wherever this is significant. The minimum safety factor against yielding shall be 1.0 for all shaft line components.

The shafts and shafting components, such as bearings, couplings and flanges shall be designed to withstand the operational propeller/ice interaction loads as given in [12].

The given loads are not intended to be used for shaft alignment calculation.

Cumulative fatigue calculations shall be conducted according to the Miner’s rule. A fatigue calculation is not necessary, if the maximum stress is below fatigue strength at 10^8 load cycles.

The torque and thrust amplitude distribution (spectrum) in the propulsion line shall be taken as (because Weibull exponent k = 1):

$$Q_A\left(N\right) = Q_{A\max} \cdot \left(1 - \frac{\log(N)}{\log\left(Z \cdot N_{ice}\right)}\right)$$

This is illustrated by the example in Figure 18.

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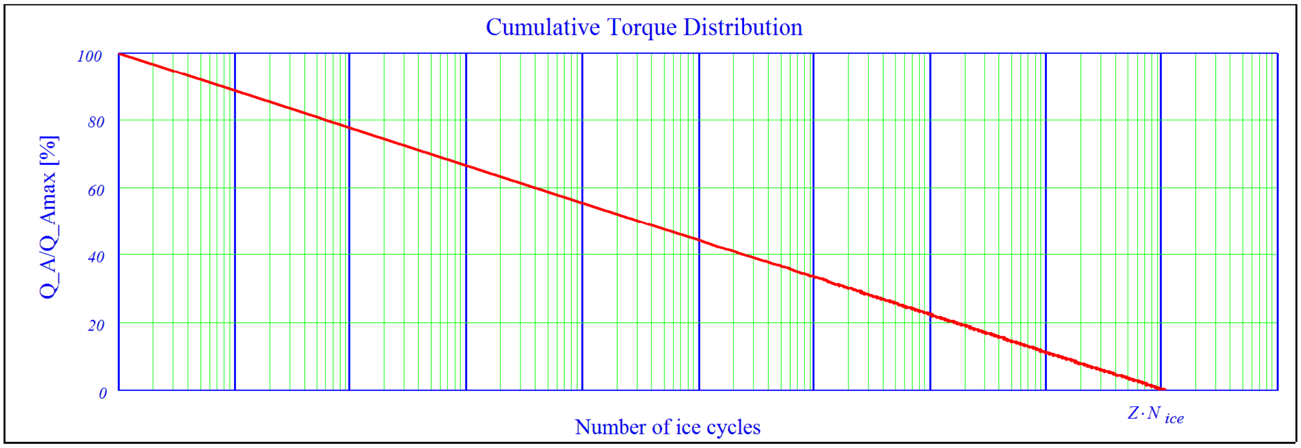

Figure 18 Cumulative torque distribution

The number of load cycles in the load spectrum is defined as $Z{\cdot}N_{ice}$.

The Weibull exponent shall be considered as k = 1.0 for both open and ducted propeller torque and bending forces. The load distribution is an accumulated load spectrum, and the load spectrum shall be divided into a minimum of ten load blocks when using the Miner summation method.

The load spectrum used counts the number of cycles for 100% load to be the number of cycles above the next step, e.g. 90 % load. This ensures that the calculation is on the conservative side. Consequently, the fewer stress blocks used the more conservative the calculated safety margin.

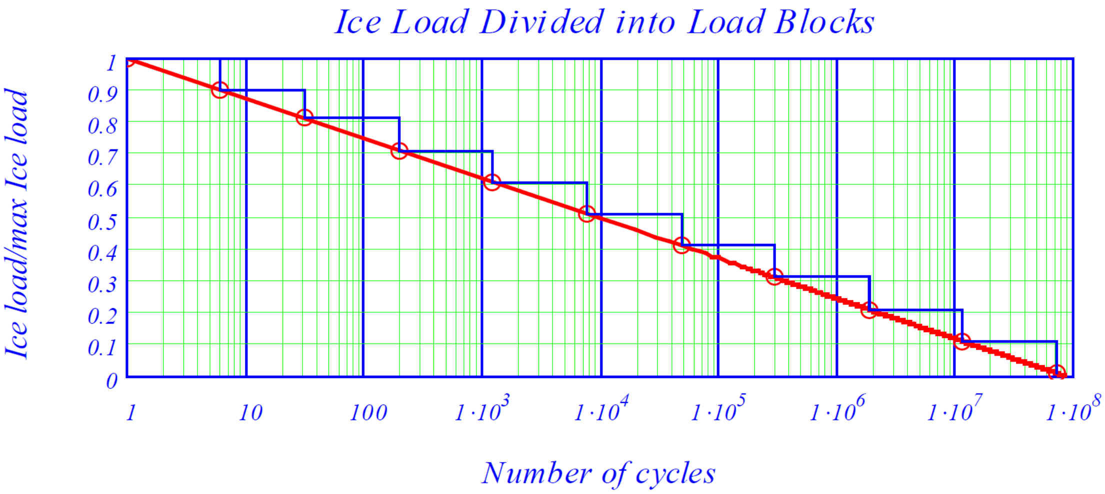

Figure 19 Example of ice load distribution (spectrum) for the shafting (k = 1)

The load spectrum is divided into n_{bl} number of load blocks for the Miner summation method.

The following formula can be used for calculation of the number of cycles for each load block.

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$$n_i = N_{ice}^{\,1-\left(1-\frac{i}{n_{bl}}\right)^k} - \sum_{i=1}^{i} n_{i-1}$$

where:

i = single load block i
n_{bl} = number of load blocks.

13.5.2 Propeller fitting to the shaft

13.5.2.1 Keyless cone mounting

The friction capacity (at 0° C) shall be at least S = 2.0 times the highest peak torque Q_{peak} as determined in [12.6] without exceeding the permissible hub stresses.

The necessary surface pressure $P_{0°C}$ may be determined as:

$$P_{0°C} = \frac{2 \cdot S \cdot Q_{peak}}{\pi \cdot \mu \cdot {D_S}^2 \cdot L \cdot 10^3}$$

where:

μ = 0.15 for steel-steel
= 0.13 for steel-bronze
D_S = shrinkage diameter at the mid-length of the taper [m]
L = effective length of taper [m].

The friction coefficients above may be increased by 0.04 if glycerine is used in wet mounting.

13.5.2.2 Key mounting

Key mounting is not permitted.

13.5.2.3 Flange mounting

The flange thickness shall be at least 25% of the required aft end shaft diameter (IACS UR M34).

Any additional stress raisers, such as recesses for bolt heads, shall not interfere with the flange fillet unless the flange thickness is increased correspondingly.

The flange fillet radius shall be at least 10% of the required shaft diameter.

The diameter of shear pins shall be calculated according to the following equation:

$$d_{pin} = 66 \cdot \sqrt{\frac{Q_{peak} \cdot S}{PCD \cdot z_{pin} \cdot \sigma_{0.2}}} \text{ [mm]}$$

where:

z_{pin} = number of shear pins
S = Safety factor (here = 1.3).

The bolts shall be designed so that the blade failure load F_{ex} in [12.4] in backward direction does not cause yielding of the bolts. The following equation shall be applied:

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$$d_b = 41 \cdot \sqrt{\frac{F_{ex} \cdot \left(0.8 \cdot \frac{D}{PCD} + 1\right)\alpha}{\sigma_{0.2} \cdot z_b}} \text{ [mm]}$$

where:

α = 1.6 torque guided tightening
= 1.3 elongation guided
= 1.2 angle guided
= 1.1 elongated by other additional means.
d_b = diameter of flange bolt [mm]
z_b = number of flange bolts.

13.5.3 Propeller shaft

13.5.3.1 Pyramid strength

The blade failure load F_{ex} in [12.4] applied parallel to the shaft (forward or backwards) shall not cause yielding. The bending moment need not to be combined with any other loads. The diameter d_p in way of the aft stern tube bearing shall not be less than:

$$d_p = 160 \cdot \sqrt[3]{\frac{F_{ex} \cdot D}{\sigma_{0.2} \cdot \left(1 - \frac{d_i^{\,4}}{d_o^{\,4}}\right)}} \text{ [mm]}$$

where:

d_p = propeller shaft required outer diameter [mm]
d_i = propeller shaft inner diameter [mm]
d_o = propeller shaft actual outer diameter [mm].

Forward from the aft stern tube bearing the shaft diameter may be reduced based on direct calculation of the actual bending moment, or by the assumption that the bending moment caused by F_{ex} is linearly reduced to 25% at the next bearing and in front of this linearly to zero at third bearing.

Bending due to maximum blade forces F_b and F_f have been disregarded since the resulting stress levels are much lower than the stresses caused by the blade failure load.

13.5.3.2 Stresses

The stresses due to the peak torque Q_{peak} shall have a minimum safety factor of S = 1.5 against yielding in plain sections and S = 1.0 in way of stress concentrations in order to avoid bent shafts.

Required diameter of:

a) plain shaft:

$$d_p = 210 \cdot \sqrt[3]{\frac{Q_{peak} \cdot S}{\sigma_{0.2} \cdot \left(1 - \frac{d_i^{\,4}}{d_o^{\,4}}\right)}} \text{ [mm]}$$

b) notched shaft:

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$$d_p = 210 \cdot \sqrt[3]{\frac{Q_{peak} \cdot S \cdot \alpha_t}{\sigma_{0.2} \cdot \left(1 - \frac{d_i^{\,4}}{d_o^{\,4}}\right)}}$$

where:

α_t = local stress concentration factor in torsion.

Notched shaft diameter shall, in any case, not be less than the required plain shaft diameter.

13.5.3.3 Torque amplitudes

The torque amplitudes [12.6.4] with the corresponding number of load cycles shall be used in an accumulated fatigue evaluation where the safety factor is S_{fat}=1.5. If the plant has high engine excited torsional vibrations (e.g. direct coupled 2-stroke engines), this shall also be considered.

13.5.3.4 Fatigue strength of shaft materials

The fatigue strengths σ_F and τ_F (3 million cycles) of shaft materials may be assessed on the basis of the material's yield or 0.2% proof strength as:

$$\sigma_F = 0.436 \cdot \sigma_{0.2} + 77 = \tau_F \cdot \sqrt{3} \text{ [MPa]}$$

This is valid for small polished specimens (no notch) and reversed stresses (see VDEH 1983 Bericht Nr. ABF11).

The high cycle fatigue (HCF) shall be assessed based on the above fatigue strengths, notch factors (i.e. geometrical stress concentration factors and notch sensitivity), size factors, mean stress influence and the required safety factor of 1.6 at 3 million cycles increasing to 1.8 at 10^9 cycles.

The low cycle fatigue (LCF) representing 10^4 cycles shall be based on the smaller value of yield or 0.7 of tensile strength/√3. The criterion utilizes a safety factor of 1.25.

The LCF and HCF as given above represent the upper and lower knees in a stress-cycle diagram. Since the required safety factors are included in these values, a Miner sum of 1.0 is acceptable.

13.5.4 Intermediate shafts

Intermediate shafts shall comply with [13.5.3.2] to [13.5.3.4].

13.5.5 Shaft connections

13.5.5.1 Shrink fit connections (keyless)

See [13.5.2.1]. A safety factor of S = 1.8 shall be applied.

13.5.5.2 Key mounting

Key mounting is not permitted.

13.5.5.3 Flange mounting

The flange thickness shall be at least 20% of the required shaft diameter (IACS UR M34).

Any additional stress raisers such as recesses for bolt heads shall not interfere with the flange fillet unless the flange thickness is increased correspondingly.

The flange fillet radius shall be at least 8% of the shaft diameter (IACS UR M34).

The diameter of ream fitted (light press fit) bolts shall be chosen so that the peak torque is transmitted with a safety factor of 1.9. This accounts for a prestress. Pins shall transmit the peak torque with a safety factor of 1.5 against yielding.

The bolts shall be designed so that the blade failure load F_{ex} in backward direction does not cause yielding.

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13.5.5.4 Splined connections

Splined shaft connections can be applied where no axial or bending loads occur. A safety factor of S = 1.5 against allowable contact and shear stress resulting from Q_{peak} shall be applied.

13.5.6 Gear transmissions

13.5.6.1 Shafts

Shafts in gear transmissions shall meet the same safety level as intermediate shafts, but where relevant bending stresses and torsional stresses shall be combined (e.g. by von Mises for static loads). Maximum permissible deflection in order to maintain sufficient tooth contact pattern shall be considered for the relevant parts of the gear shafts.

13.5.6.2 Gearing

Gears shall be designed according to Pt.4 Ch.4 Sec.2 with corresponding safety factor S against peak torque, Q_{peak}:

- tooth root stresses, S = 1.5
- pitting of flanks, S = 1.2
- scuffing, S = 1.2
- subsurface fatigue, S = 1.2 (for surface hardened gears).

Common for all criteria is the influence of load distribution over the face width. All relevant parameters shall be considered, such as elastic deflections (of mesh, shafts and gear bodies), accuracy tolerances, helix modifications, and working positions in bearings (especially for multiple input single output gears).

The load spectrum (see [13.5]) may be applied in such a way that the numbers of load cycles for the output wheel are multiplied by a factor of (number of pinions on the wheel / number of propeller blades Z). For pinions and wheels operating at higher speeds the numbers of load cycles are found by multiplication with the gear ratios. The peak torque (Q_{peak}) shall also be considered during calculations.

13.5.6.3 Bearings

See [13.5.10].

13.5.6.4 Gear wheel shaft connections

The torque capacity shall be at least 1.8 times the highest peak torque Q_{peak} (at considered rotational speed) as determined in [13.5] without exceeding the permissible hub stresses of 80% of yield.

13.5.7 Clutches

Clutches shall have a static friction torque of at least 1.3 times the peak torque Q_{peak} and dynamic friction torque 2/3 of the static.

Emergency operation of clutch after failure of e.g. operating pressure shall be made possible within reasonably short time. If this is arranged by bolts, it shall be on the engine side of the clutch in order to ensure access to all bolts by turning the engine.

13.5.8 Elastic couplings

There shall be a separation margin of at least 20% between the peak torque and the torque where any twist limitation is reached:

$$Q_{peak} < 0.8 \cdot T_{\mathrm{kmax}}(N = 1) \text{ [kNm]}$$

There shall be a separation margin of at least 20% between the maximum response torque Q_{peak} (see Figure 15) and the torque where any mechanical twist limitation and/or the permissible maximum torque of the elastic coupling, valid for at least a single load cycle (N = 1), is reached.

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A sufficient fatigue strength shall be demonstrated at design torque level $Q_r(N = x)$ and $Q_A(N = x)$. This may be demonstrated by interpolation in a Weibull torque distribution (similar to Figure 18):

$$\frac{Q_r(N=x)}{Q_r(N=1)} = 1 - \frac{\log(x)}{\log\left(Z \cdot N_{ice}\right)}$$

respectively:

$$\frac{Q_A(N=x)}{Q_A(N=1)} = 1 - \frac{\log(x)}{\log\left(Z \cdot N_{ice}\right)}$$

where $Q_r(N{=}1)$ corresponds to Q_{peak} and $Q_A(N = 1)$ to Q_{Amax}.

$Q_r(N = 5E4) \cdot S < T_{Kmax}(N = 5E4)$ [kNm]

$Q_r(N = 1E6) \cdot S < T_{KV}$ [kNm]

$Q_A(N = 5E4) \cdot S < \Delta T_{max}(N = 5E4)$ [kNm]

S is the general safety factor for fatigue, equal to 1.5.

The torque amplitude (or range Δ) shall not lead to fatigue cracking, i.e. exceeding the permissible vibratory torque. The permissible torque may be determined by interpolation in a Weibull torque distribution where T_{Kmax1} and ΔT_{Kmax} refer to 50 000 cycles and T_{KV} refers to 10^6 cycles.

See illustration in Figure 20, Figure 21, and Figure 22.

$$T_{K\max1} \geq Q_r \quad \text{at 50000 load cycles [kNm]}$$

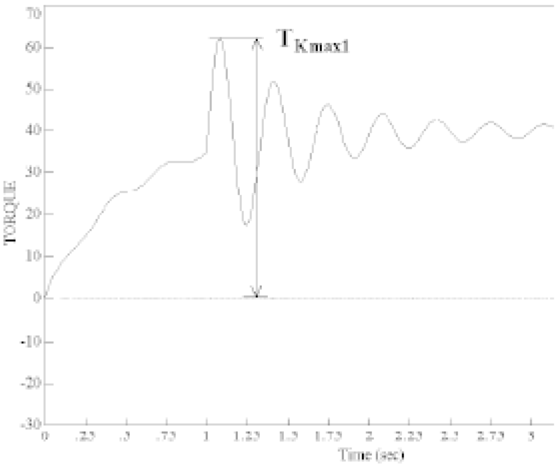

Figure 20 Illustration of T_{Kmax1}

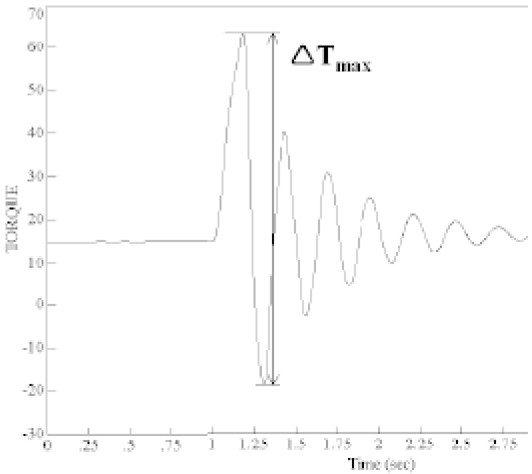

Figure 21 Illustration of ΔT_{max}

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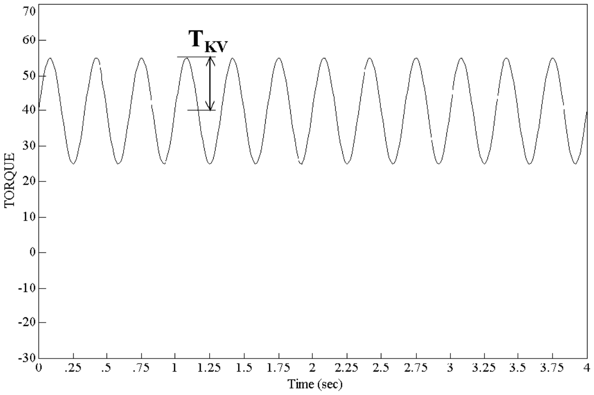

Figure 22 Illustration of T_{KV}

13.5.9 Crankshafts

Special considerations apply for plants with large inertia (e.g. flywheel, tuning wheel or PTO) in the non-driving end front of the engine (opposite to main power take off).

13.5.10 Bearings

The aft stern tube bearing as well as the next shaft line bearing shall withstand F_{ex} as given in [12.4], in such a way that the ship can maintain operational capability. Rolling bearings shall have an L_{10a} lifetime of at least 40 000 hours according to ISO 281:2007. Thrust bearings and their housings shall be designed to withstand with a safety factor S = 1.0 the maximum response thrust in [12.5] and the axial force resulting from the blade failure load F_{ex}. For the purpose of calculation, except for F_{ex}, the shafts are assumed to rotate at rated speed. For pulling propellers, special consideration shall be given to loads from ice interaction on the propeller hub.

13.5.11 Seals

Seals shall prevent egress of pollutants and be suitable for the relevant operating temperatures. Contingency plans for preventing the egress of pollutants under failure conditions shall be documented.

Seals installed shall be suitable for the intended application. The manufacturer shall provide service experience in similar applications and/or testing results for consideration.

13.6 Azimuthing main propulsors

In addition to the above requirements, special consideration shall be given to those loading cases which are extraordinary for propulsion units when compared with conventional propellers. The estimation of load cases shall reflect the way the thrusters are intended to operate on the specific ship. In this respect, for example, the loads caused by the impacts of ice blocks on the propeller hub of a pulling propeller shall be considered. Furthermore, loads resulting from the thrusters operating at an oblique angle to the flow shall 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 loss of a blade shall be considered for the propeller blade orientation which causes the maximum load on the component being studied. Typically, top-down blade orientation places the maximum bending loads on the thruster body.

Azimuth thrusters shall also be designed for estimated loads caused by thruster body/ice interaction. The thruster body shall withstand the loads obtained when the maximum ice blocks, which are given in [12.2], strike the thruster body when the ship is at a typical ice operating speed. In addition, the design situation in which an ice sheet glides along the ship’s hull and presses against the thruster body should be considered.

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The thickness of the sheet should be taken as the thickness of the maximum ice block entering the propeller, as defined in [12.2].

14 Prime movers

14.1 Propulsion engines

Engines shall be capable of being started and running the propeller in bollard condition.

Propulsion plants with CP propeller shall be capable being operated even when the CP system in full pitch as limited by mechanical stoppers.

14.2 Starting arrangements

The capacity of the air receivers shall be sufficient to provide, without recharging, 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.

If the air receivers serve any other purposes than starting the propulsion engine, they shall have additional capacity sufficient for these purposes.

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 **PC(6)** to **PC(1)**, 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.

14.3 Emergency power units

Provisions shall be made for heating arrangements to ensure ready starting from cold of the emergency power units at an ambient temperature as per the specified LMDLT for the vessel.

Emergency power units shall be equipped with starting devices with a stored energy capability of at least three consecutive starts at the above mentioned temperature. The source of stored energy shall be protected to preclude critical depletion by the automatic starting system, unless a second independent mean 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.

15 Steering systems

15.1 Rudder arrangements

See [7.2].

15.2 Rudder actuator

15.2.1 Holding torque

The rudder actuator shall be designed for a holding torque obtained by multiplying the open water torque resulting from the application of SOLAS Reg. II-1 /29.3.2 (considering however a maximum speed of 18 knots), by the following factors:

Ice class	***PC(1)***	***PC(2)***	***PC(3)***	***PC(4)***	***PC(5)***	***PC(6)***	***PC(7)***
Factor	5	5	3	3	3	1.5	1.5

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15.2.2 Design pressure

For hydraulically operated rudder actuators, the design pressure for calculations to determine the scantlings of the rudder actuator shall be at least 1.25 times the maximum working pressure corresponding to the holding torque defined in [15.2.1] (derived from SOLAS Reg. II-1 / 29.2.2). For electrically operated actuators, the same principle applies using a design torque of 1.25 times the defined holding torque.

15.2.3 Torque relief arrangements

The rudder actuator shall be protected by torque relief arrangements to account for the following (externally imposed) turning speeds, without undue pressure rise (see Pt.4 Ch.10 for definition of undue pressure rise):

Ice class	***PC(1)*** *and* ***PC(2)***	***PC(3)*** *to* ***PC(3)***	***PC(6)*** *and* ***PC(7)***
Turning speeds [deg/s]	10	7.5	6

If the rudder and actuator design can withstand such rapid loads, this special relief arrangement is not necessary and a conventional one may be used instead.

16 Equipment fastening loading accelerations

Essential equipment, their foundation arrangements and supports shall be suitable for the accelerations given in [4.1.10] to [4.1.12]. Accelerations shall be considered as acting independently.

17 Auxiliary systems

17.1 Protection from ice and snow

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

17.2 Protection from freezing

Means shall be provided to prevent damage to tanks containing liquids due to freezing.

17.3 Piping

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

18 Sea inlets, cooling water systems, and ballast tanks

18.1 Cooling water

Cooling water systems for machinery that are essential for the propulsion and safety of the ship, including sea chest inlets, shall be designed for the environmental conditions applicable to the ship's ice class.

18.2 Sea chests

At least two sea chests shall be arranged as ice boxes for ice class **PC(1)** to **PC(5)** inclusive. The calculated volume for each of the ice boxes shall be at least 1 m^3 for every 750 kW of the total installed power. For **PC(6)** and **PC(7)** there shall be at least one ice box located near the ship's centre line.

Ice boxes shall be designed for an effective separation of ice and venting of air.

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18.3 Sea inlet valves

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

Guidance note:

Butterfly valves are not considered to be full bore type valves.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

18.4 Vent pipes and shut off valves

Ice boxes and sea bays shall have vent pipes and shall have shut off valves connected directly to the shell.

18.5 Freezing prevention

Means shall be provided to prevent freezing of sea bays, ice boxes, ship side valves and fittings above the load water line.

18.6 Circulating pipes

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

18.7 Access to ice boxes

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

18.8 Openings and pipes for ice boxes

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

18.9 Ballast tanks

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

Guidance note:

Acceptable solutions for prevention of freezing can be air bubbling system. For tanks located fully or partly above the water line or lower ice water line (LIWL), whichever is lower, heat balance calculations may be provided in lieu of anti freezing arrangements.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

19 Ventilation systems

19.1 Air intakes

The air intakes for machinery and accommodation ventilation shall be located on both sides of the ship at locations where manual de-icing is possible. Anti-icing protection of the air inlets may be accepted as an equivalent solution to location on both sides of the ship and manual de-icing. Notwithstanding the above,

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multiple air intakes shall be provided for the emergency generating set and they shall be as far apart as possible.

19.2 Inlet air

The temperature of the inlet air shall be suitable for the safe operation of the machinery and the thermal comfort in the accommodation.

Accommodation and ventilation air intakes shall be provided with means of heating, if needed.

20 Alternative design

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

21 Stability and watertight integrity

21.1 General

Ships with a length L_{LL} of 24 meters and above and class notation **PC(7)** to **PC(1)** shall comply with the requirements of Pt.3 Ch.15 and IMO Res. MSC.385(94) Polar Code *Chapter 4 Subdivision and Stability* as well as the requirements of this subsection.

21.2 Intact stability

The initial metacentric height *GM* shall not be less than 0.5 m.

21.3 Requirements to watertight integrity

21.3.1 As far as practicable, tunnels, ducts or pipes which may cause progressive flooding in case of damage, shall be avoided in the damage penetration zone. If this is not possible, arrangements shall be made to prevent progressive flooding to volumes assumed intact. Alternatively, these volumes shall be assumed flooded in the damage stability calculations.

21.3.2 The scantlings of tunnels, ducts, pipes, doors, staircases, bulkheads and decks, forming watertight boundaries, shall be adequate to withstand pressure heights corresponding to the deepest equilibrium waterline in damaged condition.

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SECTION 8 DOUBLE ACTING VESSELS - DAV

1 General

1.1 Objective

The additional class notation **DAV** establishes requirements for vessels capable of proceeding with stern first in ice, without losing the capability of running effectively in lighter ice conditions and/or open waters with bow ahead.

1.2 Scope

The rules in this section cover requirements for hull structure, main propulsion and equipment for double acting vessels.

1.3 Application

1.3.1 Rules in this section are applicable to vessels intended for navigation with stern first in ice-infested polar waters and northern Baltic during the winter or areas with similar ice conditions.

1.3.2 A double acting vessel may be equipped with an ice going bow as well, with ice class notation similar to or lighter than the main ice class assigned for stern first in ice.

1.4 Assumptions

Ramming with stern is not assumed for a double acting vessel. The vessel is expected to proceed in ice with continuous aft motion instead of ramming, as the propeller is expected to mill ice while proceeding astern.

1.5 Class notations

Vessels built in compliance with requirements in this section may be assigned class notation **DAV** with relevant qualifiers, see Sec.1 Table 1.

Guidance note 1:

A double acting vessel, intended to advance with stern first in ice, may have an additional lighter ice class notation for advancing with bow first in lighter ice conditions.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note 2:

Examples of the class notation:

- **DAV(PC(3))** = double acting vessel with **PC(3)** requirements for stern first.
- **DAV(PC(4), Icebreaker)** = double acting vessel with **PC(4)** and **Icebreaker** requirements for stern first.
- **DAV(Ice(1A*))** = double acting vessel with **Ice(1A*)** requirements for stern first.

Examples for combination with lighter ice class notation for bow first:

- **DAV(PC(3)) PC(6)** = double acting vessel with **PC(3)** requirements for stern first and **PC(6)** class notation for the vessel (bow first).
- **DAV(Ice(1A*)) Ice(1C)** = double acting vessel with **Ice(1A*)** requirements for stern first and **Ice(1C)** class notation for the vessel (bow first).

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

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1.6 Symbols

For symbols and definitions not defined in this chapter, see Pt.3 Ch.1 Sec.4.

1.7 Definitions

All definitions included in Sec.1, Sec.3 and Sec.7, depending on the assigned qualifier, are applicable for this section.

2 Documentation requirements

All documentation requirements included in Sec.1, Sec.3 and Sec.7, depending on the assigned qualifier, are applicable for this section.

3 General requirements

3.1 Propulsion and steering arrangement

A double acting vessel shall be provided with azimuthing propulsion units, where astern operation is provided by turning the units around their vertical axis. Alternative propulsion and steering arrangements are subject to special consideration.

3.2 Propeller arrangement

The propeller(s) shall be located so that the entire propeller is below the ice level that corresponds to the assigned qualifier.

4 Stern first in ice with polar class

4.1 Hull area extents

4.1.1 The hull of double acting polar class vessels is divided based on the same principle as a conventional polar class vessel, with an ice breaking stern. In the longitudinal direction, there are four regions: stern, stern intermediate, midbody and bow. The stern intermediate, midbody and bow regions are further divided in the vertical direction into the bottom, lower and ice belt regions. The extent of each hull area is as illustrated in Figure 1.

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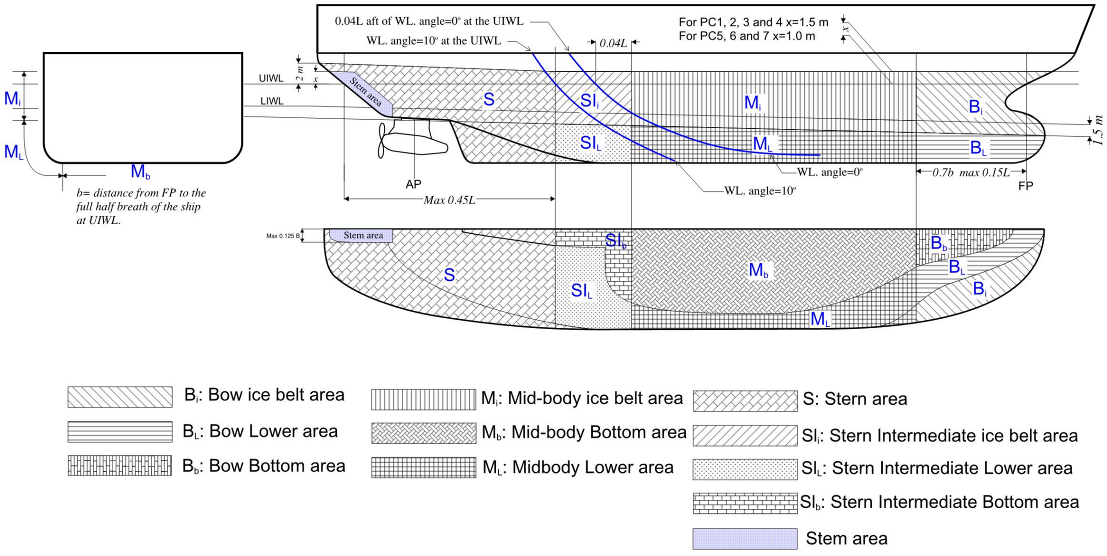

Figure 1 Hull area extents

4.1.2 The upper ice waterline (UIWL) and lower ice waterline (LIWL) are as defined in Sec.1 [9.2].

4.1.3 The stern region extends longitudinally from the stem at vessel stern to a line 0.04 *L* forward of the borderline of 0° waterline at the upper ice waterline (UIWL).

4.1.4 The forward boundary of the stern region is not required to be more than 0.45 *L* fore of the vertical line at the stern stem.

4.2 Design ice loads – hull

4.2.1 Design ice forces, calculated according to Sec.7 [4.3.3], are applicable for stern forms where buttock angle γ at the stem is positive and less than 80 degrees, and the normal frame angle β' at the centre of the aftermost sub-region, as defined in Sec.7 [4.3.1], is greater than 10 degrees.

4.2.2 The force *F*, line load *Q*, pressure *P* and load patch aspect ratio *AR*, given in Sec.7 [4.3], associated with the glancing impact load scenario, shall be based on the hull stern angels measured at the upper ice water line.

4.2.3 The waterline length of the stern shall be divided into 4 sub regions of equal length and longitudinal distance x, used for the calculation of form factor *fa* in Sec.7 [4.3.3], shall be measured from the stem at the UIWL to the midpoint of each sub-region.

The force *F*, line load *Q*, pressure *P* and load patch aspect ratio *AR* shall be calculated as given in Sec.7 [4.3], at the mid-length position of each sub-region (maximum of *F*, *Q* and *P* shall be used in the calculation of ice load parameters P_{avg}, *b* and *w*).

4.2.4 Hull area factors

The area factors, *AF* reflecting the relative magnitude of ice load expected in each area are listed in Table 1.

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Table 1 Hull area factors (*AF*) for double acting vessel intended to proceed with stern first in ice

Hull area		Area	Polar class						
			PC(1)	**PC(2)**	**PC(3)**	**PC(4)**	**PC(5)**	**PC(6)**	**PC(7)**
Stern (S)	All	S	1	1	1	1	1	1	1
Stern intermediate (SI)	Ice belt	SI$_i$	0,9	0,85	0,85	0,8	0,8	1 1)	1 1)
	Lower	SI$_l$	0,7	0,65	0,65	0,6	0,55	0,55	0,5
	Bottom	SI$_b$	0,55	0,5	0,45	0,4	0,35	0,3	0,25
Midbody (M)	Ice belt	M$_i$	0,7	0,65	0,55	0,55	0,5	0,45	0,45
	Lower	M$_l$	0,5	0,45	0,4	0,35	0,3	0,25	0,25
	Bottom	M$_b$	0,3	0,3	0,25	2)	2)	2)	2)
Bow (B)	Ice belt	B$_i$	0,75	0,7	0,65	0,6	0,5	0,4	0,35
	Lower	B$_l$	0,45	0,4	0,35	0,3	0,25	0,25	0,25
	Bottom	B$_b$	0,35	0,3	0,3	0,25	0,15	2)	2)

1) = see Sec.7 [4.1.3]

2) = strengthening for ice loads is not necessary.

4.3 Hull local scantlings

Local scantlings shall be checked according to requirement in Sec.7 considering the area factors, *AF*, listed in Table 1.

4.4 Appendages

4.4.1 Azimuthing propulsion units

Supporting structure of azimuthing propulsion units shall be designed to withstand the ice load imposed on the units as given in [4.5].

4.4.2 Acceptance criteria

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.

4.5 Main propulsion machinery

4.5.1 General

Ice loads on stern mounted propellers are assumed to be higher and more numerous than when the vessel is operating astern in ice.

4.5.2 Propeller and shafting

The propeller and shafting shall be dimensioned according to the requirements in Sec.7 [12] and Sec.7 [13]. Due regard shall be paid to the propeller location factor k$_1$ given in Sec.7 [12.1.2]. Additionally, maximum backward blade force (F_b) shall be increased by a factor of 1.1. If the vessel is assigned the class notation **DAV(PC(x), Icebreaker)**, the propeller and shafting shall be dimensioned according to Pt.5 Ch.10 Sec.10 [10]. The increased blade loads are then already accounted for.

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4.5.3 Azimuthing propulsion units

The structure of azimuthing propulsion units shall be designed to withstand ice loads as given in DNV-CG-0041 Sec.7 [1]. Due regard shall be paid to factors C_1 (the propeller shall be taken as 'front propeller'), and C_2 which shall be taken as 1.

5 Stern first in ice with class notation DAV(PC(x), Icebreaker)

5.1 General

A double acting vessel intended to operate with stern first in ice infested polar waters and assigned class notation **DAV(PC(x), Icebreaker)** shall comply with requirements in Pt.5 Ch.10 Sec.10 and requirements in this section for class notation **DAV(PC(x))** considering hull area factors in Table 2 and hull area extents shown in Figure 2.

5.2 Application

Requirements from Pt.5 Ch.10 Sec.10 [3] to Pt.5 Ch.10 Sec.10 [8] shall not be considered for double acting icebreaker.

5.3 Stem and bow region

The stem reinforcement required in Sec.7 [5.8] shall be extended vertically by x m above the UIWL, and horizontally to a line 0.06 L_{UI} forward of the stem line or 0.125 B_{UI} outboard from the centre line, whichever is reached first, see Figure 2.

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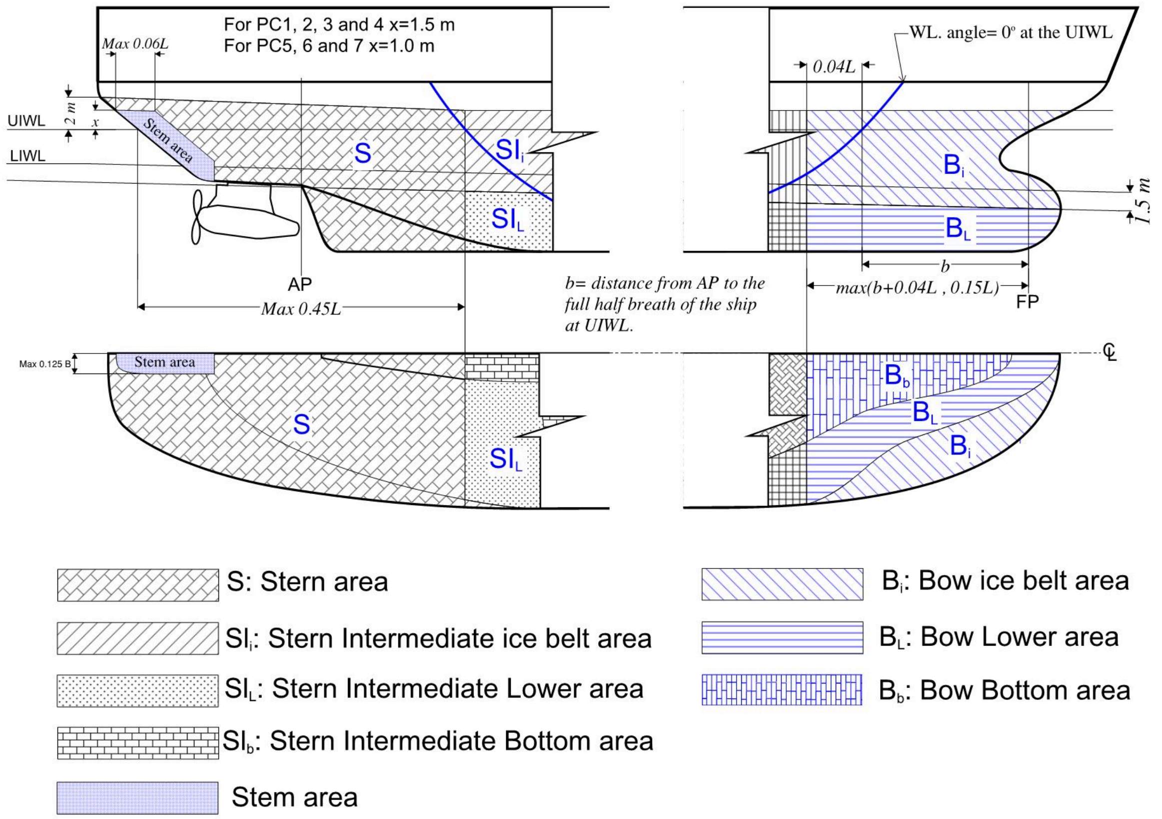

Figure 2 Stem and stern region for class notation DAV(PC(x), Icebreaker)

5.4 Hull area factors

Table 2 Hull area factors (AF) for ships with class notation DAV(PC(x), Icebreaker).

Hull area		*Area*	*Polar class*						
			PC(1)	***PC(2)***	***PC(3)***	***PC(4)***	***PC(5)***	***PC(6)***	***PC(7)***
Stern (S)	All	S	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Stern intermediate (SI)	Icebelt	SI_i	0.90	0.85	0.85	0.85	0.85	1.00 1)	1.00 1)
	Lower	SI_l	0.70	0.65	0.65	0.65	0.65	0.65	0.65
	Bottom	SI_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
Bow (B)	Icebelt	B_i	0.95	0.90	0.80	0.80	0.80	0.80	0.80

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Hull area		*Area*	*Polar class*						
			PC(1)	***PC(2)***	***PC(3)***	***PC(4)***	***PC(5)***	***PC(6)***	***PC(7)***
	Lower	B_l	0.55	0.50	0.45	0.45	0.45	0.45	0.45
	Bottom	B_b	0.35	0.30	0.30	0.30	0.30	0.30	0.30
[1] See Sec.7 [4.1.3].									

5.5 Material requirements

Material in aft ship substructure in vessels with class notations **DAV(PC(x), Icebreaker), DAT-B** and equipped with podded propulsors or azimuth thrusters shall be of class II, see Sec.6.

5.6 Main propulsion machinery

Main propulsion machinery shall be according to Pt.5 Ch.10 Sec.10 [10].

With reference to [4.5.3] in this section, for vessels with the additional class notation **DAV(PC(x), Icebreaker)**, due regard shall also be paid to factor C_3 which shall be taken as 1.25.

6 Stern first in ice with Baltic ice class

6.1 General

A double acting vessel intended to operate with stern first in ice infested northern Baltic waters or similar and assigned class notation **DAV(Ice(x))** shall comply with requirements under Sec.3 for class notation **Ice(x)** considering **DAV** requirements from [6.2] to [6.6].

6.2 Hull area extents

6.2.1 The hull of double acting ice classed vessels is divided based on the same principle as a conventional ice classed vessel, with stern first in ice. In the longitudinal direction, there are three regions: bow, midbody and stern. The extent of each hull area is illustrated in Figure 3.

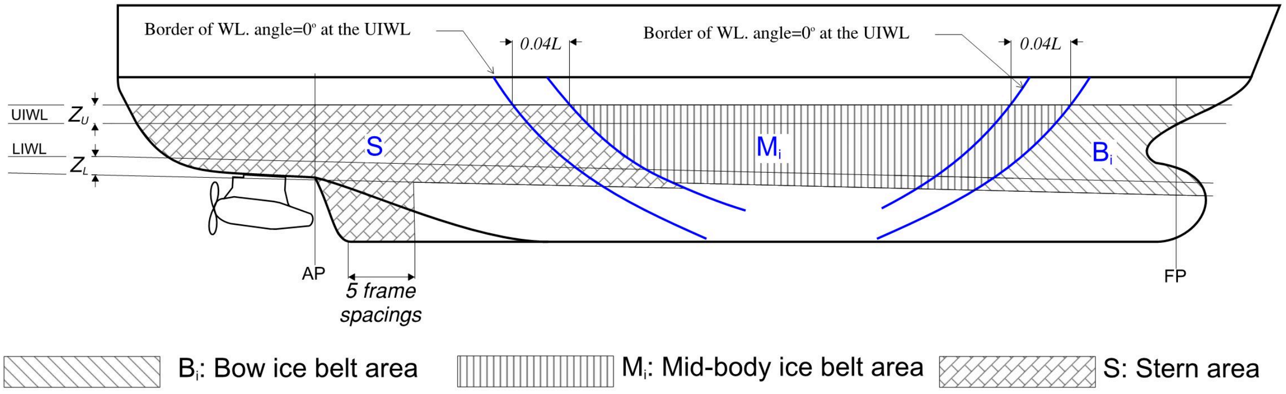

Figure 3 Hull area extents

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6.2.2 The upper ice waterline (UIWL) and lower ice waterline (LIWL) are as defined in Sec.1 [9.2].

6.2.3 The stern region extends longitudinally from the stem at vessel stern to a line parallel to and 0.04 L_{UI} forward of the aft borderline of the part of the hull where the waterlines run parallel to the center line.

For ice classes **Ice(1A*)** and **Ice(1A)** the overlap of the borderline shall not exceed 6 m, for ice classes **Ice(1B)** and **Ice(1C)** this overlap shall not exceed 5 m, see Figure 3.

6.2.4 The vertical extensions Z_U and Z_L of ice strengthening of the ice belt and framing shall be at least as given in Sec.3 Table 10 and Sec.3 Table 11, respectively.

6.3 Design ice loads

6.3.1 Available engine output

The total engine output P_S, to be used for design ice pressure calculation, shall be based on the maximum output the propulsion machinery can continuously deliver to the propeller(s) when going astern in ice.

6.3.2 Required engine output

Required minimum engine output shall be calculated according to Sec.3 [7.1.3] for the assigned qualifier and considering hull form of the vessel stern.

6.4 Hull local scantlings

Local scantlings shall be checked according to requirement in Sec.3 considering a design ice pressure calculated according to Sec.3 [7.3].

6.5 Appendages

6.5.1 Azimuthing propulsion units

Supporting structure for azimuthing propulsion units shall be designed to withstand the ice load imposed on the units as given in [6.6].

6.5.2 Acceptance criteria

The nominal von Mises stresses on thruster supporting structure shall have a minimum safety margin of 1.3 against R_{eH}, where R_{eH} denotes the specified minimum yield stress of the material in N/mm^2, see Sec.3 [15.6.5.4].

6.6 Main propulsion machinery

6.6.1 General

Ice loads on stern mounted propellers are assumed to be higher and more numerous than when the vessel is operating astern in ice.

6.6.2 Propeller and shafting

The propeller and shafting shall be dimensioned according to the requirements in Sec.3 [15]. Due regard shall be paid to the propeller location factor k_1 given in Sec.3 Table 21. Additionally, maximum backward blade force (F_b) shall be increased by a factor of 1.1.

6.6.3 Azimuthing propulsion units

The structure of azimuthing propulsion units shall be able to withstand ice loads as given in Sec.3 [15.6.5].

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APPENDIX A GUIDELINES FOR STRENGTH ANALYSIS OF THE PROPELLER BLADE USING FINITE ELEMENT METHOD

1 Guidelines for strength analysis of the propeller blade using finite element method

1.1 Requirements for finite element model

The objective of the stress analysis of ice-strengthened propeller blades shall make sure that the designed propeller blade has an acceptable margin of safety against both ultimate and fatigue strength at the design loads.

The typical locations on the propeller blades at which the highest stresses caused by ice loads occur are the fillet at the root of the blade in the case of all propeller types and the section next to the tip load area in the case of skewed propellers.

The requirement for the finite element model is that it is able to represent the complex curvilinear geometry and the thickness variation of the blade and also the geometry of the fillet at the root of the blade, in order to represent the complex three-dimensional stress state of the structure and to represent the local peak stresses needed to assess the fatigue strength of the structure with acceptable accuracy. The load of the propeller blade is dominated by bending, leading to non-constant stress distribution over the thickness of the blade. The model should also be able to represent the stress distribution over the thickness of the blade.

A conventional stress analysis approach to propeller blades utilizing beam theory, although capable of dealing with warping stresses, or an approach utilizing coarse shell elements with a rough representation of the thickness variation of the blade do not lead to acceptable accuracy in the stress analyses of ice-strengthened propeller blades.

1.2 Good engineering practice for finite element analysis

The use of solid elements is highly recommended for determining the stress distribution of the propeller blades. The use of a very dense parabolic tetrahedron mesh is recommended. Parabolic hexahedron solid elements may also be used, but hexahedra require considerably greater modelling effort. Linear elements and, especially, linear tetrahedrals should not be used in stress analysis.

As a rule of thumb, a minimum of two parabolic solid elements should be used over the thickness of the blade in the thinnest regions of the blade. Near the root region of the blade, where the geometry changes rapidly, the element size used should be chosen to be such that the local peak stress used in the fatigue assessment is obtained with good accuracy.

Additional geometric details which have a significant effect on the maximum peak stress at the root fillet should also be taken into account in the model, e.g. bolt holes located close to the root fillet. Well-shaped elements are a prerequisite for the stress analyses. The element formulation to be used should be chosen so as to be such that no locking, hour-glassing, etc. phenomena occur.

A typical parabolic tetrahedron mesh of a propeller blade used in the verification studies is presented in Figure 1 as an example.

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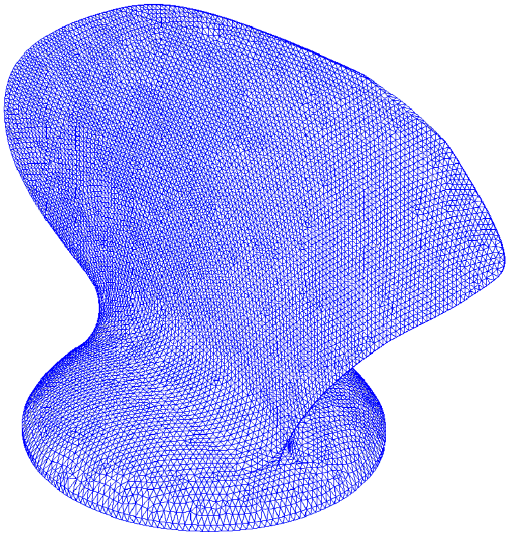

Figure 1 A typical parabolic tetrahedron mesh of a propeller blade

Shell elements may be used in the stress analyses of propeller blades, but the accuracy of the modelling approach shall be proven by measurements or extensive verification calculations covering the thickness, dimensional, and geometrical variations of the propeller blade product range to be manufactured. For example, extreme sizes and an adequate number of intermediate sizes of the propeller blade product range should be used in verification calculations or measurements. The peak stress obtained using the shell element approach shall be within acceptable accuracy and the boundary conditions shall not cause significant disturbance in the peak stresses. The root fillet geometry shall be considered in the peak stress state used in the stress analysis. The modelling of the tip region is difficult. Thus, it is allowed, for example, to finish discretization at the 0.975 chord and to make an artificial chord at the tip. The shell element formulation to be used should be chosen so as to be such that no locking, hour-glassing, etc. phenomena occur.

1.3 Boundary conditions

The boundary conditions of the blade model should be given at an adequate distance from the peak stress location in order to ensure that the boundary condition has no significant effect on the stress field used in the stress analysis.

1.4 Applied pressure loads

The pressure loads applied on the finite element model can be given either in the normal direction of the curved blade surface or alternatively as a directional pressure load. The normal pressure approach, see Figure 2, leads to a loss of the net applied transversal load as a result of the highly curved surface near the edge of the propeller blade.

Whichever approach is used, it should be ensured that the total force determined in the particular load case is applied on the model. In the normal pressure case, this can be done by scaling the load or, alternatively, by scaling the resulting stresses.

The directional pressure is better suited to propeller blade stress analyses. The pressure can be given on a surface in a direction defined using, for example, a local coordinate system, see Figure 3.

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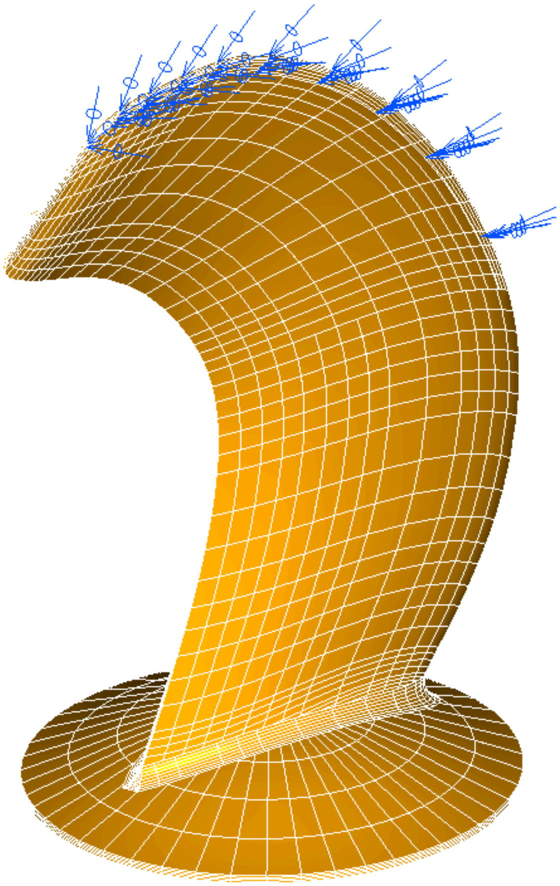

Figure 2 First alternative. One possible way to apply the pressure load to the propeller blade. If the pressure load is given in the normal direction of the highly curved blade surface, the resulting net applied load will be less than the intended load and should be scaled appropriately.

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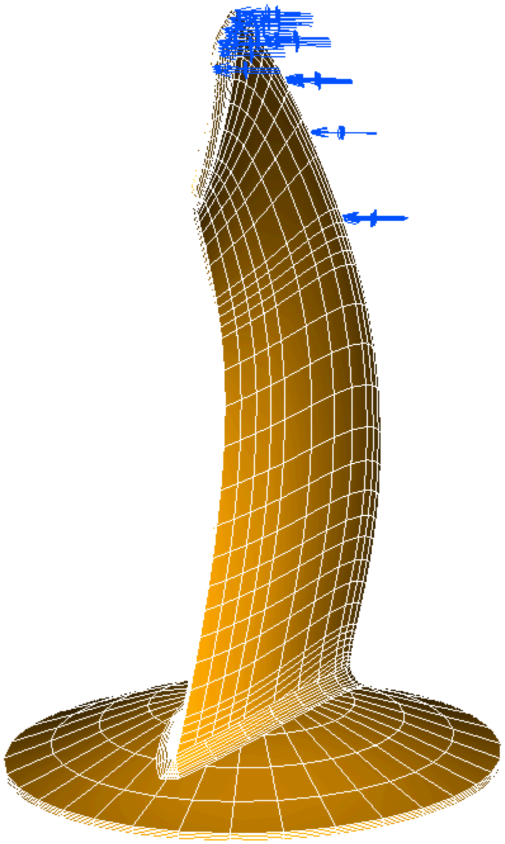

Figure 3 Second alternative. If the pressure load is given in a fixed direction, the net applied load is directly the intended load.

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CHANGES – HISTORIC

July 2023 edition

Changes July 2023, entering into force 1 January 2024

Topic	*Reference*	*Description*
Overview of the class notations	Sec.1 Table 1	Rearranged and clarified purpose and application.
Heat balance calculation	Sec.4 Table 6	Added that heat balance calculation is required.
Stability in icing conditions	Sec.4 Table 7, Sec.4 Table 9	Updated that ice accretion is, by default, required to be included in stability calculation for all vessels with the additional class notations **Winterized** or **Polar**.
Freezing of ballast and fresh water tanks	Sec.4 Table 9, Sec.4 Table 14	Added that for vessels intended to operate in low air temperature, a heat balance calculation shall be carried out unless anti-freezing measures are provided.
Requirements for communication and navigation equipment	Sec.4 Table 13, Sec.4 Table 15, Sec.5 Table 17	Added that for communication and navigation equipment not certified for BST/PST, measures, as an alternative solution, may be acceptable, and shall be documented in the winterization plan.
Documentation requirements	Sec.5 Table 5	Added documentation requirement for heat balance calculation.
Ice compression load amidship	Sec.7 [4.8]	Clarified application of design line load.

July 2022 edition

Changes July 2022, entering into force 1 January 2023

Topic	*Reference*	*Description*
Basic ice class notation **Ice-C**	Sec.1 Table 1, Sec.1 Table 2, Sec.2, Sec.3 Table 2, Sec.5 Table 6, Sec.5 Table 7	Class notation **Ice-C** has been introduced as a whole notation, without qualifier **C**, and referred to it in Sec.2 as class notation for ships intended for service in waters with light ice conditions and light localized drift ice, in river mouths and coastal areas. For the northern Baltic ice class notation, it is referred to class notation **Ice** with variable qualifiers depending on the intended ice conditions.
Ice class notation **Ice(E)**	Sec.1 Table 2, Sec.2 [1.3], Sec.3 Table 2, Sec.5 Table 6, Sec.5 Table 7	Ice class notation **Ice(E)** is removed from Sec.2.
Direct analysis acceptance criteria for Baltic ice class rules	Sec.3 [4.1.4]	Alignment with the Finnish-Swedish Ice Class Rules (FSICR) for direct analysis, where acceptance criteria for shear only shall be considered for structures analysed by use of beam models.

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Topic	*Reference*	*Description*
Engine output validity range in Baltic ice class rules	Sec.3 [7.1.3]	Alignment with the Finnish-Swedish Ice Class Rules (FSICR), where Table 4 for parameter validity range has been discarded.
Structural details requirements in Baltic ice class rules	Sec.3 [9.4.2]	Alignment with the Finnish-Swedish Ice Class Rules (FSICR), where requirements for support against instability and tripping of asymmetrical frames and frames which are not at a right angel to shell, are made valid for all ice frames within the ice reinforced area regardless of the assigned ice class.
Winterization plan	Sec.4 Table 5, Sec.5 Table 5	As the requirements for mitigating the risk of freezing and icing make up a significant part of the rules under **Winterized** and **Polar** class notations, Winterization plan is required to be submitted to cover all the necessary measures for anti-icing, anti-freezing and de-icing.
Ice accretion for both intact and damage stability	Sec.4 Table 6, Sec.5 Table 9	Ice accretion is required, as a general requirement, to be included in both intact and damage conditions.
Temperature reference for requirement under class notation **DAT**	Sec.6 [1.3.2], Sec.6 Table 1	Implementation of requirements under class notation **DAT** shall be connected to polar service temperature, PST, as key parameter, and not to mean daily average temperature, MDAT. Therefore, class notation **DAT** shall be mandatory when polar service temperature is colder than -23°C.
Design temperature for steel grade selection	Sec.6 Table 3	The design temperature t, which is the lowest mean daily average temperature, LMDAT, is required to be rounded to the nearest whole number, i.e. -10.9°C will be considered as -11°C in Sec.6 Table 6 for material grade requirement.
Minimum required engine output for polar class **PC**	Sec.7 [3.4]	An engine output guidance note on how to calculate the minimum engine power needed to advance in ice, has been developed.

July 2021 edition

Changes July 2021, entering into force 1 January 2022

Topic	*Reference*	*Description*
General section	Sec.1	A general section has been created to include all the general requirements and definitions applicable for cold climate.
Lowest ballast water line (LBWL)	Sec.1 Table 3, Sec.6 Table 3, Sec.6 Table 4	The rules have been updated so that the reference for applicability of the steel grade requirement is the lowest ballast water line (LBWL). The exposed structure is now clearly defined in the rules using the LBWL as a border. LBWL has also been defined in Sec.1 for general requirements.
Class notation **Ice(1A*F)**	Sec.3 [1.3.2]	A rule text has been included in Sec.3, stating that, where not stated otherwise, all the requirements applicable for the Baltic ice class notation **Ice(1A*)**, are applicable for **Ice(1A*F)**.
Simplified criterion for propeller blade fatigue calculation	Sec.3 Table 30	Values of coefficients in Sec.3 Table 30 are now updated in line with values provided by TraFiCom.

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Topic	*Reference*	*Description*
Stiffener spacing	Sec.3 [8.2.1], Sec.3 [9.2.1], Sec.3 [9.3.1]	Parameter s_1 has been moved under the relevant requirement in Sec.3.
Longitudinally framed plate requirement	Sec.3 [8.2.1]	Parameter f2 for calculating longitudinally framed requirement has been adjusted in our Baltic rules, where parameter h/s1 has been adjusted be lower or equal to 1.8.
Abrasion and corrosion addition	Sec.3 [8.2.1]	If an abrasion resistant coating is used, a 1 mm reduction in corrosion/abrasion addition is introduced. Included a guidance note, with reference to DNV-CP-0293, where the already type-approved abrasion resistant coating materials are listed.
Propellers with nozzle	Sec.3 [14.1.2]	A rule text has been introduced to differentiate between a propeller with and without nozzle.
Polar service temperature (PST) and Lowest mean daily low temperature (LMDLT)	Sec.4	Polar service temperature (PST) has been related to LMDLT and not MDLT in the relevant sections in the rules.
Reference to MSC.1Circ.1614	Sec.4 Table 3	Reference to IMO MSC.1/Circ.1614 (26.June 2019), has been added in the personal survival equipment, PSE.
Hydraulically operated hatches and doors	Sec.4 Table 7	A rule text has been introduced to state that alternative solutions can be considered
Baltic service temperature (BST) and lowest mean daily low temperature (LMDLT)	Sec.5	Baltic service temperature (BST) has been related to LMDLT and not MDLT in the relevant sections in the rules.
Hydraulic system for watertight and weathertight doors and hatches	Sec.5 Table 11	The rule text is moved to class guideline DNV-CG-0308.
Openings and space along escape routes	Sec.5 Table 15	Requirement for enough openings and space along escape routes has been made better and clear.
Ship length (L_{UI}), moulded breath (B_{UI}) and displacement (Δ_{UI})	Sec.7 [4.1.10] to Sec.7 [4.1.12], Sec.7 [4.3.3] to Sec.7 [4.3.4], Sec.7 [4.4.1], Sec.7 [6.2] to Sec.7 [6.4], Sec.7 [11.7.3] to Sec.7 [11.7.4], Sec.8 [5.3], Sec.8 [6.2.2]	Ship length, moulded breadth and displacement definitions are now aligned with the definitions given in IACS UR I2 as L_{UI}, B_{UI} and D_{UI}, respectively.
Abrasion and corrosion addition	Sec.7 [10.1.2]	Rule text is included to state the criteria for a coating material to be considered as effective protection against corrosion and ice-induced abrasion.

Topic	*Reference*	*Description*
Rebranding to DNV	All	This document has been revised due to the rebranding of DNV GL to DNV. The following have been updated: the company name, material and certificate designations, and references to other documents in the DNV portfolio. Some of the documents referred to may not yet have been rebranded. If so, please see the relevant DNV GL document.

July 2020 edition

Amendments January 2021, entering into force 1 July 2021

Topic	*Reference*	*Description*
Change in blade load for vessels with combination of **DAV** and **Icebreaker** class notations	Sec.7 [4.6.2]	Changed factor for backward blade load from 1.2 to 1.1 in line with revised rules for icebreakers.

Changes July 2020, entering into force 1 January 2021

Topic	*Reference*	*Description*
Minimum web thickness for ice frames	Sec.2 [9.4.2]	Removed requirement for web thickness of the frames to be 2.5% of the frame spacing for transverse frames.
Material class for machinery installation	Sec.3 Table 8 Item 2.3.1	Material classes have been reduced to be in line with **DAT** requirements.
	Sec.4 Table 12 Item 5.2.	
Alignment with IMO interim guideline for life saving appliances in polar waters MSC.1/Circ.1614, 26 June 2019	Sec.4 Table 16 Item 2.2	Establishing prescriptive requirements for allowable icing loads for life boats.
	Sec.4 Table 16 Item 5.1.1	Introducing requirement to lifeboat searchlight power capacity.
	Sec.4 Table 16 Item 6.1.1	Introducing requirement for non-magnetic means to identify heading in life boats.
	Sec.4 Table 16 Item 7.1.3, 7.2.1 and 7.3.1	Introducing requirement for group survival equipment.
	Sec.4 Table 16 Item 8.1.1, 8.1.3 and 8.2.1	Introducing requirements to life saving system operability in low temperatures.
DAT-B and **DAT**	Sec.5	— **DAT-B** is covering the basic requirements and scope in IACS UR S6. — **DAT** notation covers all requirement under **DAT-B** plus additional requirements from IMO Polar Code.

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Topic	*Reference*	*Description*
Interlink between **DAT**, **Winterized** and **Polar**	Sec.5 [2]	Clarifying the link between design temperature for materials and service temperatures in cold climate.
Guidance note for tunnel thruster/bow thruster grids	Sec.6 [7.7.4]	Introducing a guidance note for bow thruster grid reinforcement with reference to class guideline .
Acceptance criteria for non-linear FE calculations	Sec.6 [8.3]	Establish acceptance criteria for non-linear FEA for primary supporting structure.
Type approval of abrasion resistant coating	Sec.6 [10.1.2]	Introducing guidance note with reference to relevant type approval programme.
Double acting icebreaker	Sec.7	Rules for class notation **DAV** is developed to include **Icebreaker** as a qualifier for indicating the operational mode of the vessel and triggering requirements for such an operational mode. The rules have been also updated to include: — new table area factors, AF — material requirements — hull area extents — machinery requirements.

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July 2019 edition

Changes July 2019, entering into force 1 January 2020

Topic	*Reference*	*Description*
IMO Polar Code: **Polar** and **Winterized** additional class notations	Sec.3 and Sec.4	— New **Polar** class notation based on requirements in the IMO Polar Code, including all prescriptive requirements. For more functional based requirements, the new notation includes a recommended practical solution. The notation includes polar specific requirements only relevant for polar areas. — Updated **Winterized** class notation for cold areas outside the IMO Polar Code area, and hence some of the polar specific requirements have been removed.
Implementation of IACS UR S6 Rev9	Sec.5 [2.2.1]	Steel grade requirements for cargo tank boundary in contact with liquid cargo colder than -10 °C.
	Sec.5 [2.2.2]	— The word 'lower' has been changed to 'colder' for design temperature. — Table 6 has been moved from Sec.3 table 6 item C1001 and introduced in this subsection.
	Sec.5 Table 5	Class requirement, A5, for cargo tank boundary plating exposed to cold cargo, has been added in Table 4 and note 11 has been added.
	Sec.5 Table 6	Table 5 has been updated according to IACS UR S6 with respect to temperatures and steel grade requirements.
Design ice forces within the stern ice belt area	Sec.6 [4.7.4]	Subsection deleted and moved to the new class notation **DAV**, see Sec.7.
PC class notation: minimum weld requirements	Sec.6 [5.1.2]	Clarification that bottom plating shall have the same requirement as transversally framed plating regardless of framing orientation.
	Sec.6 [9.2.1]	— The weld factor f_{weld} is corrected to be aligned with changes in Pt.3 Ch.13 Sec.1. — Introduction of new factor f_{tr} for transverse frame end connection. — Simplification of shear area ration formula.
New additional class notation **DAV**	Sec.7	New **DAV** class notation covering hull structure, propulsion and equipment for ships intended to proceed mainly astern in ice infested waters.

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July 2018 edition

Changes July 2018, entering into force 1 January 2019

Topic	*Reference*	*Description*
Northern Baltic Ice / Class Notation	Sec.2 [1.5.2]	New definition text for displacement determined at multiple water lines.
	Sec.2 [7.1.1]	Clarification regarding additional sources of power for compliance with min power output requirement.
	Sec.2 Table 9	Clarification regarding engine output and additional sources of power.
	Sec.2 Table 9	Clarification regarding design factor c1.
	Sec.2 [8.1.2]	New design load definition for fore foot scantling requirement.
	Sec.2 [8.1.2]	Added recommendation for requirements for upper ice belt for vessel with a high bow wave (proved from model test) but speed is less than 18 knots.
	Sec.2 [9.4.2]	Clarification regarding asymmetrical frames not perpendicular to the shell.
	Sec.2 [9.4.2]	Clarification regarding minimum requirement for web thickness of frames (stability requirement).
	Sec.2 [15]	Subsection [15] is completely rewritten to align with original from TraFi. Subsection Sec.2 [15.8] describing DNV GL's way of applying ice loads in main class rules has been rewritten to align with current practice.

July 2017 edition

Amendments January 2018

Topic	*Reference*	*Description*
Typo error in 9.2	Sec.2 [9.2]	Correction to the section formula by adding 10^3. Adding multiplication character to sections modulus formulas to ensure consistency.
Update of DocReq	Sec.2 Table 3	Documentation requirement C040 - Design analysis for alternative designs of propulsion and steering arrangements has been updated with information to be submitted on Request (R).

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Changes July 2017, entering into force 1 January 2018

Topic	*Reference*	*Description*
Distinguishing between the design temperatures "t_d" for **Winterized** and "t" for **DAT**	Sec.3 [4.1.1]	Deletion of requirement that the temperatures shall be the same and the sentence "values are representative but not necessarily prescriptive" from the paragraph.
Alignment with IACS UR S6 Use of Steel Grades for Various Hull Members- Ships of 90 m in Length and Above	Sec.4 [2.1.1], Sec.4 Table 4	Material classes has been stepped down to be in line with IACS S6.
	Sec.4 Figure 2	Figure 2 is substituted by Sec.4 Table 5 to be in line with IACS S6.
Remove material grade in DAT covered by main class (Pt.3)	Sec.4 Figure 2	Figure 2 is substituted by Sec.4 Table 5 to be in line with IACS S6.
Clarification of rule text for ships intended to operate astern	Sec.5 [4.7.4]	Requirement has been rephrased.
Clarification of Bow length definition	Sec.5 [6.2.1]	Definition of Bow Length has become more specific.
Requirements to ice horn arrangement	Sec.5 [7.2], Sec.5 [7.3], Sec.5 [7.5] and Sec.5 [7.7]	Changed requirements to ice horn arrangement of rudder, ice horn, rudder horn, nozzles, podded propulsors and azimuth thrusters.
Requirements to vertical extension of ice horn	Sec.5 [7.2.3]	Additional text added to limit requirement to vertical extension of ice horn.
Ice load formulation on appendages	Sec.5 [7.3.2] and Sec.5 [7.5.1]	Reference to DNVGL-CG-0041 for calculation of ice load has been added.

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January 2017 edition

Main changes January 2017, entering into force 1 July 2017

• Sec.1 Basic ice strengthening - **Ice**

— Sec.1 [9.2.2]: Correction of error in formula for ice class reinforcement factor $C_{EW.}$ has been made.

• Sec.5 Polar class - **PC**

— Sec.5 [1.3]: Subparagraphs [1.3.2], [1.3.3] and [1.3.4] have been added to be aligned with IACS UR I1.
— Sec.5 [4.1.5]: Paragraph has been modified to be aligned with IACS UR I2.
— Sec.5 [4.1]: Subparagraphs [4.1.6], [4.1.7] and [4.1.8] have been added to be aligned with IACS UR I1.
— Sec.5 Table 4: Class factors have been added to be aligned with IACS UR I2.
— Sec.5 [4.3.4]: Bow area characteristics for bow forms defined in [4.1.6], have been added to be aligned with IACS UR I2.
— Sec.5 Table 5: Table has been modified to include a row for frames in bottom structures.
— Sec.5 [5.3.1]: Clarification of application of patch load on bottom stiffeners has been added to be aligned with IACS UR I2.
— Sec.5 [5.5]: Effective net web area and net elastic section modulus requirements for frames and load carrying stringers are deleted and direct calculation, as an alternative, has been addressed.
— Sec.5 [6.1]: New subparagraph, [6.1.2], has been introduced to exclude which are designed with a vertical or bulbous bow.
— Sec.5 [8.1]: Direct calculation sub-section has been rearranged and modified by adding subparagraphs to include more clarifications and acceptance criteria.
— Sec.5 [10.2.2]: Material class requirements in table 12 have been stepped downtp be aligned with IACS UR I2.
— Sec.5 Table 13: Table for steel grades for inboard framing members attached to weather exposed plating, have been deleted to be aligned with IACS UR I2.
— Sec.5 [10.2]: Paragraph [10.2.5] has been deleted to be aligned with IACS UR I2.

July 2016 edition

This document supersedes the October 2015 edition.

Main changes July 2016, entering into force 1 January 2017

• Sec.2 Ice strengthening for the northern Baltic - Ice

— Sec.2 [7.1.2]: A requirement for the restricted engine output in ice to be included in the Appendix to Classification Certificate is added.
— Sec.2 [7.3.1]: The machinery output used in the formula for K_1 is corrected with use of P_S instead of P_{min}, which is in line with the Finnish - Swedish maritime authorities for Baltic ice operations

• Sec.5 Polar class - PC

— Sec.5 [3.2.1]: In Figure 1 the word "max" is replaced with "min" in the extension of Stern ice belt area, i.e. the new extension is 0.7*b* min 0.15*L*.

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October 2015 edition

This is a new document.

The rules enter into force 1 January 2016.

Amendments 1 January 2016

• Sec.2 Ice strengthening for the Northern Baltic - Ice

— [7.1]: Re-arranged and moved rules for minimum engine output in [15.1] to be a part of subsection [7] "Design loads".

• Sec.5 Polar class - PC

— [4.7.3]: Prescriptive requirements for hull area factors (AF) were missing for ships with thrusters/podded propulsion operating astern. Table 5 is containing the new hull area factors.

— [4.8]: The requirement to clients to define the ice thickness h_{ice} has been replaced with prescriptive ice compression class factors which represents expected ice thicknesses for the different Polar Class notations. Allowable limits for normal, shear and von Mises stresses have been implemented as well.

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