TÜRK LOYDU

Chapter 33 - Polar Class Ships

JAN 2017

This latest edition incorporates all rule changes. The latest revisions are shown with a vertical line. The section title is framed if the section is revised completely. Changes after the publication of the rule are written in red colour.

Unless otherwise specified, these Rules apply to ships for which the date of contract for construction as defined in IACS PR No.29 is on or after 1st of January 2017. New rules or amendments entering into force after the date of contract for construction are to be applied if required by those rules. See Rule Change Notices on TL website for details.

"General Terms and Conditions" of the respective latest edition will be applicable (see Rules for Classification and Surveys).

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AMENDMENTS

Revised Sections	RCS No.	EIF Date*
Part II-A Section 4	04/2017	01.01.2018
Part II-B	04/2017	01.01.2018

* Entry into Force (EIF) Date is provided for general guidance only, EIF dates given in Rule Change Summary (RCS) are considered valid. In addition to the above stated changes, editorial corrections may have been made.

INTRODUCTION

1 Goal

The goal of this Code is to provide for safe ship operation and the protection of the polar environment by addressing risks present in polar waters and not adequately mitigated by other instruments of the Organization.

2 Definitions

For the purpose of this Code, the terms used have the meanings defined in the following paragraphs. Terms used in part I-A, but not defined in this section shall have the same meaning as defined in SOLAS. Terms used in part II-A, but not defined in this section shall have the same meaning as defined in article 2 of MARPOL and the relevant MARPOL Annexes.

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

2.2 *Category B ship* means a ship not included in category A, designed for operation in polar waters in at least thin first-year ice, which may include old ice inclusions.

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

2.4 *First-year ice* means sea ice of not more than one winter growth developing from young ice with thickness from 0.3 m to 2.0 m**(1)**.

2.5 *Ice free waters* means no ice present. If ice of any kind is present this term shall not be used**(1)**.

2.6 *Ice of land origin* means ice formed on land or in an ice shelf, found floating in water**(1)**.

2.7 *MARPOL* means the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto as amended by the 1997 Protocol.

2.8 *Medium first-year ice* means first-year ice of 70 cm to 120 cm thickness**(1)**.

2.9 *Old ice* means sea ice which has survived at least one summer's melt; typical thickness up to 3 m or more. It is subdivided into residual first-year ice, second-year ice and multi-year ice[1].

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

2.11 *Organization* means the International Maritime Organization.

2.12 *Sea ice* means any form of ice found at sea which has originated from the freezing of sea water **(1)**.

2.13 *SOLAS* means the International Convention for the Safety of Life at Sea, 1974, as amended.

2.14 *STCW Convention* means the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, as amended.

2.15 *Thin first-year ice* means first-year ice 30 cm to 70 cm thick.

(1) *Refer to the WMO Sea Ice Nomenclature.*

3 Sources of hazards

3.1 The Polar Code considers hazards which may lead to elevated levels of risk due to increased probability of occurrence, more severe consequences, or both:

.1 Ice, as it may affect hull structure, stability characteristics, machinery systems, navigation, the outdoor working environment, maintenance and emergency preparedness tasks and malfunction of safety equipment and systems;

.2 experiencing topside icing, with potential reduction of stability and equipment functionality;

.3 low temperature, as it affects the working environment and human performance, maintenance and emergency preparedness tasks, material properties and equipment efficiency, survival time and performance of safety equipment and systems;

.4 extended periods of darkness or daylight as it may affect navigation and human performance;

.5 high latitude, as it affects navigation systems, communication systems and the quality of ice imagery information;

.6 remoteness and possible lack of accurate and complete hydrographic data and information, reduced availability of navigational aids and seamarks with increased potential for groundings compounded by remoteness, limited readily deployable SAR facilities, delays in emergency response and limited communications capability, with the potential to affect incident response;

.7 potential lack of ship crew experience in polar operations, with potential for human error;

.8 potential lack of suitable emergency response equipment, with the potential for limiting the effectiveness of mitigation measures;

.9 rapidly changing and severe weather conditions, with the potential for escalation of incidents; and

.10 the environment with respect to sensitivity to harmful substances and other environmental impacts and its need for longer restoration.

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

4 Structure of the Code

This Code consists of Introduction, parts I and II. The Introduction contains mandatory provisions applicable to both parts I and II. Part I is subdivided into part I-A, which contains mandatory provisions on safety measures, and part I-B containing recommendations on safety. Part II is subdivided into part II-A, which contains mandatory provisions on pollution prevention, and part II-B containing recommendations on pollution prevention.

Figures illustrating 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 46.2; 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

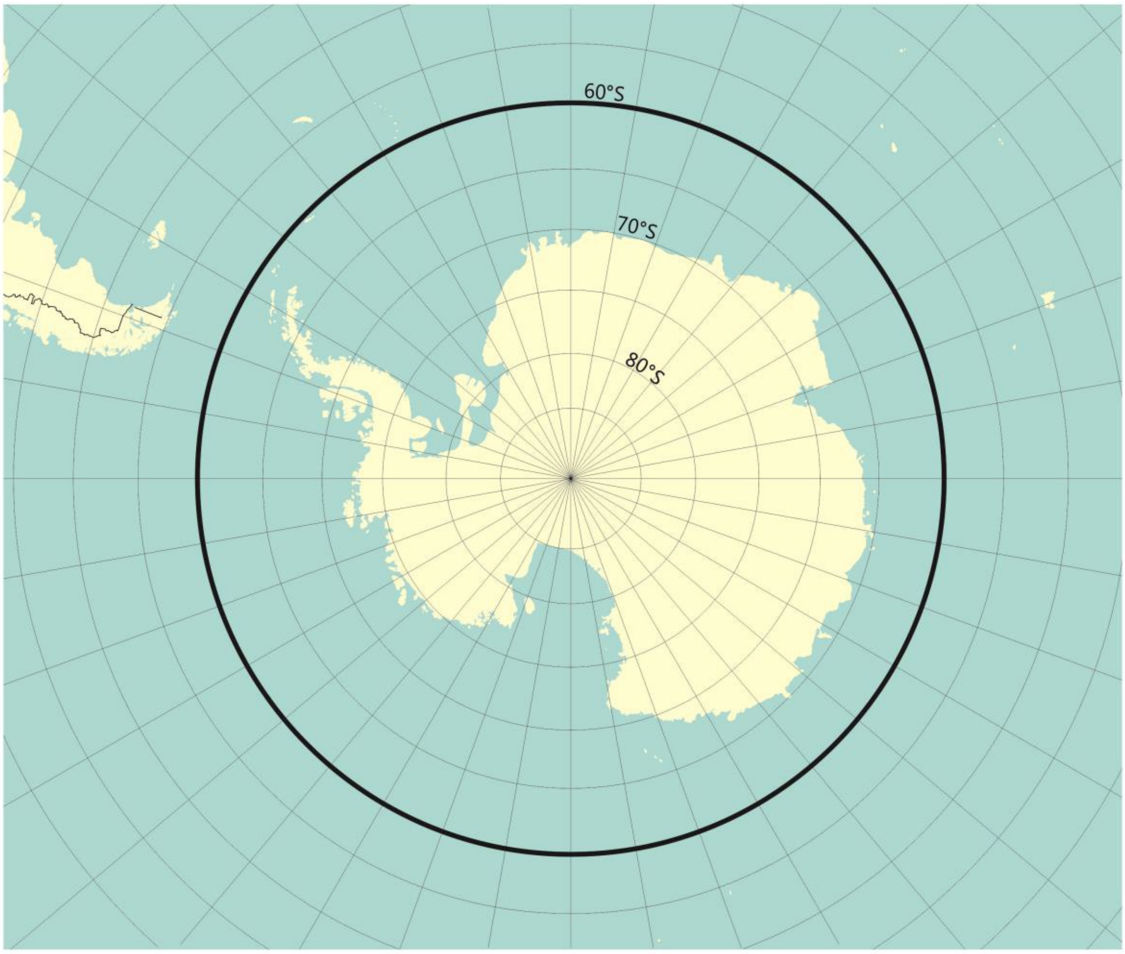

Figure 1 – Maximum extent of Antarctic area application (2)

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(2) *It should be noted that this figure is for illustrative purposes only.*

Figure 2 – Maximum extent of Arctic waters application(3)

5 Application

5.1 *The Rules for Polar Class Ships apply to ships constructed of steel and intended for independent navigation in ice-infested polar waters.*

5.2 *Ships that comply with the Section 2 and Section 3 can be considered for a Polar Class notation as listed in Table 1. The requirements of Section 2 and Section 3 are in addition to the open water Türk Loydu Rules requirements. If the hull and machinery are constructed such as to comply with the requirements of different Polar Classes, then both the hull and machinery are to be assigned the lower of these classes in the Certificate of Classification. Compliance of the hull or machinery with the requirements of a higher Polar Class is also to be indicated in the Certificate of Classification or equivalent.*

5.3 *Ships which are assigned a Polar Class notation and complying with the relevant requirements of Section 2 and Section 3 may be given the additional notation "ICE-BREAKER". "ICE-BREAKER" refers to any ship having an operational profile that includes escort or ice management functions, having powering and dimensions that allow it to undertake aggressive operations in ice-covered waters.*

(3) *It should be noted that this figure is for illustrative purposes only.*

5.4 *For ships which are assigned a Polar Class notation, the hull form and propulsion power are to be such that the ship can operate independently and at continuous speed in a representative ice condition, as defined in Table 1 for the corresponding Polar Class. For ships and ship-shaped units which are intentionally not designed to operate independently in ice, such operational intent or limitations are to be explicitly stated in the Certificate of Classification or equivalent.*

5.5 *For ships which are assigned a Polar Class notation PC 1 through PC 5, bows with vertical sides, and bulbous bows are generally to be avoided. Bow angles should in general be within the range specified in I2.3.1 (v).*

5.6 *For ships which are assigned a Polar Class notation PC 6 and PC 7, and are designed with a bow with vertical sides or bulbous bows, operational limitations (restricted from intentional ramming) in design conditions are to be stated in the Certificate of Classification or equivalent.*

Note:
- The words "Administration" and "Code", wherever mentioned, are to be understood as equivalent to the words "TL" and "Rules", respectively, however, for exemptions, waivers, and equivalents, the Administration are to be understood.
- Specific requirements of the Society which are additional to the provisions of the Polar Code as well as interpretations of some Code requirements have been identified by italic fonts.

6 Polar Classes

6.1 *The Polar Class (PC) notations and descriptions are given in Table 1. It is the responsibility of the Owner to select an appropriate Polar Class. The descriptions in 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.*

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

7 Upper and Lower Ice Waterlines

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

7.2 *The lower ice waterline is to be determined with due regard to the ship's ice-going capability in the ballast loading conditions. The propeller is to be fully submerged at the lower ice waterline.*

Table 1 - Polar Class Descriptions

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

PART I-A SAFETY MEASURES
SECTION 1 – GENERAL

1.1 Structure of this part

Each section in this part consists of the overall goal of the section, functional requirements to fulfil the goal, and regulations. A ship shall be considered to meet a functional requirement set out in this part when either:

.1 the ship's design and arrangements comply with all the regulations associated with that functional requirement; or

.2 part(s) or all of the ship's relevant design and arrangements have been reviewed and approved in accordance with regulation 4 of SOLAS chapter XIV, and any remaining parts of the ship comply with the relevant regulations.

1.2 Definitions

In addition to the definitions included in the relevant SOLAS chapters and the introduction of this Rule, the following definitions are applicable to this part.

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

1.2.2 *Escort* means any ship with superior ice capability in transit with another ship.

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

1.2.4 *Habitable environment* means a ventilated environment that will protect against hypothermia.

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

1.2.6 *Ice Class* means the notation assigned to the ship by the **TL** showing that the ship has been designed for navigation in sea-ice conditions.

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

1.2.8 *Machinery Installations* means equipment and machinery and its associated piping and cabling, which is necessary for the safe operation of the ship.

1.2.9 *Mean Daily Low Temperature* (MDLT) means the mean value of the daily low temperature for each day of the year over a minimum 10 year period. A data set acceptable to the Administration may be used if 10 years of data is not available **(4)**.

1.2.10 *Polar Class (PC)* means the ice class assigned to the ship by the TL based upon IACS Unified Requirements.

1.2.11 *Polar Service Temperature (PST) means* a temperature specified for a ship which is intended to operate in low air temperature, which shall be set at least 10°C below the lowest MDLT for the intended area and season of operation in polar waters.

1.2.12 *Ship intended to operate in low air temperature* means a ship which is intended to undertake voyages to or through areas where the lowest Mean Daily Low Temperature (MDLT) is below -10°C.

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

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

1.3 Certificate and survey

1.3.1 Every ship to which Polar Code applies shall have on board a valid Polar Ship Certificate.

1.3.2 Except as provided for in paragraph 1.3.3, the Polar Ship Certificate shall be issued after an initial or renewal survey to a ship which complies with the relevant requirements of this Rule.

1.3.3 For category C cargo ships, if the result of the assessment in paragraph 1.5 is that no additional equipment or structural modification is required to comply with the Polar Code, the Polar Ship Certificate may be issued based upon documented verification that the ship complies with all relevant requirements of the Polar Code. In this case, for continued validity of the certificate, an onboard survey should be undertaken at the next scheduled survey.

1.3.4 The certificate referred to in this regulation shall be issued either by **TL** in accordance with SOLAS regulation XI-1/1.

1.3.5 The Polar Ship Certificate shall be drawn up in the form corresponding to the model given in appendix 1 of Polar Code.

1.3.6 Polar Ship Certificate validity, survey dates and endorsements shall be harmonized with the relevant SOLAS certificates in accordance with the provisions of regulation I/14 of the SOLAS Convention. The certificate shall include a supplement recording equipment required by Polar Code.

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(4) *Refer also to additional guidance in part I-B.*

1.3.7 Where applicable, the certificate shall reference a methodology to assess operational capabilities and limitations in ice to the satisfaction of the Administration, taking into account the guidelines **(5)**.

1.4 Performance standards

1.4.1 Unless expressly provided otherwise, ship systems and equipment addressed in this Rule shall satisfy at least the same performance standards referred to in SOLAS.

1.4 2 For ships operating in low air temperature, a polar service temperature (PST) shall be specified and shall be at least 10^0C below the lowest MDLT for the intended area and season of operation in polar waters. Systems and equipment required by this Rule shall be fully functional at the polar service temperature.

1.4.3 For ships operating in low air temperature, survival systems and equipment shall be fully operational at the polar service temperature during the maximum expected rescue time.

1.5 Operational assessment

In order to establish procedures or operational limitations, an assessment of the ship and its equipment shall be carried out, taking into consideration the following:

.1 the anticipated range of operating and environmental conditions, such as:

.1 operation in low air temperature;

.2 operation in ice;

.3 operation in high latitude; and

.4 potential for abandonment onto ice or land;

.2 hazards, as listed in section 3 of the Introduction, as applicable; and

.3 additional hazards, if identified.

SECTION 2 – POLAR WATER OPERATIONAL MANUAL (PWOM)

2.1 Goal

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

2.2 Functional requirements

2.2.1 In order to achieve the goal set out in paragraph 2.1 above, the following functional requirements are embodied in the regulations of this section.

2.2.2 The Manual shall include information on the ship-specific capabilities and limitations in relation to the assessment required under paragraph 1.5.

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

(5) *Refer to MSC.1/Circ.1519.*

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

2.2.5 The Manual shall include or refer to specific procedures to be followed in the event that conditions are encountered which exceed the ship's specific capabilities and limitations in paragraph 2.2.2.

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

2.3 Regulations

2.3.1 In order to comply with the functional requirements of paragraphs 2.2.1 to 2.2.6, the Manual shall be carried on board.

2.3.2 In order to comply with the functional requirements of paragraph 2.2.2, the Manual shall contain, where applicable, the methodology used to determine capabilities and limitations in ice.

2.3.3 In order to comply with the functional requirements of paragraph 2.2.3, the Manual shall include risk-based procedures for the following:

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

.2 arrangements for receiving forecasts of the environmental conditions;

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

.4 operation of equipment required under other sections of this Rule; and

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

2.3.4 In order to comply with the functional requirements of paragraph 2.2.4, the Manual shall include risk-based procedures to be followed for:

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

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

2.3.5 In order to comply with the functional requirements of paragraph 2.2.5, the Manual shall include risk-based procedures to be followed for measures to be taken in the event of encountering ice and/or temperatures which exceed the ship's design capabilities or limitations.

2.3.6 In order to comply with the functional requirements of paragraph 2.2.6, the Manual shall include risk-based procedures for monitoring and maintaining safety during operations in ice, as applicable, including any requirements for escort operations or icebreaker assistance. Different operational limitations may apply depending on whether the ship is operating independently or with icebreaker escort. Where appropriate, the PWOM should specify both options.

SECTION 3 – SHIP STRUCTURE

3.1 Goal

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

3.2 Functional requirements

In order to achieve the goal set out in paragraph 3.1 above, the following functional requirements are embodied in the regulations of this section:

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

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

3.3 Regulations

3.3.1 In order to comply with the functional requirements of paragraph 3.2.1 above, materials of exposed structures in ships shall be approved by **TL**, taking into account Chapter 1 Hull Section 3 or other standards offering an equivalent level of safety based on the polar service temperature.

3.3.2 In order to comply with the functional requirements of paragraph 3.2.2 above, the following apply:

.1 scantlings of category A ships shall be approved by **TL**, taking into account requirements for Polar Class 1-5 defined in item from 3.4 to 3.20 or other standards offering an equivalent level of safety;

.2 scantlings of category B ships shall be approved by **TL**, taking into account requirements for Polar Class 6-7 defined in item from 3.4 to 3.20 or other standards offering an equivalent level of safety;

.3 scantlings of ice strengthened category C ships shall be approved by **TL**, taking into account acceptable standards adequate for the ice types and concentrations encountered in the area of operation; and

.4 a category C ship need not be ice strengthened if, in the opinion of the Administration, the ship's structure is adequate for its intended operation.

3.4 Hull Areas

3.4.1 *The hull of all Polar Class ships is divided into areas reflecting the magnitude of the loads that are expected to act upon them. In the longitudinal direction, there are four regions: Bow, Bow Intermediate, Midbody and Stern. The Bow Intermediate, Midbody and Stern regions are further divided in the vertical direction into the Bottom, Lower and Icebelt regions. The extent of each hull area is illustrated in Figure 3.*

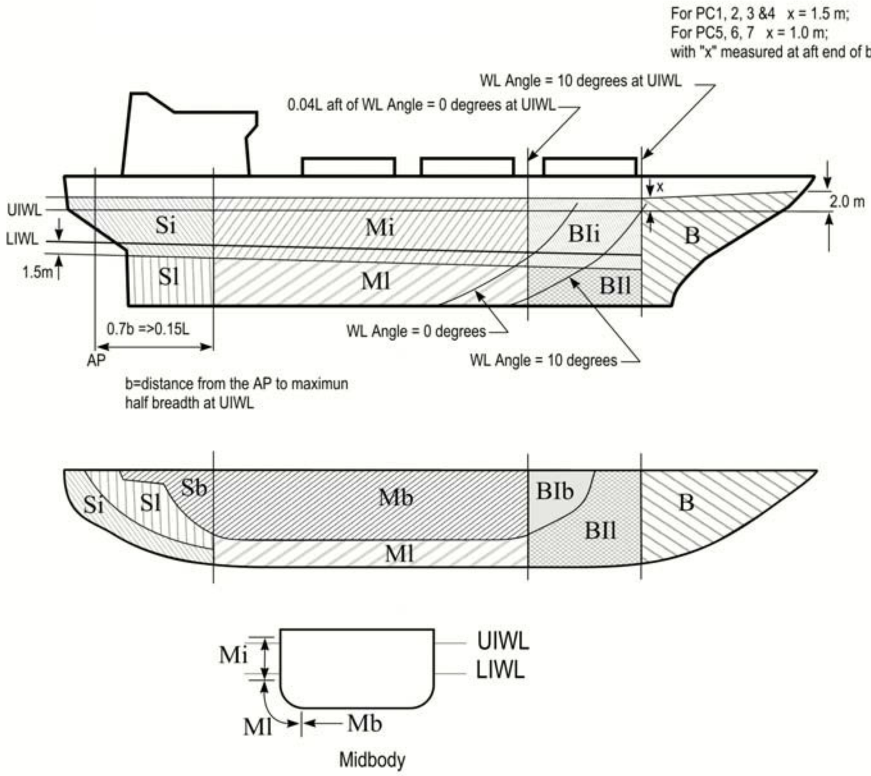

Figure 3 - Hull Area Extents

3.4.2 *The upper ice waterline (UIWL) and lower ice waterline (LIWL) are as defined in Introduction, item 7.*

3.4.3 *Figure 3 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.*

3.4.4 *Figure 3 notwithstanding, the aft boundary of the Bow region need not be more than 0.45 L aft of the forward perpendicular (FP).*

L = ship length as defined in Chapter 1, Hull, Section 1, H.2.1, but measured on the upper ice waterline (UIWL) [m]

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

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

3.4.7 *Figure 3 notwithstanding, if the ship is assigned the additional notation "Icebreaker", the forward boundary of the stern region is to be at least 0.04 L forward of the section where the parallel ship side at the upper ice waterline (UIWL) ends.*

3.4.8 *All hull areas, including the locations of the UIWL and LIWL, are to be clearly indicated on the shell expansion submitted for approval.*

3.5 Design Ice Loads

3.5.1 General

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

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

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

3.5.1.4 *In other ice-strengthened areas, the ice load parameters (Pavg, bNonBow and wNonBow) are determined independently of the hull shape and based on a fixed load patch aspect ratio, AR = 3.6.*

3.5.1.5 *Design ice forces calculated according to 3.5.2.1.3 are applicable for bow forms where the buttock angle γ at the stern is positive and less than 80 deg. and the normal frame angle β' at the centre of the foremost sub-region, as defined in 2.3.2.1(i), is greater than 10 deg.*

3.5.1.6 *Design ice forces calculated according to 3.5.2.1.4 are applicable for ships which are assigned the Polar Class PC6 or PC7 and have a bow form with vertical sides. This includes bows where the normal frame angles β' at the considered sub-regions, as defined in 3.5.2.1.1 are between 0 and 10 deg.*

3.5.1.7 *For ships which are assigned the Polar Class PC6 or PC7, and equipped with bulbous bows, the design ice forces on the bow are to be determined according to 3.5.2.1.4. In addition, the design forces are not to be taken less than those given in 3.5.2.1.3, assuming fa = 0.6 and AR = 1.3.*

3.5.1.8 *For ships with bow forms other than those defined in 3.5.1.5 to 3.5.1.7, design forces are to be specially considered by the Classification Society.*

3.5.1.9 *Ship structures that are not directly subjected to ice loads may still experience inertial loads of stowed cargo and equipment resulting from ship/ice interaction. These inertial loads, calculated according to the design accelerations specified in 6.13.2 to 6.13.4, are to be considered in the design of these structures.*

3.5.2 Glancing Impact Load Characteristics

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

Table 2 - Class factors to be used in 3.5.2.1.3

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

Table 3 - Class factors to be used in 3.5.2.1.4

Polar Class	***Crushing Failure Class Factor (CF_{CV})***	***Line Load Class Factor (CF_{QV})***	***Pressure Class Factor (CF_{PV})***
PC6	*3.43*	*2.82*	*0.65*
PC7	*2.60*	*2.33*	*0.65*

3.5.2.1 Bow Area

3.5.2.1.1 In the Bow area, the force (F), line load (Q), pressure (P) and load patch aspect ratio (AR) associated with the glancing impact load scenario are functions of the hull angles measured at the upper ice waterline (UIWL). The influence of the hull angles is captured through calculation of a bow shape coefficient (fa). The hull angles are defined in Figure 4.

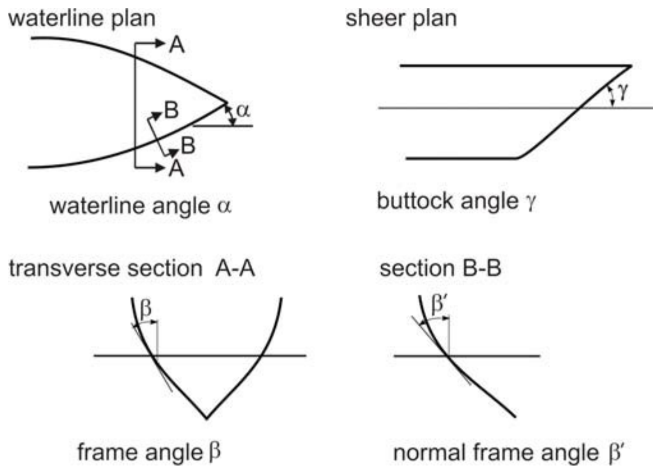

Figure 4 – Definition of Hull Angles

Note:

β' = *normal frame angle at upper ice waterline [deg]*

α = *upper ice waterline angle [deg]*

γ = *buttock angle at upper ice waterline (angle of buttock line measured from horizontal) [deg]*

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

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

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

3.5.2.1.3 The Bow area load characteristics for bow forms defined in 3.5.1.5 are determined as follows:

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

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

where

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

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

$fa_{i,3} = 0.60$

(b) Force, F_i:

$F_i = fa_i \cdot CF_C \cdot D^{0.64}$ [MN]

(c) Load patch aspect ratio, AR_i:

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

(d) Line load, Q_i:

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

(e) Pressure, P_i:

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

where i = *sub-region considered*

L = *ship length as defined in Chapter 1, Hull, Section 1, H.2.1, but measured on the upper ice waterline (UIWL) [m]*

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

α = *waterline angle [deg], see Figure 4*

β'_i = *normal frame angle [deg], see Figure 4*

D = *ship displacement [kt], 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*

CF_D = *Load Patch Dimensions Class Factor from Table 2*

3.5.2.1.4 The Bow area load characteristics for bow forms defined in 3.5.1.6 are determined as follows:

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

$fa_i \quad = \quad \alpha_i / 30$

(b) Force, F_i:

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

(c) Line load, Q_i:

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

(d) Pressure, P_i:

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

where i = sub-region considered

α = waterline angle [deg], see Figure 4

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

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

3.5.2.2 Hull Areas Other Than the Bow

3.5.2.2.1 In the hull areas other than the bow, the force (FNonBow) and line load (QNonBow) used in the determination of the load patch dimensions (bNonBow, wNonBow) and design pressure (Pavg) are determined as follows:

(a) Force, F_{NonBow}:

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

(b) Line Load, Q_{NonBow}:

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

where CF_C = Crushing failure Class Factor From Table 2

DF = ship displacement factor

$= D^{0.64}$ if $D \le CF_{DIS}$

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

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

CF_{DIS} = Displacement Class Factor from Table 2

CF_D = Load Patch Dimensions Class Factor from Table 2

3.5.3 Design Load Patch

3.5.3.1 In the Bow area, and the Bow Intermediate Icebelt area for ships with class notation PC6 and PC7, the design load patch has dimensions of width, wBow, and height, bBow, defined as follows:

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

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

where

F_{Bow} = maximum force F_i in the Bow area [MN]

Q_{Bow} = maximum line load Q_i in the Bow area [MN/m]

P_{Bow} = maximum pressure P_i in the Bow area [MPa]

3.5.3.2 In hull areas other than those covered by 3.5.3.1, the design load patch has dimensions of width, w_{NonBow}, *and height,* b_{NonBow}, *defined as follows:*

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

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

where

F_{NonBow} = force as defined in 3.5.2.2.1 (a) [MN]

Q_{NonBow} = line load as defined in 3.5.2.2.1 (b) [MN/m]

3.5.4 Pressure Within the Design Load Patch

3.5.4.1 The average pressure, Pavg, within a design load patch is determined as follows:

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

where

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

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

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

3.5.4.2 Areas of higher, concentrated pressure exist within the load patch. In general, smaller areas have higher local pressures. Accordingly, the peak pressure factors listed in Table 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	$PPF_t = (1.6 - s) \geq 1.0$
	With No Load Distributing Stringers	$PPF_t = (1.8 - s) \geq 1.2$
Frames in bottom structures		$PPF_s = 1.0$
Load Carrying Stringers Side and Bottom Longitudinals Web Frames		$PPF_s = 1.0$, if $S_w \geq 0.5 \cdot w$ $PPF_s = 2.0 - 2.0 \cdot S_w / w$, if $S_w < (0.5 \cdot w)$
where: s = frame or longitudinal spacing [m] S_w = web frame spacing [m] w = ice load patch width [m]		

3.5.5 Hull Area Factors

3.5.5.1 Associated with each hull area is an Area Factor that reflects the relative magnitude of the load expected in that area. The Area Factor (AF) for each hull area is listed in Table 5.

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

3.5.5.3 Due to their increased manoeuvrability, ships having propulsion arrangements with azimuthing thruster(s) or "podded" propellers shall have specially considered Stern Icebelt (S_i) and Stern Lower (S_l) hull area factors.

3.5.5.4 For ships assigned the additional notation "Icebreaker", the Area Factor (AF) for each hull area is listed in Table 6.

Table 5 - Hull Area Factors (AF)

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

Notes:
* See C.1.3.
** Indicates that strengthening for ice loads is not necessary.

Table 6 - Hull Area Factors (AF) for ships with additional notation "Icebreaker"

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

3.6 Shell Plate Requirements

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

$t = t_{net} + t_s$ *[mm]*

where

t_{net} = *plate thickness required to resist ice loads according to 3.6.2[mm]*

t_s = *corrosion and abrasion allowance according to 3.13 [mm]*

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

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

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

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

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

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

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

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

where

Ω = *smallest angle between the chord of the waterline and the line of the first level framing as illustrated in Figure 5 [deg].*

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

AF = *Hull Area Factor from Table 5 or Table 6*

PPF_p = *Peak Pressure Factor from Table 4*

P_{avg} = *average patch pressure as defined in 3.5.4 [MPa]*

σ_y = *minimum upper yield stress of the material [N/mm^2]*

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

l = *distance between frame supports, i.e. equal to the frame span as given in 3.7.5, but not reduced for any fitted end brackets [m]. When a load-distributing stringer is fitted, the length l need not be taken larger than the distance from the stringer to the most distant frame support.*

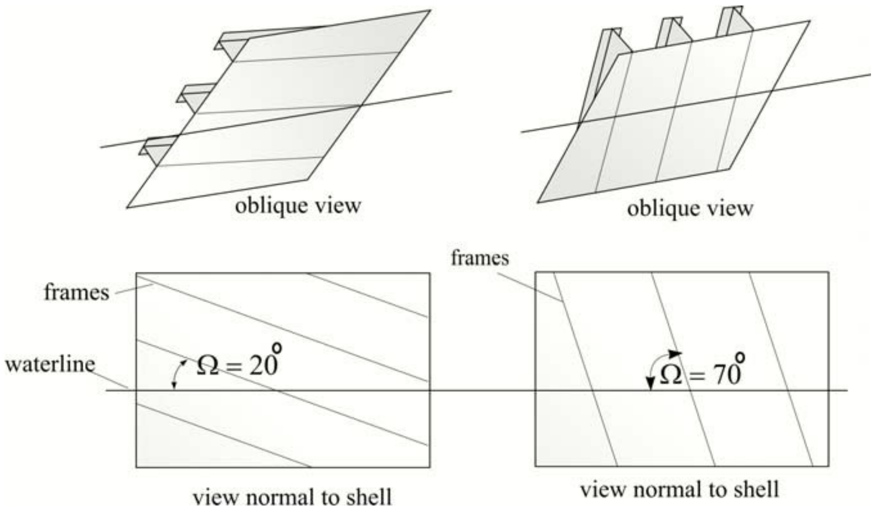

Figure 5 - Shell Framing Angle Ω

3.7 Framing - General

3.7.1 *Framing members of Polar class ships are to be designed to withstand the ice loads defined in 3.5.*

3.7.2 *The term “framing member” refers to transverse and longitudinal local frames, load-carrying stringers and web frames in the areas of the hull exposed to ice pressure, see Figure 3. Where load-distributing stringers have been fitted, the arrangement and scantlings of these are to be specially considered. In general, load-distributing stringers shall be located at or close to mid-span of transverse frames, have a web height not less than 80% of transverse frames and have at least the same web net thickness.*

3.7.3 *The strength of a framing member is dependent upon the fixity that is provided at its supports. Fixity can be assumed where framing members are either continuous through the support or attached to a supporting section with a connection bracket. In other cases, simple support is to be assumed unless the connection can be demonstrated to provide significant rotational restraint. Fixity is to be ensured at the support of any framing which terminates within an ice-strengthened area. See also 3.18.1.*

3.7.4 *The details of framing member intersection with other framing members, including plated structures, as well as the details for securing the ends of framing members at supporting sections, are to be specially considered.*

3.7.5 *The effective span of a framing member is to be determined on the basis of its moulded length. If brackets are fitted, the effective span may be reduced in accordance with the Figure 6. Brackets are to be configured to ensure stability in the elastic and post-yield response regions.*

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

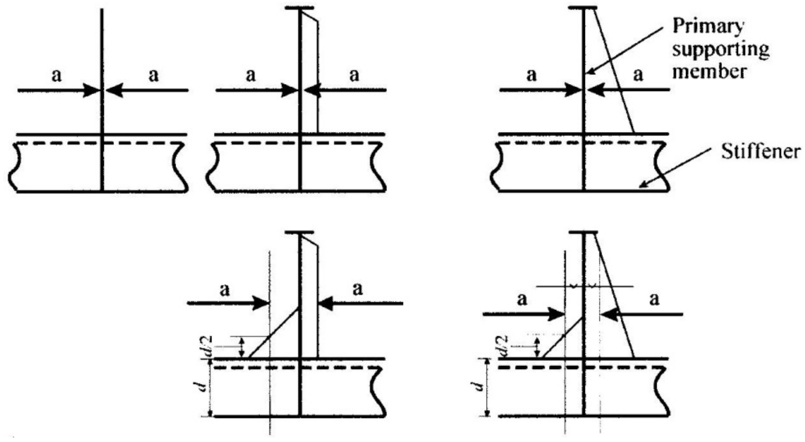

Figure 6 - Design span of framing member

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

$A_w = h \cdot t_{wn} \cdot \sin \varphi_w / 100$ [cm^2]

Where h = height of stiffener [mm], see Figure 7

t_{wn} = *net web thickness [mm]*

= $t_w - t_c$

t_w = *as built web thickness [mm], see Figure 7*

t_c = *corrosion deduction [mm] to be subtracted from the web and flange thickness (not less than t_s as required by 3.13.3)*

φ_w = *smallest angle between shell plate and stiffener web, measured at the midspan of the stiffener, see Figure 7. The angle φ_w may be taken as 90 degrees provided the smallest angle is not less than 75 degrees.*

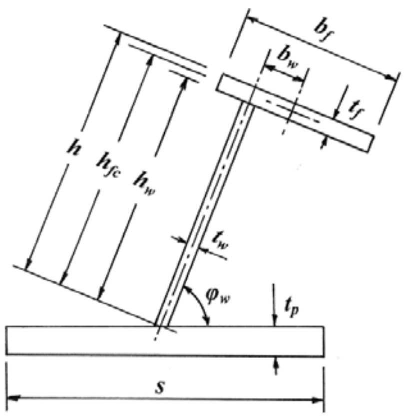

Figure 7 - Stiffener geometry

3.7.8 *When the cross-sectional area of the attached plate flange exceeds the cross-sectional area of the local frame, the actual net effective plastic section modulus, Zp, of a transverse or longitudinal frame is given by:*

$$Z_p = A_{pn} . t_{pn} / 20 + \frac{h_w^2 . t_{wn} . \sin\varphi_w}{2000} + A_{fn} . (h_{fc} . \sin\varphi_w - b_w . \cos\varphi_w) / 10 \quad [cm^3]$$

h, t_{wn}, t_c, and φ_w are as given in 3.7.7 and s as given in 3.6.2.

A_{pn} = net cross-sectional area of the local frame [cm^2]

t_{pn} = fitted net shell plate thickness [mm] (complying with t_{net} as required by 3.6.2)

h_w = height of local frame web [mm], see Figure 7

A_{fn} = net cross-sectional area of local frame flange [cm^2]

h_{fc} = height of local frame measured to centre of the flange area [mm], see Figure 7

b_w = distance from mid thickness plane of local frame web to the centre of the flange area [mm], see Figure 7

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

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

and the net effective plastic section modulus, Z_p, of a transverse or longitudinal frame is given by:

$$Z_p = t_{pn} . s . (z_{na} + t_{pn}/2) \sin\varphi_w + \frac{\left[(h_w - z_{na})^2 + z_{na}^2\right] \cdot t_{wn} \cdot \sin\varphi_w}{2000} + \frac{A_{fn} \cdot \left[\left(h_{fc} - z_{na}\right) \cdot \sin\varphi_w - b_w \cdot \cos\varphi_w\right]}{10} \quad [cm^3]$$

3.7.9 *In the case of oblique framing arrangement (70 deg > Ω > 20 deg, where Ω is defined as given in 3.6.2), linear interpolation is to be used.*

3.8 Framing – Local Frames in Bottom Structures and Transverse Local Frames in Side Structures

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

3.8.2 *The actual net effective shear area of the frame, A_w, as defined in 3.7.7, is to comply with the following condition: $A_w \geq A_t$, where:*

$A_t = 100^2 \cdot 0.5 \cdot LL \cdot s \cdot (AF \cdot PPF_t \cdot P_{avg}) / (0.577 \cdot \sigma_y)$ [cm^2]

where

LL = *length of loaded portion of span*

= *lesser of a and b [m]*

a = *local frame span as defined in 3.7.5 [m]*

b = *height of design ice load patch as defined in 3.5.3.1 or 3.5.3.2 [m]*

s = *spacing of local frame [m]*

AF = *Hull Area Factor from Table 5 or Table 6*

PPF_t = *Peak Pressure Factor, PPF_t or PPF_s as appropriate from Table 4*

P_{avg} = *average pressure within load patch as defined in 3.5.4 [MPa]*

σ_y = *minimum upper yield stress of the material [N/mm^2]*

3.8.3 *The actual net effective plastic section modulus of the plate/stiffener combination, Z_p, as defined in 3.7.8, is to comply with the following condition: $Z_p \geq Z_{pt}$, where Z_{pt} is to be the greater calculated on the basis of two load conditions: a) ice load acting at the midspan of the local frame, and b) the ice load acting near a support. The A1 parameter in defined below reflects these two conditions:*

$$Z_{pt} = 100^3 \cdot LL \cdot Y \cdot s \cdot (AF \cdot PPF_t \cdot P_{avg}) \cdot a \cdot A_1 / (4 \cdot \sigma_y) \text{ [cm}^3\text{]}$$

where

A_F, PPF_t, P_{avg}, LL, b, s, a and σ_y are as given in 3.8.2.

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

A_1 = maximum of

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

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

j = *1 for a local frame with one simple support outside the ice-strengthened areas*

= *2 for a local frame without any simple supports*

$$a_1 = A_t / A_w$$

A_t = *minimum shear area of the local frame as given in 3.8.2 [cm^2]*

A_w = *effective net shear area of the local frame (calculated according to 3.7.7) [cm^2]*

$k_w = 1 / (1 + 2 \cdot A_{fn} / A_w)$ *with* A_{fn} *as given in 3.7.8*

$k_z = z_p / Z_p$ *in general*

$=$ *0.0 when the frame is arranged with end bracket*

z_p = *sum of individual plastic section moduli of flange and shell plate as fitted* [cm^3]

= $(b_f \cdot t_{fn}^2/4 + b_{eff} \cdot t_{pn}^2/4) / 1000$

b_f = *flange breadth [mm], see Figure 7*

t_{fn} = *net flange thickness [mm]*

= $t_f - t_c$ (t_c *as given in 3.7.7)*

t_f = *as-built flange thickness [mm], see Figure 7*

t_{pn} = *the fitted net shell plate thickness [mm] (not to be less than* t_{net} *as given in 3.6.2)*

b_{eff} = *effective width of shell plate flange [mm]*

= $500 \cdot s$

Z_p = *net effective plastic section modulus of the local frame (calculated according to 3.7.8)* [cm^3]

3.8.4 *The scantlings of the local frame are to meet the structural stability requirements of 3.11.*

3.9 Framing – Longitudinal Local Frames in Side Structures

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

3.9.2 *The actual net effective shear area of the frame,* A_w*, as defined in 3.7.7, is to comply with the following condition:* $A_w \geq A_L$*, where:*

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

where

AF = *Hull Area Factor from Table 5 or Table 6*

PPF_s = *Peak Pressure Factor from Table 4*

P_{avg} = *average pressure within load patch s defined in 3.5.4 [MPa]*

$b_1 = k_o \cdot b_2$ [m]

$k_o = 1 - 0.3 / b'$

$b' = b / s$

b = height of design ice load patch as defined in 3.5.3.1 or 3.5.3.2 [m]

s = spacing of longitudinal frames [m]

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

$= s$ [m], if $b' \geq 2$

a = effective span of longitudinal local frame as given in 3.7.5 [m]

σ_y = minimum upper yield stress of the material [N/mm²]

3.9.3 *The actual net effective plastic section modulus of the plate/stiffener combination, Z_p, as defined in 3.7.8, is to comply with the following condition: $Z_p \geq Z_{pL}$, where:*

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

where

AF, PPF_s, P_{avg}, b_1, a and σ_y are as given in 3.9.2

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

$$a_4 = A_L / A_w$$

A_L = minimum shear area for longitudinal as given in 3.9.2 [cm²]

A_w = net effective shear area of longitudinal (calculated according to 3.7.7) [cm²]

k_{wl} = $1 / (1 + 2 \cdot A_{fn} / A_w)$ with A_{fn} as given in 3.7.8

3.9.4 *The scantlings of the longitudinals are to meet the structural stability requirements of 3.11.*

3.10 Framing - Web Frames and Load Carrying Stringers

3.10.1 *Web frames and load-carrying stringers are to be designed to withstand the ice load patch as defined in 3.5. The load patch is to be applied at locations where the capacity of these members under the combined effects of bending and shear is minimised.*

3.10.2 *Web frames and load-carrying stringers are to be dimensioned such that the combined effects of shear and bending, nowhere exceed the minimum upper yield stress of the material σ_y. Where the structural configuration is such that members do not form part of a grillage system, the appropriate peak pressure factor (PPF) from Table 4 is to be used. Special attention is to be paid to the shear capacity in way of lightening holes and cut-outs in way of intersecting members.*

3.10.3 *For determination of scantlings of load carrying stringers, web frames supporting local frames, or web frames supporting load carrying stringers forming part of a structural grillage system, appropriate methods as outlined in 3.19 are normally to be used.*

3.10.4 *The scantlings of web frames and load-carrying stringers are to meet the structural stability requirements of 3.11.*

3.11 Framing - Structural Stability

3.11.1 *To prevent local buckling in the web, the ratio of web height (hw) to net web thickness (twn) of any framing member is not to exceed:*

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

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

where

h_w = *web height*

t_{wn} = *net web thickness*

σ_y = *minimum upper yield stress of the material [N/mm²]*

3.11.2 *Framing members for which it is not practicable to meet the requirements of 3.11.1 (e.g. load carrying stringers or deep web frames) are required to have their webs effectively stiffened. The scantlings of the web stiffeners are to ensure the structural stability of the framing member. The minimum net web thickness for these framing members is given by:*

$$t_{wn} = 2.63\text{x}10^{-3}.c_1\sqrt{\sigma_y/(5.34 + 4.(c_1/c_2)^2)}\ [mm]$$

where

$c_1 = h_w - 0.8 \cdot h$ *[mm]*

h_w = *web height of stringer / web frame [mm] (see Figure 8)*

h = *height of framing member penetrating the member under consideration (0 if no such framing member) [mm] (see Figure 8)*

c_2 = *spacing between supporting structure oriented perpendicular to the member under consideration [mm] (see Figure 8)*

σ_y = *minimum upper yield stress of the material [N/mm²]*

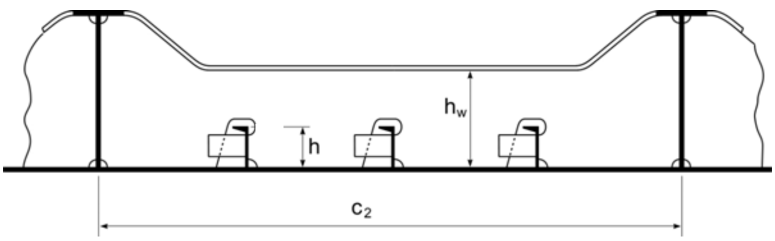

Figure 8 - Parameter Definition for Web Stiffening

3.11.3 *In addition, the following is to be satisfied:*

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

where

σ_y = *minimum upper yield stress of the shell plate in way of the framing member [N/mm²]*

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

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

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

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

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

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

$b_{out} = b_f / 2 + b_w - t_w / 2$ *[mm] (see Figure 7)*

where

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

σ_y = *minimum upper yield stress of the material [N/mm²]*

3.12 Plated Structures

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

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

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

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

3.12.3 *The stability of the plated structure is to adequately withstand the ice loads defined in 3.5.*

3.13 Corrosion/Abrasion Additions and Steel Renewal

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

__3.13.2__ The values of corrosion/abrasion additions, t_s, to be used in determining the shell plate thickness are listed in Table 7.

__3.13.3__ Polar Class ships are to have a minimum corrosion/abrasion addition of t_s = 1.0 mm applied to all internal structures within the ice-strengthened hull areas, including plated members adjacent to the shell, as well as stiffener webs and flanges.

Table 7 - Corrosion/Abrasion Additions for Shell Plating

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

__3.13.4__ Steel renewal for ice strengthened structures is required when the gauged thickness is less than t_{net} + 0.5 mm.

3.14 Materials

__3.14.1__ Steel grades of plating for hull structures are to be not less than those given in Tables 9 based on the as-built thickness, the Polar Class and the Material Class of structural members according to 3.14.2.

Table 8 - Material Classes for Structural Members

Structural Members	Material Class
Shell plating within the bow and bow intermediate icebelt hull areas (B, B_{Ii})	II
All weather and sea exposed SECONDARY and PRIMARY, as defined in Chapter 1, Hull, Section 3, Table 3.2, structural members outside 0.4L amidships	I
Plating materials for stem and stern frames, rudder horn, rudder, propeller nozzle, shaft brackets, ice skeg, ice knife and other appendages subject to ice impact loads	II
All inboard framing members attached to the weather and sea-exposed plating, including any contiguous inboard member within 600 mm of the plating	I
Weather-exposed plating and attached framing in cargo holds of ships which by nature of their trade have their cargo hold hatches open during cold weather operations	I
All weather and sea exposed SPECIAL, as defined in Chapter 1, Hull, Section 3, Table 3.2, structural members within 0.2L from FP	II

__3.14.2__ Material classes specified in Chapter 1, Hull, Section 3, Table 3.2 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 plating are given in Table 7. Where the material classes in Table 7 and those in Chapter 1, Hull, Section 3, Table 3.2 differ, the higher material class is to be applied.

3.14.3 *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 9, are to be obtained from Chapter 1, Hull, Section 3, Table 3.7 and 3.8 based on the Material Class for Structural Members in Table 7 above, regardless of Polar Class.*

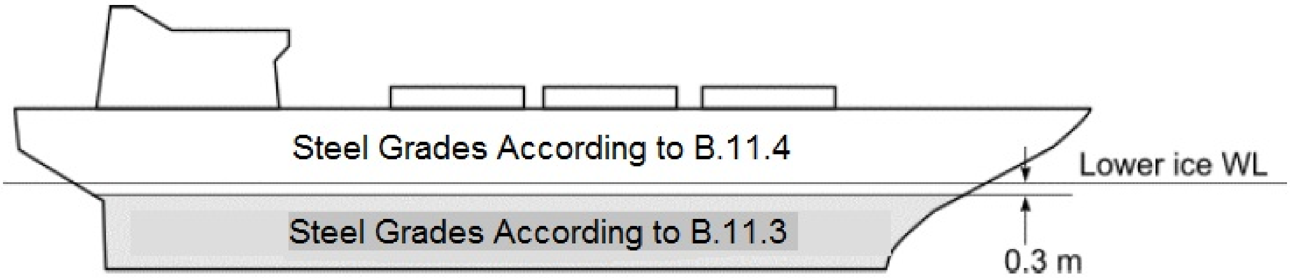

Figure 9 - Steel Grade Requirements for Submerged and Weather Exposed Shell Plating

3.14.4 *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 9, are to be not less than given in Table 9.*

Table 9 - Steel Grades for Weather Exposed Plating

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

Notes:

1) *Includes weather-exposed plating of hull structures and appendages, as well as their outboard framing members, situated above a level of 0.3 m below the lowest ice waterline.*

2) *Grades D, DH are allowed for a single strake of side shell plating not more than 1.8 m wide from 0.3 m below the lowest ice waterline.*

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

3.15 Longitudinal Strength

3.15.1 Application

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

3.15.1.2 *Intentional ramming is not considered as a design scenario for sihps which are designed with vertical or bulbous bows, see 5.6. hence the longitudinal strength requirements given in 3.15 is not to be considered for ships with stern angle γ_{stem} equal to or larger than 80 deg.*

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

3.15.2 Design Vertical Ice Force at the Bow

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

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

where

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

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

K_I = indentation parameter = K_f / K_h

a) *for the case of a blunt bow form*

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

b) *for the case of wedge bow form (α_{stem} < 80 deg), e_b =1 and the above simplifies to*

$K_f = (\tan(\alpha_{stem}) / \tan^2(\gamma_{stem}))^{0.9}$

$K_h = 0.01 \cdot A_{wp}$ [MN/m]

CF_L = *Longitudinal Strength Class Factor from Table 1*

e_b = *bow shape exponent which best describes the waterplane (see Figures 10 and 11)*

= *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 [deg] (buttock angle as per Figure 4 measured on the centreline)*

α_{stem} = *waterline angle measured in way of the stem at the upper ice waterline (UIWL) [deg] (see Figure 10)*

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

B = greatest ship moulded breadth [m]

L_B = bow length used in the equation $y = B / 2 \cdot (x/L_B)^{eb}$ [m] (see Figures 10 and 11)

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

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

CF_F = Flexural Failure Class Factor from Table 1

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

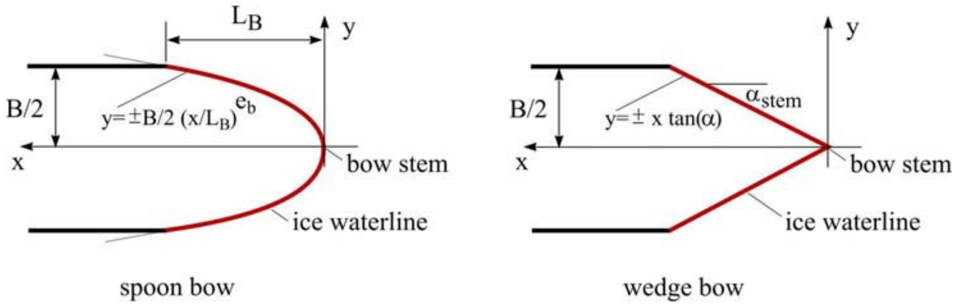

Figure 10 - Bow Shape Definition

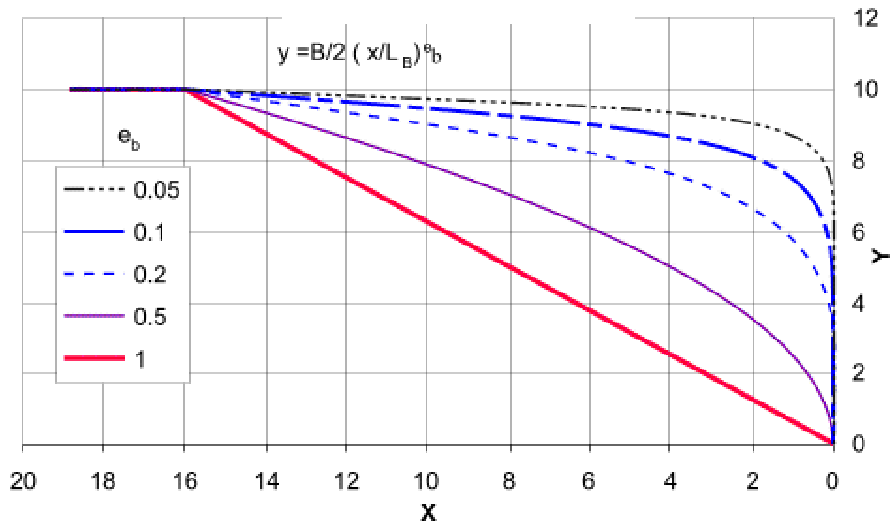

Figure 11 - Illustration of e_b Effect on the Bow Shape for B = 20 and L_B =16

3.15.3 Design Vertical Shear Force

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

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

where

C_f = longitudinal distribution factor to be taken as follows:

(a) Positive shear force

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

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

(b) Negative shear force

C_f = 0.0 at the aft end of L

C_f = -0.5 between 0.2 L and 0.6L from aft

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

Intermediate values are to be determined by linear interpolation

3.15.3.2 The applied vertical shear stress, τa, is to be determined along the hull girder in a similar manner as in Chapter 1, Hull, Section 3, Table 3.24 by substituting the design vertical ice shear force for the design vertical wave shear force.

3.15.4 Design Vertical Ice Bending Moment

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

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

where

L = ship length as defined in Chapter 1, Hull, Section 1, H.2.1, but measured on the upper ice waterline [UIWL] [m]

γ_{stem} is as given in 3.15.2.

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

C_m = 1.0 between 0.5L and 0.7L from aft

C_m = 0.3 at 0.95L from aft

C_m = 0.0 at the forward end of L

Intermediate values are to be determined by linear interpolation.

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

3.15.4.2 The applied vertical bending stress, σa, is to be determined along the hull girder in a similar manner as in Chapter 1, Hull, Section 3, Table 3.23a and 3.23b, by substituting the design vertical ice bending moment for the design vertical wave bending moment. The ship still water bending moment is to be taken as the maximum sagging moment.

3.15.5 Longitudinal Strength Criteria

3.15.5.1 The strength criteria provided in Table 10 are to be satisfied. The design stress is not to exceed the permissible stress.

Table 10 - Longitudinal Strength Criteria

Failure Mode	Applied Stress	Permissible Stress when $\sigma_y / \sigma_u \leq 0.7$	Permissible Stress when $\sigma_y / \sigma_u > 0.7$
Tension	σ_a	$\eta \cdot \sigma_y$	$\eta \cdot 0.41\ (\sigma_u + \sigma_y)$
Shear	τ_a	$\eta \cdot \sigma_y / (3)^{0.5}$	$\eta \cdot 0.41\ (\sigma_u + \sigma_y) / (3)^{0.5}$
Buckling	σ_a	σ_c for plating and for web plating of stiffeners $\sigma_c / 1.1$ for stiffeners	
	τ_a	τ_c	

where

σ_a = *applied vertical bending stress [N/mm²]*

τ_a = *applied vertical shear stress [N/mm²]*

σ_y = *minimum upper yield stress of the material [N/mm²]*

σ_u = *ultimate tensile strength of material [N/mm²]*

σ_c = *critical buckling stress in compression, according to Chapter 1, Hull, Section 3, Table 3.19 [N/mm²]*

τ_c = *critical buckling stress in shear, according to Chapter 1, Hull, Section 3, Table 3.20 [N/mm²]*

η = *0.8*

η = *0.6 for ships which are assigned the additional notation "Icebreaker"*

3.16 Stem and Stern Frames

3.16.1 *The stem is to be shaped in such a way that it can break ice effectively. The thickness of the stem plating is not to be less than 1.3 times the thickness of the adjacent shell plating.*

3.16.2 *The stern frame is to be shaped in such a way that it can displace broken ice effectively.*

3.16.3 *For Polar Class ships requiring **ICE-B3** or **ICE-B4** equivalency (see Chapter 1, Hull, Section 14.A), the requirements of Chapter 1, Hull, Section 14.D.7 to D.10 need also to be observed.*

3.17 Appendages

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

3.17.2 *All manoeuvring arrangements, e.g. rudder stocks, rudder couplings, rudder bearings, rudder bodies, ice horns, propeller nozzles, podded propulsors, azimuth thrusters etc., are to be dimensioned to withstand the design ice force defined in 3.5.2.2.1, adjusted by the appropriate hull area factor in Table 5. Alternative design ice force definitions, including reduced design ice forces below the lower ice waterline (LIWL) and longitudinal design ice forces (where applicable), may be agreed with **TL**.*

3.17.3 *The design ice force shall be applied at locations where the capacity of these structural members under the combined effects of bending, shear and torsion (where applicable) is minimised. A stress analysis shall demonstrate that equivalent stresses in the structure nowhere exceed the minimum upper yield stress of the material* σ_y.

3.17.4 *The thickness of rudder and nozzle plating is to be determined according to 3.6.*

3.17.5 *Rudders and rudder stocks shall be protected from ice loads with an ice horn which is fitted directly abaft the rudder and which extends a minimum distance of 1.5 CFD [m] below the lower ice waterline (LIWL) defined in 7. When dimensioning the ice horn and the uppermost part of the rudder, it may be assumed that the design ice patch is acting over both structures, i.e. the design ice force defined in 3.17.2 may be distributed between them.*

3.17.6 *When bilge keels are fitted, it is required that they be divided into several independent lengths to limit possible damage to the shell.*

3.18 Local Details

3.18.1 *The intersection and termination of framing members at supporting structures, i.e. stringers, web frames, decks or bulkheads, shall be arranged to enable the transfer of ice-induced loads (bending moments and shear forces), generally by means of direct welding, collar plates, lugs, connection brackets or heel stiffeners.*

3.18.2 *The loads carried by a member in way of cut-outs are not to cause instability. Where necessary, the structure is to be stiffened.*

3.19 Direct Calculations

3.19.1 *Direct calculations are not to be utilised as an alternative to the analytical procedures prescribed for the shell plating and local frame requirements given in 3.6, 3.8 and 3.9.*

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

3.19.3 *Where direct calculations are used to check the strength of structural arrangements (e.g. arrangements which may need to be specially considered), the load patch specified in 3.5 is to be applied, without being combined* *with any other loads. The load patch is to e applied at locations where the capacity of these members under the combined effects of bending and sheer is minimized. Special attention is to be paid to the shear capacity in way of lightening holes and cut-outs in way of intersecting members.*

3.19.4 *.the strength evaluation of web frames and stringers may be performed based on linear or non-linear analysis. Recognized structural idealization and calculation methods are to be applied, but the detailed requirements are to be specified by TL. In the strength evaluation, the guidance given in 3.19.5 and 3.19.6 may generally be considered.*

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

3.19.5.1 *Web plates and flange elements in compression and shear to fulfil relevant buckling criteria as specified by TL.*

3.19.5.2 *Nominal sheer stresses in member web plates to be less than* $\sigma_y / \sqrt{3}$

3.19.5.3 *Nominal von Mises stresses in member flanges to less than* $1.15\ \sigma_y$

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

3.19.6.1 *The analysis is to reliably capture buckling and plastic deformation of the structure.*

3.19.6.2 *The acceptance criteria are to ensure a suitable margin against fracture and major buckling and yielding causing significant loss of stiffness*

3.19.6.3 *Permanent lateral and out-of plane deformation of considered member are to be minor relative to the relevant structural dimensions*

3.19.6.4 *Detailed acceptance criteria to be decided by TL.*

3.20 Welding

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

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

SECTION 4 –SUBDIVISION AND STABILITY

4.1 Goal

The goal of this section is to ensure adequate subdivision and stability in both intact and damaged conditions.

4.2 Functional requirements

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

.1 ships shall have sufficient stability in intact conditions when subject to ice accretion; and

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

4.3 Regulations

4.3.1 Stability in intact conditions

4.3.1.1 In order to comply with the functional requirement of paragraph 4.2.1, 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:

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

.2 7.5 kg/m^2 for the projected lateral area of each side of the ship above the water plane; and

.3 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% and the static moments of this area by 10%.

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

.1 designed to minimize the accretion of ice; and

.2 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.

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

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

4.3.2 Stability in damaged conditions

4.3.2.1 In order to comply with the functional requirements of paragraph 4.2.2, ships of categories A and B, constructed on or after 1 January 2017, 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.

4.3.2.2 The ice damage extents to be assumed when demonstrating compliance with paragraph 4.3.2.1 shall be such that:

.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;

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

.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.

SECTION 5 – WATERTIGHT AND WEATHERTIGHT INTEGRITY

5.1 Goal

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

5.2 Functional requirements

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

5.3 Regulations

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

.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; and

.2 in addition, for ships intended to operate in low air temperature the following apply:

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

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

SECTION 6 – MACHINERY INSTALLATIONS

6.1 Goal

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

6.2 Functional requirements

6.2.1 In order to achieve the goal set out in paragraph 6.1 above, the following functional requirements are embodied in the regulations of this section.

6.2.1.1 Machinery installations shall provide functionality under the anticipated environmental conditions, taking into account:

.1 ice accretion and/or snow accumulation;

.2 ice ingestion from seawater;

.3 freezing and increased viscosity of liquids;

.4 seawater intake temperature; and

.5 snow ingestion.

6.2.1.2 In addition, for ships intended to operate in low air temperatures:

.1 machinery installations shall provide functionality under the anticipated environmental conditions, also taking into account:

.1 cold and dense inlet air; and

.2 loss of performance of battery or other stored energy device; and

.2 materials used shall be suitable for operation at the ships polar service temperature.

6.2.1.3 In addition, for ships ice strengthened in accordance with section 6, machinery installations shall provide functionality under the anticipated environmental conditions, taking into account loads imposed directly by ice interaction.

6.3 Regulations

6.3.1 In order to comply with the functional requirement of paragraph 6.2.1.1 above, taking into account the anticipated environmental conditions, the following apply:

.1 machinery installations and associated equipment shall be protected against the effect of ice accretion and/or snow accumulation, ice ingestion from sea water, freezing and increased viscosity of liquids, seawater intake temperature and snow ingestion;

.2 working liquids shall be maintained in a viscosity range that ensures operation of the machinery; and

.3 seawater supplies for machinery systems shall be designed to prevent ingestion of ice, **(6)** or otherwise arranged to ensure functionality.

6.3.2 In addition, for ships intended to operate in low air temperatures, the following apply:

.1 in order to comply with the functional requirement of paragraph 6.2.1.2 above, exposed machinery and electrical installation and appliances shall function at the polar service temperature;

.2 in order to comply with the functional requirement of paragraph 6.2.1.2.1 above, 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; and

(6) *Refer to MSC/Circ.504, Guidance on design and construction of sea inlets under slush ice conditions.*

.3 in order to comply with the functional requirements of paragraph 6.2.1.2.2 above, materials of exposed machinery and foundations shall be approved by **TL**, taking into account requirements defined in items from 6.4 to 6.14 or other standards offering an equivalent level of safety based on the polar service temperature.

6.3.3 In addition, for ships ice strengthened in accordance with section 3, in order to comply with the functional requirements of paragraph 6.2.1.3 above, the following apply:

.1 scantlings of propeller blades, propulsion line, steering equipment and other appendages of category A ships shall be approved by **TL**, taking into account requirements for Polar Class 1-5 defined in items from 6.4 to 6.14 ;

.2 scantlings of propeller blades, propulsion line, steering equipment and other appendages of category B ships shall be approved by **TL**, taking into account requirements for Polar Class 6-7 defined in items from 6.4 to 6.14; and

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

6.4 General

6.4.1 Definitions

The following main parameters are used:

CP = Controllable pitch propeller

d = Propeller hub diameter [m]

D = Diameter of propeller [m]

EAR = Expanded blade area ratio [-]

FP = Fixed pitch propeller

LIWL = Minimum ballast waterline in ice

n = Rotational propeller speed [rps]

N = Number of loads

R = Radius of the propeller [m]

S = Safety factor [-]

z = Number of propeller blades

ϕ *= Propeller rotation angle [degrees]* *μ = Friction coefficient [-]*

6.4.2 Drawings and particulars to be submitted

(i) Details of the environmental conditions and the required ice class for the machinery, if different from ship's ice class.

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

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

(iv) Calculations and documentation indicating compliance with the requirements of this Section.

6.5 Materials

6.5.1 Materials exposed to sea water

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

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

6.5.2 Materials exposed to sea water temperature

Materials exposed to sea water temperature shall be of steel or other approved ductile material. An average impact energy value of 20 J taken from three tests is to be obtained at minus 10 ºC. This requirement applies to 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. For definition of structural boundaries exposed to sea water temperature see Figure 9.

6.5.3 Material exposed to low air temperature

Materials of essential components exposed to low air temperature shall be of steel or other approved ductile material. An average impact energy value of 20 J taken from three Charpy V tests is to be obtained at 10 ºC below the lowest design temperature. This does not apply to surface hardened components, such as bearings and gear teeth. For definition of structural boundaries exposed to sea water temperature see Figure 9.

6.6 Design Principles

6.6.1 General

All components and systems shall be designed such that the task of the ship in the relevant ice and weather conditions can be fulfilled with reasonable safety. The principle of the pyramid of strength has to be followed.

6.6.2 Ship operation in case of damage

Single screw vessels classed PC1 to PC5 inclusive shall have means provided to ensure sufficient vessel operation in the case of propeller damage including CP-mechanism (i.e. pitch control mechanism). Sufficient ship operation means that the ship shall 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 assistance provided the availability can be demonstrated (condition for approval, to be mentioned in Class Certificate).

6.6.3 Propulsion line components

The strength of the propulsion line shall be designed:

a) For maximum loads in 6.7.2. (for open and ducted propellers respectively) and 6.8.1.;

b) Such that the plastic bending of a propeller blade shall not cause damages in other propulsion line components;

c) With sufficient fatigue strength as determined in e.g. 6.7.2.2, 6.8.2.2 and 6.9.1.2.3.

6.6.4 Reverse operation of propellers

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

6.6.5 Drainage

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

6.7 Propeller

6.7.1 General

These Rules cover open and ducted type propellers situated at the stern of a vessel having controllable pitch or fixed pitch blades. Ice loads on bow propellers and pulling type propellers shall receive special consideration. The given loads are expected, single occurrence, maximum values for the whole ships service life for normal operational conditions. These loads do not cover off-design operational conditions, for example when a stopped propeller is dragged through ice. These Rules apply also for azimuthing (geared and podded) thrusters considering loads due to propeller ice interaction. However, ice loads due to ice impacts on the body of azimuthing thrusters are not covered by section 6.

The loads given herein are total loads (unless otherwise stated) during ice interaction and are to be applied separately (unless otherwise stated) and are intended for component strength calculations only. The different loads given here are to be applied separately.

6.7.2 Propeller blades

6.7.2.1 Design ice loads

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

6.7.2.1.1 Ice Class Factors

The Table 11 lists the design ice thickness and ice strength index to be used for estimation of the propeller ice loads.

Table 11 Definition of ice strength index

Ice Class	H_{ice} [m]	S_{ice} [-]	S_{qice} [-]
PC1	4.0	1.2	1.15
PC2	3.5	1.1	1.15
PC3	3.0	1.1	1.15
PC4	2.5	1.1	1.15
PC5	2.0	1.1	1.15
PC6	1.75	1	1
PC7	1.5	1	1

H_{ice} Ice thickness for machinery strength design

S_{ice} Ice strength index for blade ice force

S_{qice} Ice strength index for blade ice torque

6.7.2.1.2 Design Ice Loads for Open Propellers

6.7.2.1.2.1 Maximum Backward Blade Force, F_b

When $D < D_{limit}$;

$$F_b = -27\, S_{ice}[nD]^{0.7}\left[\frac{EAR}{Z}\right]^{0.3}[D]^2 \quad [kN] \qquad (1)$$

when $D \geq D_{limit}$;

$$F_b = -23\, S_{ice}[nD]^{0.7}\left[\frac{EAR}{Z}\right]^{0.3}[H_{ice}]^{1.4}[D] \quad [kN] \qquad (2)$$

Where;

$$D_{limit} = 0.85 \cdot (H_{ice})^{1.4} \quad [m] \qquad (3)$$

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

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

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

b) Load case 2: a load equal to 50% of the F_b is to be applied on the propeller tip area outside of 0.9R.

c) Load case 5: for reversible propellers a load equal to 60% of the F_b is to be applied from 0.6R to the tip and from the blade trailing edge to a value of 0.2 chord length.

See load cases 1, 2 and 5 in Table 1 of Appendix 2.

6.7.2.1.2.2 Maximum Forward Blade Force F_f

When $D < D_{limit}$;

$$F_f = 250\left[\frac{EAR}{Z}\right]D^2 \quad [kN] \tag{4}$$

when $D \geq D_{limit}$;

$$F_f = 500\left[\frac{1}{1-\frac{d}{D}}\right]H_{ice}\left[\frac{EAR}{Z}\right][D] \quad [kN] \tag{5}$$

where;

$$D_{limit} = \left(\frac{2}{1-\frac{d}{D}}\right)H_{ice} \tag{6}$$

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

a) Load case 3: from 0.6R to the tip and from the blade leading edge to a value of 0.2 chord length.

b) Load case 4: a load equal to 50% of the F_f is to be applied on the propeller tip area outside of 0.9R.

c) Load case 5: for reversible propellers a load equal to 60% F_f is to be applied from 0.6R to the tip and from the blade trailing edge to a value of 0.2 chord length.

See load cases 3, 4 and 5 in Table 1 of Appendix 2.

6.7.2.1.3 Design Ice Loads for Ducted Propellers

6.7.2.1.3.1 Maximum Backward Blade Force F_b

When $D < D_{limit}$;

$$F_b = -9.5\, S_{ice} \left[\frac{EAR}{Z}\right]^{0.3} [nD]^{0.7}\, D^2 \quad [kN] \tag{7}$$

when $D \geq D_{limit}$;

$$F_b = -66\, S_{ice} \left[\frac{EAR}{Z}\right]^{0.3} [nD]^{0.7}\, D^{0.6}\, [H_{ice}]^{1.4} \quad [kN] \tag{8}$$

where $D_{limit} = 4.H_{ice}$

n shall be taken as in 6.7.2.1.2.1.

F_b is to be applied as a uniform pressure distribution to an area on the back side for the following load cases (see Table 2 of Appendix 2):

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

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

6.7.2.1.3.2 Maximum Forward Blade Force F_f

When $D \leq D_{limit}$;

$$F_f = 250 \,.\left[\frac{EAR}{Z}\right].\, D^2 \quad [kN] \tag{9}$$

when $D > D_{limit}$;

$$F_f = 500 \,.\left[\frac{EAR}{Z}\right].\, D \,.\, \frac{1}{\left(1 - \frac{d}{D}\right)} \,.\, H_{ice} \quad [kN] \tag{10}$$

where;

$$D_{limit} = \frac{2}{\left(1 - \frac{d}{D}\right)} \,.\, H_{ice} \quad [m] \tag{11}$$

F_f is to be applied as a uniform pressure distribution to an area on the face (pressure) side for the following load case (see Table 2 Appendix 2):

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

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

6.7.2.1.4 Blade Failure Load for Both Open and Ducted Propeller F_{ex}

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

The blade failure load is:

$$F_{ex} = \frac{0.3 \cdot c \cdot t^2 \cdot \sigma_{ref}}{0.8 \cdot D - 2 \cdot r} 10^3 \text{ [kN]} \qquad (12)$$

$$\sigma_{ref} = 0.6 \cdot \sigma_{0.2} + 0.4 \cdot \sigma_u \quad \text{[MPa]} \qquad (13)$$

*where σ_u (maximum ultimate tensile strength) and $\sigma_{0.2}$ (maximum yield or 0.2 % proof strength) are representative values for the blade material. Representative in this respect means values for the considered section. These values may either be obtained by means of tests, or commonly accepted "thickness correction factors" approved by **TL**. If not available, maximum specified values shall be used.*

c, t and r are respectively the actual chord length, thickness and radius of the cylindrical root section of the blade at the weakest section outside root fillet, and typically will be at the termination of the fillet into the blade profile.

6.7.2.1.5 Maximum Propeller Ice Torque applied to both, open and ducted propeller Q_{max}

When $D < D_{limit}$;

$$Q_{max} = 105 \times (1 - d/D) \times S_{qice} \times (P_{0.7} / D)^{0.16} \times (t_{0.7} / D)^{0.6} \times (nD)^{0.17} \times D^3 \quad \text{[kNm]} \qquad (14)$$

when $D \geq D_{limit}$;

$$Q_{max} = 202 \times (1 - d/D) \times S_{qice} \times H_{ice}^{1.1} \times (P_{0.7} / D)^{0.16} \times (t_{0.7} / D)^{0.6} \times (nD)^{0.17} \times D^{1.9} \quad \text{[kNm]}$$
(15)

where;

$D_{limit} = 1.81 . H_{ice}$ [m]

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

$t_{0.7}$ = Max thickness at 0.7 radius

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

Table 12 Rotational speed at bollard condition

Propeller type	***n***
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	$0.85.n_n$

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

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

6.7.2.2 Dynamic analysis of blade-fatigue

6.7.2.2.1 Number of ice loads N_{ice}

Number of load cycles N_{ice} in the load spectrum per blade is to be determined according to the formula:

$$N_{ice} = k_1 \cdot k_2 \cdot N_{class} \cdot n \tag{16}$$

N_{class} = *Reference number of impacts per propeller rotation speed for each ice class, according to Table 13.*

Table 13 Reference number of impacts

Ice Class	*PC1*	*PC2*	*PC3*	*PC4*	*PC5*	*PC6*	*PC7*
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* $0 \le f \le 1$

= $0{,}6 - 0{,}2 \cdot f$ *when* $1 < f \le 2{,}5$

= $0{,}1$ *when* $f > 2{,}5$

where the immersion function f is:

$$f = \frac{h_0 - H_{ice}}{D/2} - 1 \tag{17}$$

h_0 = *Depth of the propeller centreline at the minimum ballast waterline in ice (LIWL) of the ship [m]*

6.7.2.2.2 Distribution of ice loads

The ice load spectrum is assumed to be of the Weibull type distribution and has the general form:

$$P\left[\frac{F_{ice}}{(F_{ice})_{maks}} \ge \frac{F}{(F_{ice})_{maks}}\right] = e^{\left[-\left(\frac{F}{(F_{ice})_{maks}}\right)^k \cdot \ln(N_0)\right]} \tag{18}$$

k = *Shape parameter of the spectrum*

N_0 = *Number of load cycles in the spectrum*

F_{ice} = *Random variable for ice loads on the blade,*

$0 \leq F_{ice} \leq (F_{ice})_{max}$

The Weibull distributions with shape parameters k = 0.75 and k = 1 are shown in Fig. 12.

It is suggested that the distribution with a shape parameter k = 0.75 is used for open propellers and k = 1 for ducted propellers.

6.7.2.2.3 Equivalent fatigue stress σ_{fat}

The equivalent fatigue stress for 100 million stress cycles which produces the same fatigue damage as the load distribution is:

$$\sigma_{fat} = \rho \cdot (\sigma_{ice})_{max} \quad (19)$$

$$(\sigma_{ice})_{max} = 0,5 \cdot [(\sigma_{ice})_{fmax} - (\sigma_{ice})_{bmax}] \quad (20)$$

$(\sigma_{ice})_{max}$ = *Mean value of the principal stress amplitudes resulting from design forward and backward blade forces at the location being studied.* [N/mm^2]

$(\sigma_{ice})_{fmax}$ = *Principal stress resulting from forward load F_f (6.7.2.1.2.2 and 6.7.2.1.3.2)* [N/mm^2]

$(\sigma_{ice})_{bmax}$ = *Principal stress resulting from backward load F_b (6.7.2.1.2.1 and 6.7.2.1.3.1)* [N/mm^2]

6.7.2.2.4 Calculation of ρ-parameter for reduction of ice load spectrum

For calculation of equivalent fatigue stress two types of S-N curves are available.

a) *Two slope S-N curve (slopes 4.5 and 10), see Figure 12.*

b) *One slope S-N curve(the slope can be chosen), see Figure 14.*

The type of the S-N-curve shall be selected to correspond to the material properties of the blade. If the SN- curve is not known the two slope S-N curve shall be used, see Figure 13.

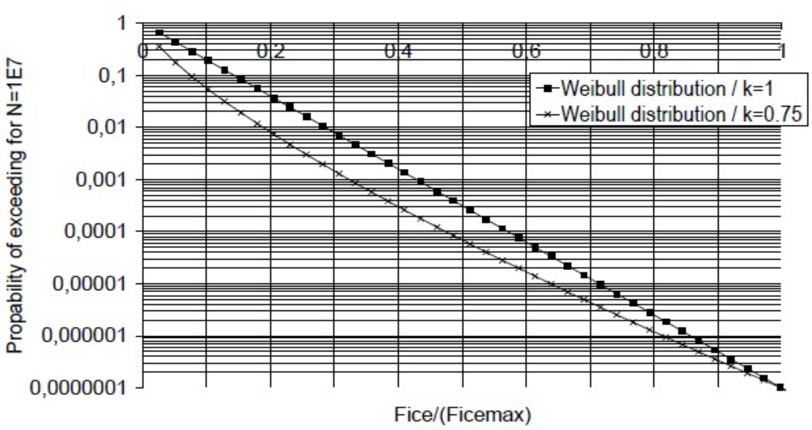

Figure 12 – The rainflow distribution of blade bending moment for Gudingen and Weibull distributions with shape parameters 0.75 and 1

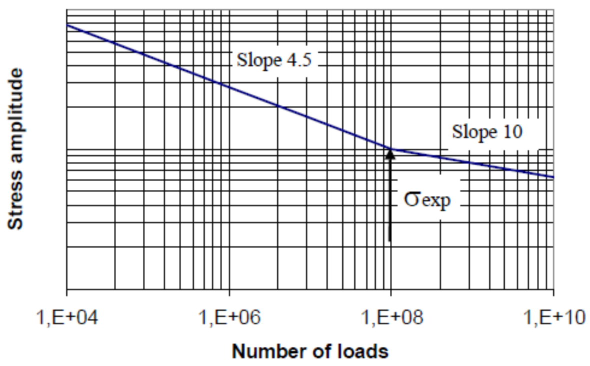

Figure 13 – Two Slope S-N Curve

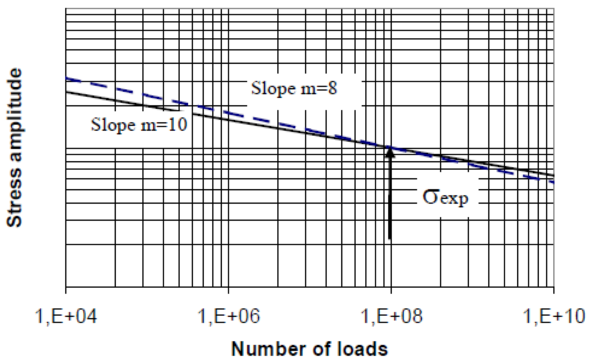

Figure 14 – Constant Slope S-N Curve

a) Calculation of ρ parameter for two slope S-N curve

The parameter ρ relates the maximum ice load to the distribution of ice loads according to the regression formulae:

$\rho = C_1 \cdot (\sigma_{ice})_{max}{}^{c_2} \cdot \sigma_n{}^{c_3} \cdot \log (N_{ice})^{c_4}$
(21)

$\sigma_{fl} = \gamma_\varepsilon \cdot \gamma_v \cdot \gamma_m \cdot \sigma_{exp}$
(22)

γ_ε = *Reduction factor for scatter and 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 should be used for the reduction factors if actual values are not available: γ_ε = 0,67, γ_v = 0,75, and γ_m = 0,75. [N/mm^2],*

The coefficients C_1, C_2, C_3 and C_4 are given in Table 14.

Table 14 Definition of Calculation coefficients

Coefficients	*Open propeller*	*Ducted propeller*
C_1	0,000711	0,000509
C_2	0,0645	0,0533
C_3	-0,0565	-0,0459
C_4	2,22	2,584

Table 15 Characteristic fatigue strengths for cast propeller materials at zero and 60 MPa mean stress

Material	***Experimental fatigue strength [MPa] at 1x10^8 cycles in sea water***	***σ_{fl} [MPa] at zero mean stress***	***σ_{fl} [MPa] at 60 Mpa mean stress***
Ni Al Bronze	*110*	*55*	*41*
Ni Mn Bronze	*80*	*40*	*30*
High tensile brass	*72*	*36*	*27*
Ferritic stainless steel	*50*	*25*	*19*

b) Calculation of ρ parameter for constant-slope S-N curve

For materials with a constant-slope S-N curve, see Fig 14, the ρ factor shall be calculated with the following formula:

$$\rho = \left(G \frac{N_{ice}}{N_R} \right)^{1/m} \cdot \left[\ln\left(N_{ice}\right) \right]^{-1/k} \qquad (23)$$

where k is the shape parameter of the Weibull distribution k = 1.0 for ducted propellers and k= 0.75 for open propellers and m is the slope of the S-N curve.

N_R = Reference number of load cycles (10^8)
m = Slope parameter

Values for the G parameter are given in Table 16.

Table 16 Value for the G parameter for different m/k ratios

m/k	***G***	***m/k***	***G***	***m/k***	***G***
3	*6*	***5,5***	*287,9*	***8***	*40320*
3.5	*11,6*	***6***	*720*	***8.5***	*119292*
4	*24*	***6,5***	*1871*	***9***	*362880*
4.5	*52,3*	***7***	*5040*	***9.5***	*1,133E6*
5	*120*	***7,5***	*14034*	***10***	*3,623E6*

6.7.2.3 Acceptability of blades

6.7.2.3.1 Maximum Blade Stresses σ_{calc}

Blade stresses are to be calculated using the backward and forward loads given in 6.7.2.1.2 and 6.7.2.1.3. The stresses shall be calculated with recognised and well documented FE-analysis or other acceptable alternative method. The stresses on the blade shall not exceed the allowable stresses for the blade material given below.

Calculated blade stress for maximum ice load shall comply with the following:

$\sigma_{calc} < \sigma_{ref} / S$ *[MPa]* (24)

S = Safety factor
= 1.5

σ_{ref} *= Reference stress, defined as:*

$\sigma_{ref} = 0.7 \cdot \sigma_u$ *[MPa]* (25)

or

$\sigma_{ref} = 0.6 \cdot \sigma_{0.2} + 0.4 \cdot \sigma_u$ *[MPa]* (26)

whichever is less.

Where σ_u and $\sigma_{0.2}$ are representative values for the blade material.

6.7.2.3.2 Blade Tip and Edge Thickness $t_{1.0\,PC}$, t_{EPC}

The blade edges and tip have to be designed such that during normal operation, ice contact and ice milling, no essential damage can be expected.

The blade tip thickness has to be greater than $t_{1,0\,PC}$ given by the following formula:

$$t_{1,0\,PC} = \left(t_{1,0\,B} + 2 \cdot D\right)\sqrt{\frac{500}{\sigma_{ref}}} \quad [mm] \qquad (27)$$

The tip thickness $t_{1.0\,PC}$ has to be measured at a distance x_{th} perpendicular to the contour edge, above 0.975 R. It needs to be demonstrated that the thickness is smoothly interpolated between lower bound leading edge thickness at 0.975 R, tip and lower bound trailing edge at 0.975 R. The basic tip thickness $t_{1.0B}$ has to be chosen according to Table 17.

Table 17 Basic tip thickness for propeller blades

Ice Class	PC1	PC2	PC3	PC4	PC5	PC6	PC7
$t_{1.0\,B}$ [mm]	30	28	26	24	22	19	16

$x_{th} = Min\,(0.025\, c_{0.975\,R}\,;\, 45)$ *[mm]* (28)

x_{th} *= Distance from the blade edge [mm]*

The blade edge thickness t_{EPC} measured at a distance of x_{th} along the cylindrical section at any radius up to 0.975 R has to be not less than 50 % of the tip thickness. This requirement is not applicable to the trailing edge of non reversible propellers.

6.7.2.3.3 Acceptability criterion for fatigue

The equivalent fatigue stress at all locations on the blade has to fulfil the following acceptability criterion:

$$\frac{\sigma_{fl}}{\sigma_{fat}} \geq 1{,}5 \qquad (29)$$

$$\sigma_{fl} = \gamma_\varepsilon \cdot \gamma_v \cdot \gamma_m \cdot \sigma_{exp} \qquad (30)$$

γ_ε = *The reduction factor for scatter and 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 sea water. The following values should be used for the reduction factors if actual values are not available: γ_ε = 0.67, γ_v = 0.75 and γ_m = 0.75 [N/mm^2]*

6.7.2.4 Propeller blade mounting

6.7.2.4.1 Loads

Blade flanges and bolts are to be designed to withstand the blade failure force F_{ex} given in 6.7.2.1.4.

Separate means, e.g. dowel pins, have to be provided in order to withstand the maximum spindle torque Q_{smax} (see 6.7.3.1).

6.7.2.4.2 Acceptability of bolts and pins

Blade bolts shall have following minimum section modulus (based on minimum diameter of shank or thread core) around bolt pitch circle, or an other relevant axis for non circular joints, parallel to considered root section:

$$W_{bolt} = \frac{S \cdot F_{ex} \cdot (0{,}8D - 2r_{bolt})}{2 \cdot \sigma_{0,2}} \cdot 10^6 \quad [mm^3] \qquad (31)$$

r_{bolt} = Radius to the bolt plan [m]

S = Safety factor

= 1.5

$\sigma_{0,2}$ = Minimum specified yield strength of bolt material [N/mm^2]

Blade bolt pre-tension shall be sufficient to avoid separation between mating surfaces with maximum forward and backward ice loads as defined in 6.7.2.1.2 and 6.7.2.1.3 (open and ducted propeller respectively). Usually 60 %-70 % of bolt yield strength is sufficient.

A safety factor of S = 1.5 is required to withstand the spindle torque load Q_{smax} (1). The diameter of dowel pins may be calculated by using the following formula:

$$d = 10^3 \sqrt{\frac{S \cdot Q_{smax} \cdot 8 \cdot \sqrt{3}}{PCD \cdot i \cdot \pi \cdot \sigma_{0,2}}} \quad [mm] \qquad (32)$$

i = Number of pins

Q_{smax} = According to formula (35)

PCD = Pitch circle diameter [mm]

S = Safety factor

= 1.5

$\sigma_{0,2}$ = Minimum specified yield strength of bolt material [N/mm^2]

6.7.3 Pitching mechanism

6.7.3.1 Loads due to Maximum Blade Spindle Torque for open and ducted propellers Q_{smax}

Spindle torque Q_{smax} around the spindle axis of the blade fitting shall be calculated both for the load cases described in 6.7.2.1.3 and 6.7.2.1.4 for F_b and F_f. If these spindle torque values are less than the default value given below, the default minimum value shall be used.

Default Value:

$$Q_{spindle} = 0.25 \cdot F \cdot c_{0.7} \quad [kNm] \qquad (33)$$

where

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

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

$$Q_{sex} = F_{ex} \cdot \frac{2}{3} \cdot L_{ex} \quad [kNm] \qquad (34)$$

Additionally the spindle torque caused by the blade breaking force F_{ex} (6.7.2.1.4) has to be calculated:

L_{ex} = Maximum of distance from spindle axis to the leading or trailing edge at radius 0.8 R [m]

The maximum spindle torque can be determined by:

$$Q_{smax} = MAX\,(Q_{spindle}; Q_{sex}; Q_{sf}; Q_{sb}) - Q_{fr1} - Q_{fr2} \quad [kNm] \qquad (35)$$

Q_{sf} and Q_{sb} are the spindle torques due to the blade forward and backward acting ice load, F_f and F_b respectively, as given in the load cases 6.7.2.1.2 and 6.7.2.1.3.

Q_{fr1} = friction torque in blade bearings caused by reaction forces due to F_{ex} [kNm]

Q_{fr2} = friction between connected surfaces resulting from blade bolt pretension forces [kNm]

In calculating Q_{fr} a friction coefficient = 0.15 may normally be applied.

6.7.3.2 Dynamic loads for fatigue analysis Q_{samax}

Fatigue strength is to be considered for parts transmit- ting the spindle torque from blades to a servo system considering ice spindle torque acting on one blade. The maximum amplitude is defined as:

$$Q_{samax} = \frac{Q_{sb} + Q_{sf}}{2} \quad [kNm] \tag{36}$$

Q_{sf} and Q_{sb} see 6.7.3.1.

6.7.3.3 Acceptability of pitching mechanism

Static calculations have to demonstrate that the components of CP mechanisms are to be designed to withstand the blade failure spindle torque Q_{sex} and maximum spindle torque Q_{smax}.

The maximum spindle torque Q_{smax} shall not lead to any consequential damages.

Provided that calculated stresses duly considering local stress concentrations are less than yield strength, or maximum 70 % of σ_u of respective materials, detailed fatigue analysis is not required. In opposite case components shall be analysed for cumulative fatigue, based on a maximum loading by Q_{samax} (see 6.7.3.2). Similar approach as used for shafting (see 6.8.2.2) may be applied.

6.7.3.4 Servo pressure

Minimum design pressure for servo system shall be taken as a pressure caused by Q_{samax} reduced by relevant friction losses in bearings caused by the respective ice loads.

6.7.4 Mounting of Propeller

6.7.4.1 Keyless cone mounting

The friction capacity shall be at least 2,0 times the highest peak torque Q_{peak} as determined in without exceeding 75 % (bronze) and 80 % (steel) respectively of yield strength of the hub in terms of von Mises stress.

The necessary surface pressure at 0 °C can be determined as:

$$p = \frac{\sqrt{\Theta^2 \cdot T^2 + f \cdot \left(Q^2 + T_r^2\right)} - \Theta \cdot T}{A \cdot f} \quad [MPa] \tag{37}$$

$$f = \left(\frac{\mu_o}{S}\right)^2 - \Theta^2 \tag{38}$$

Θ = Half conicity of the shaft [-]

T_r = Propeller response thrust [kN]

$Q = Q_{peak}$ according to 6.8.1.1.2 [kNm]

A = Effective contact area of the shrink fit [mm^2]

μ_0 = 0.15 for steel-steel,

= 0.13 for steel-bronze

S = 2.0

The backward response thrust T_r for pushing propellers and the forward response thrust for pulling propellers respectively has to be inserted and a negative sign shall be used.

6.7.4.2 Key mounting

Key mounting is not permitted.

6.7.4.3 Flange mounting

a) The flange thickness is to be at least 25 % of the shaft diameter.

b) Any additional stress raisers such as recesses for bolt heads shall not interfere with the flange fillet.

c) The flange fillet radius is to be at least 10 % of the shaft diameter.

d) The diameter of ream fitted (light press fit) bolts shall be chosen so that the peak torque Q_{peak} does not cause shear stresses beyond 30 % of the yield strength of the bolts.

e) The bolts are to be designed so that the blade failure load F_{ex} in any direction (forward or backwards) does not cause yielding or flange opening.

6.8 Shafting

6.8.1 Design Loads

6.8.1.1 Torque

6.8.1.1.1 Torque due to a single blade impact Q(φ)

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

$$Q(\varphi) = C_q * Q_{max} * \sin(\varphi\,(180 / \alpha_i)) \quad [kNm] \quad \text{when } \varphi = 0...\alpha_i \qquad (39)$$

Q_{max} see 6.7.2.1.5.

$$Q(\varphi) = 0 \qquad \text{when } \varphi = \alpha_i ....360 \qquad (40)$$

where C_q and α_i parameters are given in Table 18 below.

Table 18 – Parameters for torque excitation

Torque excitation	*Propeller-ice interaction*	C_q	α_i
Case 1	*Single ice block*	*0.5*	*45*
Case 2	*Single ice block*	*0.75*	*90*
Case 3	*Single ice block*	*1.0*	*135*
Case 4	*Two ice blocks with 45 degree phase in rotation angle*	*0.5*	*45*

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

$$n_Q = 2 \cdot H_{ice} \tag{41}$$

The number of impacts is $z \cdot n_Q$.

See Figure 1 in Appendix 2.

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

The response torque at any shaft component shall be analysed considering excitation torque at the propeller, the actual engine torque Q_e and mass elastic system.

Q_e = *Actual maximum engine torque at considered speed*

6.8.1.1.2 Response torque in the propulsion system Qr (t) and its maximum Qpeak

6.8.1.1.2.1\ *The maximum torque Q_{peak} may be calculated using one of the following three different approaches (a – c). With increasing simplification of method, the result Q_{peak} becomes higher.*

a) Transient torsional vibration analysis

The response torque at any component in the propulsion system shall be analysed considering the above excitation torque at the propeller, the actual engine torque Q_e, and the mass elastic system. See Figure 15.

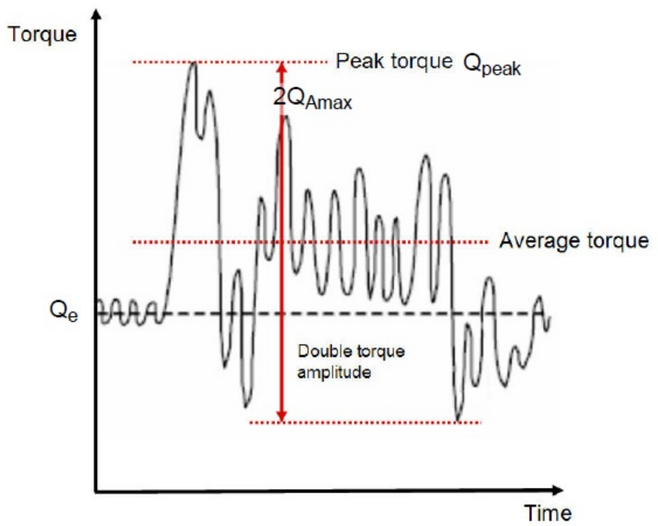

Figure 15 – Definition of torque

The response torque $Q_r(t)$ in all components shall be determined by means of transient torsional vibration analysis of the propulsion line. Calculations have to be carried out for all excitation cases given above (6.8.1.1.1) and the response has to be applied on top of the mean hydrodynamic torque in bollard condition at considered propeller rotational speed.

$$Q_r(t) = Q(\varphi) + Q_e \quad [kNm] \tag{42}$$

b) Steady state torsional vibration calculation

The response torque Q_r at any component of the propulsion system can be calculated by a steady state torsional vibration calculation (TVC) considering the ice excitation in 6.8.1.1.1 by using excitation factors f_I and f_{II} for the 1st and 2nd propeller order as well as with a factor f_{static} for a static part on the basis of Table 19.

Table 19 – Parameters for torsional vibration calculation

No.of blades	**Excitation case (acc. to Fig.1 of Appendix 2)**	f_I	f_{II}	f_{static}
3	1	0,40	0	0,36
	2	0,32	0,05	0,72
	3	0	0,27	0,24
4	1	0,32	0,06	0,48
	2	0	0,05	0,95
	3	0	0,21	0,32
5	1	0,16	0	0,60
	2	0,17	0	1,20
	3	0	0,10	0,40
6	1	0	0,04	0,72
	2	0,10	0	1,43
	3	0	0	0,48
7	1	0,10	0	0,84
	2	0,15	0,02	1,67
	3	0	0,07	0,56
All values as fraction of Q_{max} (for use in TVC f_I and f_{II} are to be multiplied by the ratio of Q_{max} / Q_{nom})				

Q_{max} = Propeller ice torque according to 6.7.2.1.5 [kNm]

Q_{nom} = Nominal engine torque at maximum continuous rating (MCR) [kNm]

The response torque Q_r for every single speed within the operating range for each ice excitation case (Fig.1 of Appendix 2) shall be calculated according to:

$$Q_r = Q_e + Q_{static} + Q_{dyn} \quad [kNm] \tag{43}$$

Q_e = Actual mean torque at considered speed [kNm]

$Q_{static} = f_{static} \cdot Q_{max}$ [kNm]

= static part of ice excitation torque according to Table 19

Q_{dyn} = result of TVC for alternating torque by using propeller excitation factors f_I and f_{II} acc. to Table 19 [kNm]

The highest peak torque Q_{peak} is equal to the highest response torque Q_r calculated over all excitation cases (see 6.8.1.1.1) within the operating range.

c) Simple formula

If it can be demonstrated that no resonance of first or second blade order against any elastic element such as main and generator couplings (PTO) occur over the whole operating speed range, the highest peak torque in the propeller shaft Q_{peak} can be calculated by using the following formula:

$$Q_{peak} = 1.4\,(Q_{max} + Q_{nom})\ \text{[kNm]} \qquad (44)$$

or alternatively, if Q_{max} cannot be determined due to lack of propeller geometry information:

$$Q_{peak} = 3 \cdot Q_{nom}\ \text{[kNm]} \qquad (45)$$

For gear equipped propulsion systems the maximum torque for components on input side of the gear Q_{peak} in shall be calculated with the following formula based on the maximum torque Q_{peak} according to equations (44) respectively (45):

$$Q_{peak\,in} = \frac{1{,}3 \cdot I_H}{I_H \cdot \frac{1}{u^2} + I_I} \cdot Q_{peak} \quad \text{[kNm]} \qquad (46)$$

I_H = Moment of inertia for masses with engine speed [kgm^2]

I_I = Moment of inertia for masses with propeller speed [kgm^2]

u = Reduction ratio (engine speed / propeller speed) [-]

For all components on output side of the gear Q_{peak} applies.

6.8.1.1.2.2 *The results of the three excitation cases are to be used in the following way for Q_{peak} and Q_{Amax}:*

- *The highest peak 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 is to be determined as half of the range from maximum to minimum torque and is referred to as Q_{Amax} (see Fig. 15).*

6.8.1.2 Thrust

6.8.1.2.1 Maximum Propeller Ice Thrust applied to the shaft

$$T_f = 1.1 \cdot F_f \quad \text{[kN]} \qquad (47)$$

$T_b = 1.1 \cdot F_b$ [kN] (48)

For F_f, F_b see 6.7.2.1.2 and 6.7.2.1.3.

6.8.1.2.2 Maximum Response Thrust T_r

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

Maximum Shaft Thrust Forwards: $T_r = T_n + 2.2 \times T_f$ [kN] (49)

Maximum Shaft Thrust Backwards: $T_r = 1.5 \times T_b$ [kN] (50)

T_n = *Propeller bollard thrust [kN]*
T_f = *Maximum forward propeller ice thrust [kN]*

T_b = *Maximum backward propeller ice thrust [kN]*

If hydrodynamic bollard thrust T_n is not known, T_n is to be taken as follows:

Table 20 – Propeller bollard thrust

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

T = *Nominal propeller thrust at MCR at free running open water conditions*

6.8.2 Dimensioning and acceptability

6.8.2.1 Propeller shaft

The propeller shaft is to be designed to fulfil the following:

The blade failure load F_{ex} (see 6.7.2.1.4) applied on the propeller blade at 0.8 R radius parallel to the shaft (forward or backwards) shall not cause yielding. The bending moment need not to be combined with any other load.

This requires a minimum diameter d_p in way of the aft stern tube bearing of:

$$d_p = 160 \cdot \sqrt[3]{\frac{F_{ex} \cdot D}{\sigma_y}} \quad [mm] \qquad (51)$$

σ_y = *Minimum specified yield or 0.2 % proof strength of the propeller shaft material [MPa]*

In front of the aft stern tube bearing the diameter may be reduced based on the assumption that the bending moment is linearly reduced to 20 % 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 (6.7.2.1.2 and 6.7.2.1.3) has been disregarded, because the resulting stress levels are much below the stresses due to the blade failure load F_{ex}.

6.8.2.2 Propeller and intermediate shafts

6.8.2.2.1 *The stresses due to the peak torque Q_{peak} (6.8.1.1.2) shall have a minimum safety factor of 1.25 against yielding in plain sections and 1.0 in way of stress concentrations in order to avoid bent shafts.*

The minimum diameter is:

Plain shaft:

$$d_p = 225 \cdot \sqrt[3]{\frac{Q_{peak}}{\sigma_y}} \quad [mm] \tag{52}$$

Notched shaft:

$$d_p = 210 \cdot \sqrt[3]{\frac{Q_{peak} \cdot \alpha_t}{\sigma_y}} \quad [mm] \tag{53}$$

where α_t is the local stress concentration factor in torsion.

6.8.2.2.2 *The torque amplitudes, based on Q_{peak}, with the foreseen number of cycles, as defined in 6.9.1.2.3, shall be used in an accumulated fatigue evaluation where the safety factor is 1.5 compared with the 50 % survival probability curve. If the plant also has high engine excited torsional vibrations (e.g. direct coupled 2-stroke engines), this has also to be considered.*

6.8.2.2.3 *For plants with reversing direction of rotation the stress range $\Delta\tau \cdot \alpha_t$ resulting from forward $Q_{peakforward}$ to astern $Q_{peakastern}$ shall not exceed twice the yield strength (in order to avoid stress-strain hysteresis loop) with a safety factor of 1.25, i.e.:*

$$\Delta\tau \cdot \alpha_t \le \frac{2 \cdot \sigma_y}{\sqrt{3} \cdot 1{,}25} \quad [MPa] \tag{54}$$

where α_t is the local stress concentration factor in torsion.

6.8.2.3 Shaft connections

6.8.2.3.1 Shrink fit couplings (keyless)

The friction capacity shall be at least 1.8 times the highest peak torque Q_{peak} as determined in 6.8.1.1.2 without exceeding 80 % of yield strength (steel).

The necessary surface pressure can be determined according to equation (37).

6.8.2.3.2 Key mounting

Key mounting is not permitted.

6.8.2.3.3 Flange mounting

The following requirements have to be considered:

a) Any additional stress raisers such as recesses for bolt heads shall not interfere with the flange fillet

b) The diameter of ream fitted (light press fit) bolts or pins shall be chosen so that the peak torque Q_{peak} (see 6.8.1.1.2) does not cause shear stresses be- yond 30 % of the yield strength of the bolts or pins.

c) The bolts are to be designed so that the blade failure load F_{ex} (see 6.7.2.1.4) in backward direction does not cause yielding or flange mating surface separation. Depending on flange position, a reduction of bending load according to 6.8.2.1 is permitted.

6.8.2.4 Bearings

6.8.2.4.1 General

All shaft bearings are to be designed to withstand the propeller blade ice interaction loads according to 6.7.2. For the purpose of calculation, the shafts are assumed to rotate at rated speed. Reaction forces due to the response torque Q_r (φ) (e.g. in gear transmissions) are to be considered. Additionally the aft stern tube bearing as well as the next shaft line bearings are to withstand a bending moment caused by F_{ex} as given in 6.7.2.1.4, in such a way that the ship can maintain operational capability. The pressures in these bearings are to be assessed based on the bending moment distribution given in 6.8.2.1. For low operational propeller speeds (e.g. for drives with electric motors or for drives with several motors/ propellers and some of the propellers part-time in "wind milling") suitable measures for maintaining bearing lubrication (e.g. additional hydrostatic lubrication) are to be provided.

6.8.2.4.2 Thrust bearings

Thrust bearings and their housings are to be designed to withstand maximum response thrust T_r according to 6.8.1.2.2 and the force resulting from the blade failure load F_{ex} in 6.7.2.1.4. For the purpose of calculation, except for F_{ex}, the shafts are assumed to rotate at rated speed.

6.8.2.4.3 Roller bearings

Roller bearings are to have a L_{10h} lifetime of at least 40000 hours. The calculation of lifetime is to be based on reaction forces from the torque spectrum and principles given in 6.9.1.2.3.

6.8.2.5 Seals

Seals are to be provided to prevent egress of pollutants and shall be suitable for the operating temperatures. Contingency plans for preventing the egress of pollutants under failure conditions are to be documented.

Seals are to be of proven design.

6.9 Gears, Flexible Couplings, Clutches

6.9.1 Gear transmissions

6.9.1.1 Calculation of maximum torque $Q_{peak\ g}$

For gear equipped propulsion systems it has to be demonstrated that the gear transmission withstands loads based on the maximum torque $Q_{peak\ g}$. The maximum torque can be calculated with the following formula:

$$Q_{peak\ g} = \frac{1{,}3 \cdot I_H \cdot u^2}{I_H \cdot u^2 + I_L} \cdot Q_{peak} \qquad [kNm] \qquad (55)$$

$Q_{peak\ g}$ = Maximum torque in gear mesh side [kNm]

I_H = Moment of inertia for masses with higher speed [kgm^2]

I_L = Moment of inertia for masses with lower speed [kgm^2]

u = Reduction ratio (input speed / output speed)

Q_{peak} = see 6.8.1.1.2

6.9.1.2 Calculation of the load-bearing capacity of cylindrical and bevel gearing

6.9.1.2.1 General

The sufficient load capacity of the gear-tooth system is to be demonstrated by load capacity calculations while maintaining the required safety margins for the criteria stated below. Cylindrical gears can be assessed on the basis of the international standard ISO 6336 Pt. 1–6, provided that "methods B" are used. Other calculation methods may be accepted provided that they are reasonably equivalent.

It is recommended to assess bevel gears by equivalent methods. The use of ISO 10300 is only accepted within the given limitations of the ratio face width/module.

6.9.1.2.2 Load distribution factors

Common for all criteria is the influence of load distribution over the face width. All relevant parameters are to be considered, such as elastic deflections (of mesh, shafts and gear bodies), accuracy tolerances, helix modifications and working positions in bearings (especially for twin input single output gears).

6.9.1.2.3 Contact stress

The safety against pitting shall be assessed against the given load spectrum as well as the ordinary loads (open water running) by means of accumulated fatigue analyses (stated in ISO 6336 Pt 6) with a minimum resulting safety factor S_H of 1.2 (ref. ISO 6336 Pt 1, 2 and 6).

The ice load spectrum for the output gear is defined as:

100 % of $Q_{peak\,g}$ with n_Q cycles

80 % of $Q_{peak\,g}$ with $(z\,N_{ice})^{0.2}\,n_Q$ cycles

60 % of $Q_{peak\,g}$ with $(z\,N_{ice})^{0.4}\,n_Q$ cycles

40 % of $Q_{peak\,g}$ with $(z\,N_{ice})^{0.6}\,n_Q$ cycles

20 % of $Q_{peak\,g}$ with $(z\,N_{ice})^{0.8}\,n_Q$ cycles ($n_Q = 2\,H_{ice}$)

n_Q = see formula (41)

For pinions and wheels with higher speed the numbers of load cycles n_Q are found by multiplication with the gear ratios.

6.9.1.2.4 Tooth root stress

Tooth root safety shall be assessed in the same way as for contact stress but with a minimum safety factor S_F of 1.5 (ref. ISO 6336 Pt 1, 3 and 6).

6.9.1.2.5 Scuffing

The scuffing safety (flash temperature method according to DIN 3990, Part 4) based on the peak torque $Q_{peak\,g}$ shall be at least 1.2 when the FZG class of the oil is assumed one stage below specification.

6.9.1.2.6 Flank subsurface fatigue

Sub-surface fatigue is mainly influenced by material microstructure, surface hardness and hardness depth. Up to now there is no standardized calculation procedure available. Therefore a careful review of each parameter concerning subsurface fatigue is necessary. For case carburized gears the case depth should be within the recommended range stated in ISO 6336-5 clause 5.6.2/c. It should be noted that high overloads can initiate subsurface fatigue cracks that may lead to a premature failure. In lieu of reliable analyses UT inspection intervals may be used.

6.9.1.3 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).

6.9.1.4 Bearings

See 6.8.2.4.

6.9.2 Flexible couplings

Couplings shall be designed such that frequent occurrence of peak torques Q_{peak} (6.8.1.1.2) will not lead to fatigue cracking, i.e. exceeding the permissible vibratory torques T_{Kmax1} or ΔT_{max} of the coupling. The permissible torque may be determined by interpolation in a log-log torque-cycle diagram where T_{Kmax1} respectively ΔT_{Kmax} refers to 50000 cycles, see illustration in Figure 16 and 17.

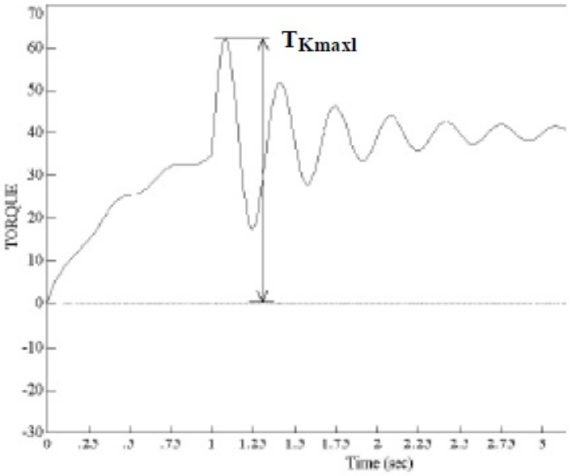

Figure 16 – Definition of torque amplitude T_{Kmax1}

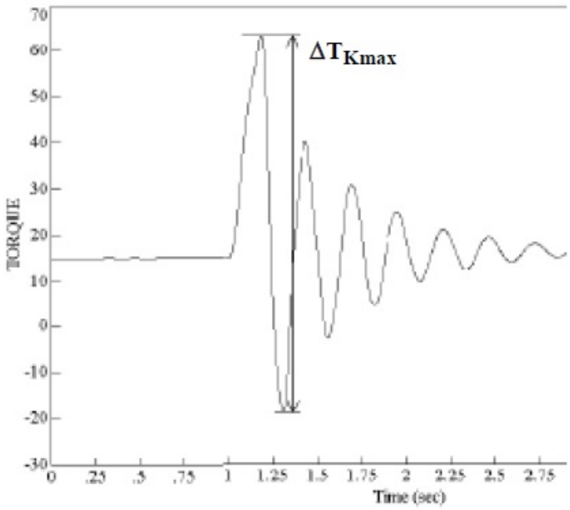

Figure 17 - Definition of torque amplitude ΔT_{Kmax}

There shall be a separation margin of at least 20 % between the peak torque Q_{peak} and the torque where any twist limitation is reached.

6.9.3 Clutches

Clutches shall have a static friction torque of at least 1.3 times the peak torque Q_{peak} and a dynamic friction torque of 2/3 of the static one.

Emergency operation of the clutch after failure, e.g. loss of operating pressure, shall be established within a reasonably short time. If this is arranged by bolts, they shall be situated on the engine side of the clutch in order to ensure access to all bolts by turning the engine.

6.10 Azimuth Propulsors

6.10.1 General

In addition to the above requirements special consideration shall be given to the loading cases which are extraordinary for propulsion units when compared with conventional propellers. Estimation of the loading cases must reflect the operational realities of the ship and the thrusters. In this respect, for example, the loads caused by impacts *of ice blocks on the propeller hub of a pulling propeller must be considered. Also loads due to thrusters operating in an oblique angle to the flow must be considered.*

6.10.2 Design Ice Loads

Azimuth propulsors shall be designed for the following loads. As far as appropriate, the loads have to be applied simultaneously.

6.10.2.1 *Ice pressure on strut based on defined location area of the strut / ice interaction as per 3.17.2.*

6.10.2.2 *Ice pressure on pod based on defined location area of thruster body / ice interaction as per 3.17.2.*

6.10.2.3 *Plastic bending of one propeller blade F_{ex} (see 6.7.2.1.4) in the worst position (typically top-down) or maximum response thrust T_r (see 6.8.1.2.2).*

6.10.2.4 *Steering gear design torque Q_{SG} shall be at least 60 % of steering torque expected at propeller ice milling condition defined as Q_{max} (see 6.7.2.1.5):*

$$Q_{SG} = 0{,}6 \frac{Q_{max}}{0{,}8 \cdot R} \cdot \ell \quad [kNm] \qquad (56)$$

ℓ = distance from the propeller plane to steering (azimuth) axis [m]

6.10.2.5 *Steering gear shall be protected by effective means limiting excessive torque caused by:*

a) Ice milling torque exceeding design torque and leading to rotation of unit.

b) Torque caused by plastic bending of one propeller blade in the worse position (related to steering gear) and leading to rotation of the unit.

Steering gear shall be ready for operation after above loads a) or b) have disappeared.

6.10.3 Acceptability of azimuth thrusters

It has to be demonstrated that the individual components can withstand the loads given in 6.10.2 and in its respective section with a safety factor as required for the individual component.

The housing has to have a safety of 1.0 with respect to yield.

For bolted connections the same safety factor as for the housing itself has to be demonstrated. However, opening of the mating surfaces is not permitted.

Slewing bearings of roller type are to have a L_{10h} lifetime of at least 40000 hours. The calculation of lifetime is to be based on reaction forces from the thrust spectrum given in 6.10.2.

A safety of S = 2.5 against static loads given in 6.10.2 has to be demonstrated.

6.11 Prime Movers

6.11.1 Propulsion Engines

6.11.1.1 General

Engines are to be capable of being started and running the propeller in bollard condition.

Propulsion plants with CP propeller are to be capable being operated even in case with the CP system in full pitch as limited by mechanical stoppers.

6.11.1.2 Crankshafts

Special considerations apply for plants with large inertia (e.g. flywheel, tuning wheel or PTO) in the front of the engine (opposite to main power take off).

6.11.2 Emergency Power Units

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

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 means of starting is provided. A second source of energy shall be provided for an additional three starts within 30 min., unless manual starting can be demonstrated to be effective.

6.12 Auxiliary Systems

6.12.1 General

In addition to the requirements for ice class ICE-B4 (see Chapter 4 – Machinery, Section 16) the following shall be observed.

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

6.12.1.2 *Suitable material for low temperatures shall be used for the pipes, valves and fittings which are exposed to sea water or cold air.*

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

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

6.12.1.5 *Systems subject to freezing shall be drainable.*

6.12.1.6 *Additional heating of lube oil may be needed for equipment located in machinery spaces.*

6.12.1.7 *Transverse thrusters (not used for propulsion) shall be designed to avoid self destruction in case propeller is blocked by ice.*

6.12.2 Sea Inlets and cooling water systems

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

6.12.2.2 *At least two sea chests are to be arranged as ice boxes for class PC1 to PC5 inclusive where. The calculated volume for each of the ice boxes shall be at least 1m^3 for every 750 kW of the total installed power. For PC6 and PC7 there shall be at least one ice box located preferably near centre line.*

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

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

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

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

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

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

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

6.12.3 Ballast and other tanks

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

6.12.3.2 *Fresh water, ballast, fuel & lube oil tanks shall be carefully located and fitted with heating facilities.*

6.12.3.3 *Heating facilities may be needed also for further tanks (e.g. tanks for sludge, leakage, bilge water, sewage, etc.), pending on location and media.*

6.12.4 Ventilation System

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

The air intakes are to be sufficient for safe operation of the ship in heavy weather respectively in ice storm conditions.

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

6.12.4.3 *The temperature of inlet air provided to machinery from the air intakes shall be suitable for the safe operation of the machinery. Direct ducting to the engines with own heating facilities shall be considered.*

6.12.5 Steering systems

6.12.5.1 *Rudder stops are to be provided and integrated into the hull. The design ice force on rudder shall be transmitted to the rudder stops without damage to the steering system.*

Ice horn shall in general be fitted to protect the rudder in centre position. Design shall be performed according to 3.17.

6.12.5.2 The effective holding torque of the rudder actuator, at safety valve set pressure, is obtained by multiplying the open water requirement at design speed (maximum18 knots) by the factors defined in Table 21, but not less than the working torque according to Chapter 4 – Machinery, Section 9, A.4.1.2.

Table 21 – Factor for holding torque of rudder actuator

Ice class	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Factor	5	5	3	3	3	2	1.5

The design pressure for calculating the scantlings of piping and other steering gear components subjected to internal hydraulic pressure shall be at least 1.25 times the set pressure of the safety valves, but not less than the design pressure according to Chapter 4 – Machinery, Section 9, A.4.1.2.

6.12.5.3 It is considered for a Polar Class ship to be able to move her rudder somewhat faster than a seagoing ship operating in open water. So the requirements according to Chapter 4 – Machinery, Section 9, A.3.2 shall be extended to a turning speed according to Table 22.

The minimum discharge capacity of the relief valve(s) as mentioned under 6.12.5.2 shall be determined by the turning speed of the rudder actuator according to Table 22.

Table 22 – Turning speeds for rudder actuator

Ice class	PC1-2	PC3-5	PC6-7
Turning speeds [deg/s]	8	6	4

6.12.5.4 The minimum discharge capacity of the additional relief valve(s) as mentioned under 6.12.5.3 shall be determined by the turning speed for the rudder actuator according to Table 23.

Table 23 - Turning speeds of the rudder actuator for rudders pushed rapidly hard over

Ice class	PC1-2	PC3-5	PC6-7
Turning speeds [deg/s]	40	20	10

The fast acting relieve system shall not allow to cause more than 50 % increase of torque above the set pressure of relief valves according to 6.12.5.2 due to a too slowly acting torque release system. In some cases, a fast acting relief valve with typically 10 milliseconds response time, or a bursting disc, will be needed.

Furthermore, if the specified angular velocity results in an increase in torque of greater than 50 % due to constriction of hydraulic flow, means shall be provided to allow for an improved flow. In some cases a dump tank for the hydraulic fluid may be required.

Following any event, the system capability shall be regained quickly.

6.13 Foundation of Equipment

6.13.1 General

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

6.13.2 Longitudinal Impact Accelerations, a_1

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

$$a_1 = \left(F_{IB}/\Delta\right)\left\{\left[1.1\tan\left(\gamma + \Phi\right)\right] + \left[7\frac{H}{L}\right]\right\} \; [m/s^2] \qquad (57)$$

F_{IB} = *Vertical impact force, defined in 3.15.2*

Δ = *Displacement of the ship [kt]*

γ = *Bow stem angle at waterline [deg.]*

Φ = *Maximum friction angle between steel and ice, normally taken as 10° [deg.]*

H = *Distance in meters from the waterline to the point being considered [m]*

L = *Length between perpendiculars [m]*

6.13.3 Vertical Impact Acceleration, a_v

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

$$a_v = 2.5\,(F_{IB}/\Delta)\,F_x \qquad [m/s^2] \qquad (58)$$

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

Intermediate values to be interpolated linearly.

6.13.4 Transverse Impact Acceleration, a_t

Combined transverse impact acceleration at any point along hull girder:

$$a_t = 3\,\frac{F_i\,F_x}{\Delta} \qquad [m/s^2] \qquad (59)$$

F_i = *Total force normal to shell plating in the bow area due to oblique ice impact, defined in 3.5.2.1.3*

F_x = *1.5 at FP*

= *0.25 at midships*

= *0.5 at AP*

= *1.5 at AP for vessels conducting ice breaking astern*

Intermediate values to be interpolated linearly.

6.14 Alternative Design

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

SECTION 7 – FIRE SAFETY/PROTECTION

7.1 Goal

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

7.2 Functional requirements

7.2.1 In order to achieve the goal set out in paragraph 7.1 above, the following functional requirements are embodied in the regulations of this section:

.1 all components of fire safety systems and appliances if installed in exposed positions shall be protected from ice accretion and snow accumulation;

.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;

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

.4 means shall be provided to remove or prevent ice and snow accretion from accesses; and

.5 extinguishing media shall be suitable for intended operation.

7.2.2 In addition, for ships intended to operate in low air temperature, the following apply:

.1 all components of fire safety systems and appliances shall be designed to ensure availability and effectiveness under the polar service temperature; and

.2 materials used in exposed fire safety systems shall be suitable for operation at the polar service temperature.

7.3 Regulations

7.3.1 In order to comply with the requirement of paragraph 7.2.1.1, the following apply:

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

.2 all two-way portable radio communication equipment shall be operable at the polar service temperature.

7.3.2 In order to comply with the requirement of paragraph 7.2.1.2, the following apply:

.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 is to 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 ship; and

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

7.3.3 In addition, for ships intended to operate in low air temperature, the following apply:

.1 In order to comply with the requirement of paragraph 7.2.2.1, portable and semi-portable extinguishers shall be located in positions protected from freezing temperatures, as far as practical. Locations subject to freezing are to be provided with extinguishers capable of operation under the polar service temperature.

.2 In order to comply with the functional requirements of paragraph 7.2.2.2 above, materials of exposed fire safety systems shall be approved by **TL**, taking into account UR S6 (*Chapter 1, Hull, Section 3)* or other standards offering an equivalent level of safety based on the polar service temperature.

SECTION 8 – LIFE-SAVING APPLIANCES AND ARRANGEMENTS

8.1 Goal

The goal of this section is to provide for safe escape, evacuation and survival.

8.2 Functional requirements

In order to achieve the goal set out in paragraph 8.1 above, the following functional requirements are embodied in the regulations of this section:

8.2.1 *Escape*

8.2.1.1 Exposed escape routes shall remain accessible and safe, taking into consideration the potential icing of structures and snow accumulation.

8.2.1.2 Survival craft and muster and embarkation arrangements shall provide safe abandonment of ship, taking into consideration the possible adverse environmental conditions during an emergency.

8.2.2 *Evacuation*

All life-saving appliances and associated equipment shall provide safe evacuation and be functional under the possible adverse environmental conditions during the maximum expected time of rescue.

8.2.3 *Survival*

8.2.3.1 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.

8.2.3.2 Life-saving appliances and associated equipment shall take account of the potential of operation in long periods of darkness, taking into consideration the intended voyage.

8.2.3.3 Taking into account the presence of any hazards, as identified in the assessment in Part A-1, section 1, 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. These resources shall provide:

.1 a habitable environment;

.2 protection of persons from the effects of cold, wind and sun;

.3 space to accommodate persons equipped with thermal protection adequate for the environment;

.4 means to provide sustenance;

.5 safe access and exit points; and

.6 means to communicate with rescue assets.

8.3 Regulations

8.3.1 Escape

In order to comply with the functional requirements of paragraphs 8.2.1.1 and 8.2.1.2 above, the following apply:

.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;

.2 in addition, for ships constructed on or after 1 January 2017, exposed escape routes shall be arranged so as not to hinder passage by persons wearing suitable polar clothing; and

.3 in addition, for ships intended to operate in low air temperatures, adequacy of embarkation arrangements shall be assessed, having full regard to any effect of persons wearing additional polar clothing.

8.3.2 Evacuation

In order to comply with the functional requirement of paragraph 8.2.2 above, the following apply:

.1 ships shall have means to ensure safe evacuation of persons, including safe deployment of survival equipment, when operating in ice-covered waters, or directly onto the ice, as applicable; and

.2 where the regulations of this section are achieved by means of adding devices requiring a source of power, this source shall be able to operate independently of the ship's main source of power.

8.3.3 Survival

8.3.3.1 In order to comply with the functional requirement of paragraph 8.2.3.1 above, the following apply:

.1 for passenger ships, a proper sized immersion suit or a thermal protective aid shall be provided for each person on board; and

.2 where immersion suits are required, they shall be of the insulated type.

8.3.3.2 In addition, for ships intended to operate in extended periods of darkness, in order to comply with the functional requirements of paragraph 8.2.3.2 above, searchlights suitable for continuous use to facilitate identification of ice shall be provided for each lifeboat.

8.3.3.3 In order to comply with the functional requirement of paragraph 8.2.3.3 above, the following apply:

.1 no lifeboat shall be of any type other than partially or totally enclosed type;

.2 taking into account the assessment referred to in section 1, appropriate survival resources, which address both individual (personal survival equipment) and shared (group survival equipment) needs, shall be provided, as follows:

.1 life-saving appliances and group survival equipment that provide effective protection against direct wind chill for all persons on board;

.2 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; and

.3 personal survival equipment that provide sufficient protection to prevent frostbite of all extremities; and

.3 in addition, whenever the assessment required under paragraph 1.5 identifies a potential of abandonment onto ice or land, the following apply:

.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;

.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 containers for group survival equipment shall be designed to be easily movable over the ice and be floatable;

.4 whenever the assessment identifies the need to carry personal and group survival equipment, means shall be identified of ensuring that this equipment is accessible following abandonment;

.5 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;

.6 passengers shall be instructed in the use of the personal survival equipment and the action to take in an emergency; and

.7 the crew shall be trained in the use of the personal survival equipment and group survival equipment.

8.3.3.4 In order to comply with the functional requirement of paragraph 8.2.3.3.4 above, adequate emergency rations shall be provided, for the maximum expected time of rescue.

SECTION 9 – SAFETY OF NAVIGATION

9.1 Goal

The goal of this section is to provide for safe navigation.

9.2 Functional requirements

In order to achieve the goal set out in paragraph 9.1 above, the following functional requirements are embodied in the regulations of this section.

9.2.1 Nautical information

Ships shall have the ability to receive up-to-date information including ice information for safe navigation.

9.2.2 Navigational equipment functionality

9.2.2.1 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.

9.2.2.2 Systems for providing reference headings and position fixing shall be suitable for the intended areas.

9.2.3 Additional navigational equipment

9.2.3.1 Ships shall have the ability to visually detect ice when operating in darkness.

9.2.3.2 Ships involved in operations with an icebreaker escort shall have suitable means to indicate when the ship is stopped.

9.3 Regulations

9.3.1 Nautical information

In order to comply with the functional requirement of paragraph 9.2.1 above, ships shall have means of receiving and displaying current information on ice conditions in the area of operation.

9.3.2 Navigational equipment functionality

9.3.2.1 In order to comply with the functional requirement of paragraph 9.2.2.1 above, the following apply:

.1 ships constructed on or after 1 January 2017, ice strengthened in accordance with section 3, shall have either two independent echo-sounding devices or one echo-sounding device with two separate independent transducers;

.2 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;

.3 for ships operating in areas, and during periods, where ice accretion is likely to occur, means to prevent the accumulation of ice on antennas required for navigation and communication shall be provided; and

.4 in addition, for ships ice strengthened in accordance with section 3, the following apply:

.1 where equipment required by SOLAS chapter V or this section have sensors that project below the hull, such sensors shall be protected against ice; and

.2 in category A and B ships constructed on or after 1 January 2017, the bridge wings shall be enclosed or designed to protect navigational equipment and operating personnel.

9.3.2.2 In order to comply with the functional requirement of paragraph 9.2.2.2 above, the following apply:

.1 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; and

.2 ships proceeding to latitudes over 80 degrees 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.

9.3.3 Additional navigational equipment

9.3.3.1 In order to comply with the functional requirement of paragraph 9.2.3.1 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.

9.3.3.2 In order to comply with the functional requirement of paragraph 9.2.3.2, ships involved in operations with an icebreaker escort shall be equipped with a manually initiated flashing red light visible from astern to indicate when the ship is stopped. This light shall have a range of visibility of at least two nautical miles, and the horizontal and vertical arcs of visibility shall conform to the stern light specifications required by the International Regulations for Preventing Collisions at Sea.

SECTION 10 – COMMUNICATION

10.1 Goal

The goal of this section is to provide for effective communication for ships and survival craft during normal operation and in emergency situations.

10.2 Functional requirements

In order to achieve the goal set out in paragraph 10.1 above, the following functional requirements are embodied in the regulations of this section.

10.2.1 Ship communication

10.2.1.1 Two-way voice and/or data communications ship-to-ship and ship-to-shore shall be available at all points along the intended operating routes.

10.2.1.2 Suitable means of communications shall be provided where escort and convoy operations are expected.

10.2.1.3 Means for two-way on-scene and SAR coordination communications for search and rescue purposes including aeronautical frequencies shall be provided.

10.2.1.4 Appropriate communication equipment to enable telemedical assistance in polar areas shall be provided.

10.2.2 Survival craft and rescue boat communications capabilities

10.2.2.1 For ships intended to operate in low air temperature, all rescue boats and lifeboats, whenever released for evacuation, shall maintain capability for distress alerting, locating and on-scene communications.

10.2.2.2 For ships intended to operate in low air temperature, all other survival craft, whenever released, shall maintain capability for transmitting signals for location and for communication.

10.2.2.3 Mandatory communication equipment for use in survival craft, including liferafts, and rescue boats shall be capable of operation during the maximum expected time of rescue.

10.3 Regulations

10.3.1 Ship communication

10.3.1.1 In order to comply with the functional requirements of paragraph 10.2.1.1 above, 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 and the anticipated low temperature.

10.3.1.2 In order to comply with the functional requirements of paragraph 10.2.1.2 above, ships intended to provide icebreaking escort shall be equipped with a sound signaling system mounted to face astern to indicate escort and emergency manoeuvres to following ships as described in the International Code of Signals.

10.3.1.3 In order to comply with the functional requirements of paragraph 10.2.1.3 above, two-way on-scene and SAR coordination communication capability in ships shall include:

- **.1** voice and/or data communications with relevant rescue coordination centres; and
- **.2** equipment for voice communications with aircraft on 121.5 and 123.1 MHz.

10.3.1.4 In order to comply with the functional requirements of paragraph 10.2.1.4 above, the communication equipment shall provide for two-way voice and data communication with a Telemedical Assistance Service (TMAS).

10.3.2 Survival craft and rescue boat communications capabilities

10.3.2.1 For ships intended to operate in low air temperature, in order to comply with the functional requirements of paragraph 10.2.2.1 above, all rescue boats and lifeboats, whenever released for evacuation, shall:

.1 for distress alerting, carry one device for transmitting ship to shore alerts;

.2 in order to be located, carry one device for transmitting signals for location; and

.3 for on-scene communications, carry one device for transmitting and receiving on-scene communications.

10.3.2.2 For ships intended to operate in low air temperature, in order to comply with the functional requirements of paragraph 10.2.2.2 above, all other survival craft shall:

.1 in order to be located, carry one device for transmitting signals for location; and

.2 for on-scene communications, carry one device for transmitting and receiving on-scene communications.

10.3.2.3 In order to comply with the functional requirements of paragraph 10.2.2.3 above, recognizing the limitations arising from battery life, procedures shall be developed and implemented such that mandatory communication equipment for use in survival craft, including liferafts, and rescue boats are available for operation during the maximum expected time of rescue.

SECTION 11 – VOYAGE PLANNING

11.1 Goal

The goal of this section is to ensure that the Company, master and crew are provided with sufficient information to enable operations to be conducted with due consideration to safety of ship and persons on board and, as appropriate, environmental protection.

11.2 Functional requirement

In order to achieve the goal set out in paragraph 11.1 above, the voyage plan shall take into account the potential hazards of the intended voyage.

11.3 Requirements

In order to comply with the functional requirement of paragraph 11.2 above, the master shall consider a route through polar waters, taking into account the following:

.1 the procedures required by the PWOM;

.2 any limitations of the hydrographic information and aids to navigation available;

.3 current information on the extent and type of ice and icebergs in the vicinity of the intended route;

.4 statistical information on ice and temperatures from former years;

.5 places of refuge;

.6 current information and measures to be taken when marine mammals are encountered relating to known areas with densities of marine mammals, including seasonal migration areas; **(7)**

.7 current information on relevant ships' routing systems, speed recommendations and vessel traffic services relating to known areas with densities of marine mammals, including seasonal migration areas; **(7)**

.8 national and international designated protected areas along the route; and

.9 operation in areas remote from search and rescue (SAR) capabilities. **(8)**

SECTION 12 –MANNING AND TRAINING

12.1 Goal

The goal of this section is to ensure that ships operating in polar waters are appropriately manned by adequately qualified, trained and experienced personnel.

12.2 Functional requirements

In order to achieve the goal set out in paragraph 12.1 above, companies shall ensure that masters, chief mates and officers in charge of a navigational watch on board ships operating in polar waters shall have completed training to attain the abilities that are appropriate to the capacity to be filled and duties and responsibilities to be taken up, taking into account the provisions of the STCW Convention and the STCW Code, as amended.

12.3 Regulations

12.3.1 In order to meet the functional requirement of paragraph 12.2 above while operating in polar waters, masters, chief mates and officers in charge of a navigational watch shall be qualified in accordance with chapter V of the STCW Convention and the STCW Code, as amended, as follows:

Ice conditions	Tankers	Passenger ships	Other
Ice Free	Not applicable	Not applicable	Not applicable
Open waters	Basic training for master, chief mate and officers in charge of a navigational watch	Basic training for master, chief mate and officers in charge of a navigational watch	Not applicable

(7) *Refer to MEPC/Circ.674 on Guidance document for minimizing the risk of ship strikes with cetaceans.*
(8) *Refer to MSC.1/Circ.1184 on Enhanced contingency planning guidance for passenger ships operating in areas remote from SAR facilities and resolution A.999(25) on Guidelines on voyage planning for passenger ships operating in remote areas.*

Ice conditions	Tankers	Passenger ships	Other
Ice Free	Not applicable	Not applicable	Not applicable
Other waters	Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch	Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch	Advanced training for master and chief mate. Basic training for officers in charge of a navigational watch.

12.3.2 The Administration may allow the use of a person(s) other than the master, chief mate or officers of the navigational watch to satisfy the requirements for training, as required by paragraph 12.3.1, provided that:

.1 this person(s) shall be qualified and certified in accordance with regulation II/2 of the STCW Convention and section A-II/2 of the STCW Code, and meets the advance training requirements noted in the above table;

.2 while operating in polar waters the ship has sufficient number of persons meeting the appropriate training requirements for polar waters to cover all watches;

.3 this person(s) is subject to the Administration's minimum hours of rest requirements at all times;

.4 when operating in waters other than open waters or bergy waters, the master, chief mate and officers in charge of a navigational watch on passenger ships and tankers shall meet the applicable basic training requirements noted in the above table; and

.5 when operating in waters with ice concentration of more than 2/10, the master, chief mate and officers in charge of a navigational watch on cargo ships other than tankers shall meet the applicable basic training requirements noted in the above table.

12.3.3 The use of a person other than the officer of the navigational watch to satisfy the requirements for training does not relieve the master or officer of the navigational watch from their duties and obligations for the safety of the ship.

12.3.4 Every crew member shall be made familiar with the procedures and equipment contained or referenced in the PWOM relevant to their assigned duties.

PART I-B

ADDITIONAL GUIDANCE REGARDING THE PROVISIONS OF THE INTRODUCTION AND PART I-A

1 ADDITIONAL GUIDANCE TO SECTION 2 (DEFINITIONS) OF THE INTRODUCTION

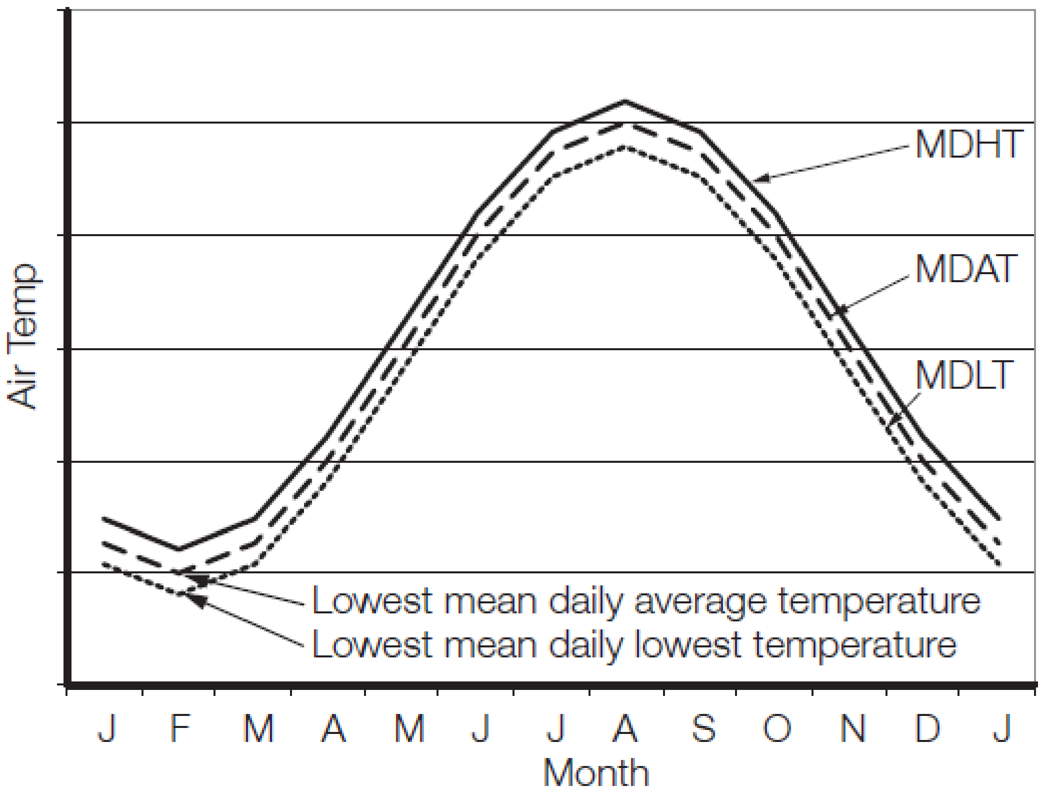

Fig. 1.1.1 Design air temperature

Definitions used in the figure above MDHT – Mean

Daily High Temperature MDAT – Mean Daily Average

Temperature MDLT – Mean Daily Low Temperature

Guidance instructions for determining MDLT:

1 Determine the daily low temperature for each day for a 10 year period.

2 Determine the average of the values over the 10 year period for each day.

3 Plot the daily averages over the year.

4 Take the lowest of the averages for the season of operation.

2 ADDITIONAL GUIDANCE TO SECTION 1 (GENERAL)

1 Limitations for operating in ice

1.1 Limitations for operation in ice can be determined using systems, tools or analysis that evaluate the risks posed by the anticipated ice conditions to the ship, taking into account factors such as its ice class, seasonal changing of ice strength, icebreaker support, ice type, thickness and concentration. The ship's structural capacity to resist ice load and the ship's planned operations should be considered. The limitations should be incorporated into an ice operational decision support system.

1.2 Limitations for operating in ice should be determined using an appropriate methodology, such methodologies exist, have been in use for a number of years and have been validated with service experience. Existing methodologies and other systems may be acceptable to the Administration.

1.3 Operation in ice should take into account any operational limitations of the ship; extended information on the ice operational methodology contained in the PWOM; the condition of the ship and ship's systems, historical weather/ice data and weather/ice forecasts for the intended area of operation, current conditions including visual ice observations, sea state, visibility and the judgment of qualified personnel.

2 Operational assessment

2.1 This guidance is intended to support shipowners carrying out, and Administrations reviewing, the assessment required in part I-A, section 1.5, for operational limitations and procedures for the Polar Ship Certificate.

2.2 Steps for an operational assessment:

- **.1** identify relevant hazards from section 3 of the Introduction and other hazards based on a review of the intended operations;
- **.2** develop a model **(9)** to analyse risks considering:
  - **.1** development of accident scenarios;
  - **.2** probability of events in each accident scenario; and
  - **.3** consequence of end states in each scenario;
- **.3** assess risks and determine acceptability:
  - **.1** estimate risk levels in accordance with the selected modelling approach; and
  - **.2** assess whether risk levels are acceptable; and

(9) *Reference is made to the techniques in appendix 3 of the Revised guidelines for Formal Safety Assessment (FSA) for use in the IMO Rule-Making Process (MSC-MEPC.2/Circ.12/Rev.1) and standard IEC/ISO 31010 "Risk management – Risk assessment techniques".*

.4 in the event that risk levels determined in steps 1 to 3 are considered to be too high, identify current or develop new risk control options that aim to achieve one or more of the following:

.1 reduce the frequency of failures through better design, procedures, training, etc.;

.2 mitigate the effect of failures in order to prevent accidents;

.3 limit the circumstances in which failures may occur; or

.4 mitigate consequences of accidents; and

.5 incorporate risk control options for design, procedures, training and limitations, as applicable.

3 Performance standards

A system previously accepted based on manufacturer certifications, classification society certifications and/or satisfactory service of existing systems may be acceptable for installation on new and existing ships if no performance or testing standards are accepted by the Organization.

3 ADDITIONAL GUIDANCE TO SECTION 2 (POLAR WATER OPERATIONAL MANUAL (PWOM))

3.1 Recommendation on the content of the Polar Water Operational Manual

The Polar Water Operational Manual (PWOM) is intended to address all aspects of operations addressed by section 2 of part I-A. When appropriate information, procedures or plans exist elsewhere in a ship's documentation, the PWOM itself does not need to replicate this material, but may instead cross-reference the relevant reference document.

A model Table of Contents is found in appendix 1.

The model follows the general structure of section 2. Not every section outlined below will be applicable to every polar ship. Many category C ships that undertake occasional or limit polar voyages will not need to have procedures for situations with a very low probability of occurrence. However, it may still be advisable to retain a common structure for the PWOM as a reminder that if assumptions change then the contents of the manual may also need to be updated. Noting an aspect as "not applicable" also indicates to the Administration that this aspect has been considered and not merely omitted.

3.2 Guidance on navigation with icebreaker assistance

With respect to navigation with icebreaker assistance, the following should be considered:

.1 while approaching the starting point of the ice convoy to follow an icebreaker/icebreakers or in the case of escorting by icebreaker of one ship to the point of meeting with the icebreaker, ships should establish radio communication on the VHF channel 16 and act in compliance with the icebreaker's instructions;

.2 the icebreaker rendering the icebreaker assistance of ship ice convoy should command ships in the ice convoy;

.3 position of a ship in the ice convoy should be determined by the icebreaker rendering the assistance;

.4 ship within the ice convoy, in accordance with the instructions of the icebreaker rendering the assistance, should establish communication with the icebreaker by VHF channel indicated by the icebreaker;

.5 the ship, while navigating in the ice convoy, should ensure compliance with the instructions of the icebreaker;

.6 position in the ice convoy, speed and distance to a ship ahead should be as instructed by the icebreaker;

.7 the ship should immediately notify the icebreaker of any difficulties to maintain the position within the ice convoy, speed and/or distance to any other ship in the ice convoy; and

.8 the ship should immediately report to the icebreaker of any damage.

3.3 Guidance on the development of contingency plans

In developing the ship's contingency plans ships should consider damage control measures arrangements for emergency transfer of liquids and access to tanks and spaces during salvage operations.

See also additional guidance to section 9.

4 **ADDITIONAL GUIDANCE TO SECTION 3 (SHIP STRUCTURE)**

Method for determining equivalent ice class

1 The guidance presented below is intended to assist in determining equivalency with standards acceptable to the Organization, as referenced in sections 3 and 6 of Polar Code. The methodology is consistent with guidance developed by the Organization **(10)** while allowing for the use of a simplified approach.

2 The basic approach for considering equivalency for categories A and B ships can be the same for both new and existing ships. It involves comparing other ice classes to the IACS Polar Classes. For ice classes under category C, additional information on comparisons of strengthening levels is available for the guidance of owners and Administrations. **(11)** The responsibility for generating the equivalency request and supporting information required should rest with the owner/operator. Review/approval of any equivalency request should be undertaken by **TL**. Easy-to-use tools have been developed for determination of compliance with the IACS Polar Class structural requirements.

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

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

3 The scope of a simplified equivalency assessment (referring to paragraphs 6.1 to 6.3 below) is expected to be limited to materials selection, structural strength of the hull and propulsion machinery.

4 If there is not full and direct compliance, then an equivalent level of risk can be accepted in accordance with guidance provided by the Organization. An increase in the probability of an event can be balanced by a reduction in its consequences. Alternatively, a reduction in probability could potentially allow acceptance of more serious consequences. Using a hull area example, a local shortfall in strength level or material grade could be accepted if the internal compartment is a void space, for which local damage will not put the overall safety of the ship at risk or lead to any release of pollutants.

5 For existing ships, service experience can assist in risk assessment. As an example, for an existing ship with a record of polar ice operations a shortfall in the extent of the ice belt (hull areas) may be acceptable if there is no record of damage to the deficient area; i.e. a ship that would generally meet PC 5 requirements but in limited areas is only PC 7 could still be considered as a category A, PC 5 ship. In all such cases, the ship's documentation should make clear the nature and scope of any deficiencies.

6 The process includes the following stages of assessment:

- **.1** select the target Polar Class for equivalency;
- **.2** compare materials used in the design with minimum requirements under the IACS Polar Class URs; identify any shortfalls; and
- **.3** compare strength levels of hull and machinery components design with requirements under the IACS Polar Class URs; quantify levels of compliance.

7 Where gaps in compliance are identified in steps 1 to 3, additional steps should be necessary to demonstrate equivalency, as outlined below:

- **.4** identify any risk mitigation measures incorporated in the design of the ship (over and above the requirements of the Code and IACS URs);
- **.5** where applicable, provide documentation of service experience of existing ships, in conditions relevant to the target ice class for equivalency; and
- **.6** undertake an assessment, taking into account information from steps 1 to 5, as applicable, and on the principles outlined in paragraphs 2 to 6 above.

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

9 Where a ship in categories A or B is provided with an equivalency for ice class by its flag State, this should be noted in its Polar Ship Certificate.

5 ADDITIONAL GUIDANCE TO SECTION 4 (SUBDIVISION AND STABILITY)

No additional guidance

6 ADDITIONAL GUIDANCE TO SECTION 5 (WATERTIGHT AND WEATHERTIGHT INTEGRITY)

No additional guidance.

7 ADDITIONAL GUIDANCE TO SECTION 6 (MACHINERY INSTALLATIONS)

Refer to additional guidance to section 3.

8 ADDITIONAL GUIDANCE TO SECTION 7 (FIRE SAFETY/PROTECTION)

No additional guidance.

9 ADDITIONAL GUIDANCE TO SECTION 8 (LIFE-SAVING APPLIANCES AND ARRANGEMENTS)

9.1 Sample personal survival equipment

When considering resources to be included with the personal survival equipment, the following should be taken into account:

Suggested equipment
Protective clothing (hat, gloves, socks, face and neck protection, etc.)
Skin protection cream
Thermal protective aid
Sunglasses
Whistle
Drinking mug
Penknife
Polar survival guidance
Emergency food
Carrying bag

9.2 Sample group survival equipment

When considering resources to be included in the group survival equipment, the following should be taken into account:

Suggested equipment
Shelter – tents or storm shelters or equivalent – sufficient for maximum number of persons
Thermal protective aids or similar – sufficient for maximum number of persons
Sleeping bags – sufficient for at least one between two persons
Foam sleeping mats or similar – sufficient for at least one between two persons
Shovels – at least 2
Sanitation (e.g. toilet paper)
Stove and fuel – sufficient for maximum number of persons ashore and maximum anticipated time of rescue

Suggested equipment
Emergency food – sufficient for maximum number of persons ashore and maximum anticipated time of rescue
Flashlights – one per shelter
Waterproof and windproof matches – two boxes per shelter
Whistle
Signal mirror
Water containers & water purification tablets
Spare set of personal survival equipment
Group survival equipment container (waterproof and floatable)

10 ADDITIONAL GUIDANCE TO SECTION 9 (SAFETY OF NAVIGATION)

10.1 Radars equipped with enhanced ice detection capability should be promoted used, in particular, in shallow waters.

10.2 As the chart coverage of polar waters in many areas may not currently be adequate for coastal navigation, navigational officers should:

.1 exercise care to plan and monitor their voyage accordingly, taking due account of the information and guidance in the appropriate nautical publications;

.2 be familiar with the status of hydrographic surveys and the availability and quality of chart information for the areas in which they intend to operate;

.3 be aware of potential chart datum discrepancies with GNSS positioning; and

.4 aim to plan their route through charted areas and well clear of known shoal depths, following established routes whenever possible.

10.3 Any deviations from the planned route should be undertaken with particular caution. For example, and when operating on the continental shelf:

.1 the echo-sounder should be working and monitored to detect any sign of unexpected depth variation, especially when the chart is not based on a full search of the sea floor; and

.2 independent cross-checking of positioning information (e.g. visual and radar fixing and GNSS) should be undertaken at every opportunity. Mariners should ensure to report to the relevant charting authority (Hydrographic Office) any information that might contribute to improving the nautical charts and publications.

10.4 Ships should be fitted with:

.1 a suitable means to de-ice sufficient conning position windows to provide unimpaired forward and astern vision from conning positions; and

.2 an efficient means of clearing melted ice, freezing rain, snow, mist and spray from outside and accumulated condensation from inside. A mechanical means to clear moisture from the outside face of a window should have operating mechanisms protected from freezing or the accumulation of ice that would impair effective operation.

11 ADDITIONAL GUIDANCE TO SECTION 10 (COMMUNICATION)

11.1 Limitations of communication systems in high latitude

11.1.1 Current maritime digital communication systems were not designed to cover Polar waters.

11.1.2 VHF is still largely used for communication at sea, but only over short distances (line of sight) and normally only for voice communication. HF and MF are also used for emergency situations. Digital VHF, mobile phone systems and other types of wireless technology offer enough digital capacity for many maritime applications, but only to ships within sight of shore-based stations, and are, therefore, not generally available in polar waters. AIS could also be used for low data-rate communication, but there are very few base stations, and the satellite-based AIS system is designed for data reception only.

11.1.3 The theoretical limit of coverage for GEO systems is 81.3° north or south, but instability and signal dropouts can occur at latitudes as low as 70° north or south under certain conditions. Many factors influence the quality of service offered by GEO systems, and they have different effects depending on the system design.

11.1.4 Non-GMDSS systems may be available and may be effective for communication in polar waters.

11.2 Advice for the operation of multiple alerting and communication devices in the event of an incident

A procedure should be developed to ensure that when survival craft are in close proximity, not more than two alerting or locating devices are activated (as required by regulation 10.3.2) at the same time. This is to:

.1 preserve battery life;

.2 enable extended periods of time for the transmission of alerting or locating signals; and

.3 avoid potential interference.

11.3 For satellite distress beacons, although multiple beacon transmissions can be detected successfully by the satellite system, it is not recommended to activate multiple beacons, unless the survival craft operating the beacons are widely dispersed, as this can cause interference on direction-finding equipment.

11.4 Advice on location and communication equipment to be carried by rescue boats and survival craft

In determining the equipment to be carried for transmitting signals for location, the capabilities of the search and rescue resources likely to respond should be borne in mind. Responding ships and aircraft may not be able to home to 406/121.5 MHz, in which case other locating devices (e.g. AIS-SART) should be considered.

12 ADDITIONAL GUIDANCE TO SECTION 11 (VOYAGE PLANNING)

In developing and executing a voyage plan ships should consider the following:

.1 in the event that marine mammals are encountered, any existing best practices should be considered to minimize unnecessary disturbance; and

.2 planning to minimize the impact of the ship's voyage where ships are trafficking near areas of cultural heritage and cultural significance.

See also additional guidance to section 9.

13 ADDITIONAL GUIDANCE TO SECTION 12 (MANNING AND TRAINING)

No additional guidance.

PART II-A
POLLUTION PREVENTION MEASURES

SECTION 1 – PREVENTION OF POLLUTION BY OIL

1.1 Operational requirements

1.1.1 In Arctic waters any discharge into the sea of oil or oily mixtures from any ship shall be prohibited.

1.1.2 The provisions of paragraph 1.1.1 shall not apply to the discharge of clean or segregated ballast.

1.1.3 Subject to the approval of the Administration, a category A ship constructed before 1 January 2017 that cannot comply with paragraph 1.1.1 for oil or oily mixtures from machinery spaces and is operating continuously in Arctic waters for more than 30 days shall comply with paragraph 1.1.1 not later than the first intermediate or renewal survey, whichever comes first, one year after 1 January 2017. Until such date these ships shall comply with the discharge requirements of MARPOL Annex I regulation 15.3.

1.1.4 Operation in polar waters shall be taken into account, as appropriate, in the Oil Record Books, manuals and the shipboard oil pollution emergency plan or the shipboard marine pollution emergency plan as required by MARPOL Annex I.

1.2 Structural requirements

1.2.1 For category A and B ships constructed on or after 1 January 2017 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.

1.2.2 For category A and B ships other than oil tankers constructed on or after 1 January 2017, 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.

1.2.3 For category A and B oil tankers of less than 5,000 tonnes deadweight constructed on or after 1 January 2017, the entire cargo tank length shall be protected with:

.1 double bottom tanks or spaces complying with the applicable requirements of regulation 19.6.1 of MARPOL Annex I; and

.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.

1.2.4 For category A and B ships constructed on or after 1 January 2017 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.

SECTION 2 – CONTROL OF POLLUTION BY NOXIOUS LIQUID SUBSTANCES IN BULK

2.1 Operational requirements

2.1.1 In Arctic waters any discharge into the sea of noxious liquid substances (NLS), or mixtures containing such substances, shall be prohibited.

2.1.2 Operation in polar waters shall be taken into account, as appropriate, in the Cargo Record Book, the Manual and the shipboard marine pollution emergency plan for noxious liquid substances or the shipboard marine pollution emergency plan as required by MARPOL Annex II.

2.1.3 For category A and B ships constructed on or after 1 January 2017, the carriage of NLS identified in section 17, column e, as ship type 3 or identified as NLS in section 18 of the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk in cargo tanks of type 3 ships shall be subject to the approval of the Administration. The results shall be reflected on the International Pollution Prevention Certificate for the Carriage of Noxious Liquid Substances in Bulk or Certificate of Fitness identifying the operation in polar waters.

SECTION 3 –PREVENTION OF POLLUTION BY HARMFUL SUBSTANCES CARRIED BY SEA IN PACKAGED FORM

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SECTION 4 –PREVENTION OF POLLUTION BY SEWAGE FROM SHIPS

4.1 Definitions

4.1.1 *Constructed* means a ship the keel of which is laid or which is at a similar stage of construction.

4.1.2 *Ice-shelf* means a floating ice sheet of considerable thickness showing 2 to 50 m or more above sea-level, attached to the coast. **(12)**

4.1.3 *Fast ice* means sea ice which forms and remains fast along the coast, where it is attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs. **(12)**

4.2 Operational requirements

4.2.1 Discharges of sewage within polar waters are prohibited except when performed in accordance with MARPOL Annex IV and the following requirements:

.1 the ship is discharging comminuted and disinfected sewage in accordance with regulation 11.1.1 of MARPOL Annex IV at a distance of more than 3 nautical miles from any ice-shelf or fast ice and shall be as far as practicable from areas of ice concentration exceeding 1/10; or

.2 the ship is discharging sewage that is not comminuted or disinfected in accordance with regulation 11.1.1 of MARPOL Annex IV and at a distance of more than 12 nautical miles from any ice-shelf or fast ice and shall be as far as practicable from areas of ice concentration exceeding 1/10; or

(12) *Refer to the WMO Sea-Ice Nomenclature.*

.3 the ship has in operation an approved sewage treatment plant **(13)** certified by the Administration to meet the operational requirements in either regulation 9.1.1 or 9.2.1 of MARPOL Annex IV, and discharges sewage in accordance with regulation 11.1.2 of Annex IV and shall be as far as practicable from the nearest land, any ice-shelf, fast ice or areas of ice concentration exceeding 1/10.

4.2.2 Discharge of sewage into the sea is prohibited from category A and B ships constructed on or after 1 January 2017 and all passenger ships constructed on or after 1 January 2017, except when such discharges are in compliance with paragraph 4.2.1.3 of this section.

4.2.3 Notwithstanding the requirements of paragraph 4.2.1, category A and B ships that operate in areas of ice concentrations exceeding 1/10 for extended periods of time, may only discharge sewage using an approved sewage treatment plant certified by the Administration to meet the operational requirements in either regulation 9.1.1 or 9.2.1 of MARPOL Annex IV. Such discharges shall be subject to the approval by the Administration.

SECTION 5 – PREVENTION OF POLLUTION BY GARBAGE FROM SHIPS

5.1 Definitions

5.1.1 *Ice-shelf* means a floating ice sheet of considerable thickness showing 2 to 50 m or more above sea-level, attached to the coast[21].

5.1.2 *Fast ice* means sea ice which forms and remains fast along the coast, where it is attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs **(14)**

5.2 Operational requirements

5.2.1 In Arctic waters, discharge of garbage into the sea permitted in accordance with regulation 4 of MARPOL Annex V, shall meet the following additional requirements:

.1 discharge into the sea of food wastes is only permitted when the ship is as far as practicable from areas of ice concentration exceeding 1/10, but in any case not less than 12 nautical miles from the nearest land, nearest ice-shelf, or nearest fast ice;

.2 food wastes shall be comminuted or ground and shall be capable of passing through a screen with openings no greater than 25 mm. Food wastes shall not be contaminated by any other garbage type;

.3 food wastes shall not be discharged onto the ice;

.4 discharge of animal carcasses is prohibited; and

.5 discharge of cargo residues that cannot be recovered using commonly available methods for unloading shall only be permitted while the ship is en route and where all the following conditions are satisfied:

.1 cargo residues, cleaning agents or additives, contained in hold washing water do not include any substances classified as harmful to the marine environment, taking into account guidelines developed by the Organization;

(13) *Refer to resolution MEPC.2(VI), resolution MEPC.159(55) or resolution MEPC.227(64), as amended, as applicable.*

(14) *Refer to the WMO Sea-Ice Nomenclature.*

.2 both the port of departure and the next port of destination are within Arctic waters and the ship will not transit outside Arctic waters between those ports;

.3 no adequate reception facilities are available at those ports taking into account guidelines developed by the Organization; and

.4 where the conditions of subparagraphs 5.2.1.5.1, 5.2.1.5.2 and 5.2.1.5.3 of this paragraph have been fulfilled, discharge of cargo hold washing water containing residues shall be made as far as practicable from areas of ice concentration exceeding 1/10, but in any case not less than 12 nautical miles from the nearest land, nearest ice shelf, or nearest fast ice.

5.2.2 In the Antarctic area, discharge of garbage into the sea permitted in accordance with regulation 6 of MARPOL Annex V, shall meet the following additional requirements:

.1 discharges under regulation 6.1 of MARPOL Annex V shall be as far as practicable from areas of ice concentration exceeding 1/10, but in any case not less than 12 nautical miles from the nearest fast ice; and

.2 food waste shall not be discharged onto ice.

5.2.3 Operation in polar waters shall be taken into account, as appropriate, in the Garbage Record Book, Garbage Management Plan and the placards as required by MARPOL Annex V.

PART II-B

ADDITIONAL GUIDANCE REGARDING THE PROVISIONS OF THE INTRODUCTION AND PART II-A

1 Additional guidance to section 1

1.1 Ships are encouraged to apply regulation 43 of MARPOL Annex I when operating in Arctic waters.

1.2 Non-toxic biodegradable lubricants or water-based systems should be considered in lubricated components located outside the underwater hull with direct seawater interfaces, like shaft seals and slewing seals.

2 Additional guidance to section 2

Category A and B ships, constructed on or after 1 January 2017 and certified to carry noxious liquid substances (NLS), are encouraged to carry NLS identified in section 17, column e, as ship type 3 or identified as NLS in section 18 of the *International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk*, in tanks separated from the outer shell by a distance of not less than 760 mm.

3 Additional guidance to section 5

In order to minimize the risks associated with animal cargo mortalities, consideration should be given to how animal carcasses will be managed, treated, and stored on board when ships carrying such cargo are operating in polar waters. Reference is made in particular to the *2017 Guidelines for the implementation of MARPOL Annex V* (resolution MEPC 295(71)) and the *2012 Guidelines for the development of garbage management plans* (resolution MEPC.220(63)).

4 Additional guidance under other environmental conventions and guidelines

4.1 Until the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* enters into force, the ballast water management provisions of the ballast water exchange standard, set out in regulation D-1, or the ballast water performance standard, set out in regulation D-2 of the Convention should be considered as appropriate. The provisions of the *Guidelines for ballast water exchange in the Antarctic treaty area* (resolution MEPC.163(56)) should be taken into consideration along with other relevant guidelines developed by the Organization.

4.2 In selecting the ballast water management system, attention should be paid to limiting conditions specified in the appendix of the Type Approval Certificate and the temperature under which the system has been tested, in order to ensure its suitability and effectiveness in polar waters.

4.3 In order to minimize the risk of invasive aquatic species transfers via biofouling, measures should be considered to minimize the risk of more rapid degradation of anti-fouling coatings associated with polar ice operations. Reference is made in particular to the *2011 Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species* (resolution MEPC.207(62)).

Table: Example of matters related to anti-fouling systems taken into consideration by some ice-going ships

(this table is used by some operators of ice-going ships)

	Hull	**Sea chest**
Year round operation in ice-covered polar waters		• Abrasion resistant coating. • Compliant with the AFS Convention. Thickness of anti-fouling system to be decided by shipowner.
Intermittent operation in ice-covered polar waters	• Abrasion resistant low friction ice coating. • In sides, above bilge keel, max thickness of anti-fouling system 75 µm, to protect hull between application of anti-fouling system and next anticipated voyage to ice-covered waters. In bottom area thickness to be decided by shipowner. Composition of anti-fouling system should also be decided by the shipowner.	• Compliant with the AFS Convention. Thickness of anti-fouling system to be decided by shipowner.
Category B and C vessels	• Compliant with the AFS Convention. Thickness of anti-fouling system to be decided by shipowner.	• Compliant with the AFS Convention. Thickness of anti-fouling system to be decided by shipowner.

APPENDIX 1

Model table of contents for the Polar Water Operational Manual (PWOM) SAFETY MEASURES

Division 1 – Operational capabilities and limitations

Chapter 1 Operation in ice

1.1 Operator guidance for safe operation

Guidance: The PWOM should establish the means by which decisions as to whether ice conditions exceed the ship's design limits should be made, taking into account the operational limitations on the Polar Ship Certificate. An appropriate decision support system, such as 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, can be used... Bridge personnel should be trained in the proper use of the system to be utilized. For ships that will operate only in ice-free waters, procedures to ensure that will keep the ship from encountering ice should be established.

1.2 Icebreaking capabilities

Guidance: The PWOM should provide information on the ice conditions in which the ship can be expected to make continuous progress. This may be drawn, for example from numerical analysis, model test or from ice trials. Information on the influence of ice strength for new or decayed ice and of snow cover may be included.

1.3 Manoeuvring in ice

1.4 Special features

Guidance: Where applicable, the PWOM should include the results of any equivalency analyses made to determine Polar Ship category/ice class. The manual should also provide information on the use of any specialized systems fitted to assist in ice operations.

Chapter 2 Operation in low air temperatures

2.1 System design

Guidance: The PWOM should list all ship systems susceptible to damage or loss of functionality by exposure to low temperatures, and the measures to be adopted to avoid malfunction.

Chapter 3 Communication and navigation capabilities in high latitudes

Guidance: The PWOM should identify any restrictions to operational effectiveness of communications and navigational equipment that may result from operating in high latitudes.

Chapter 4 Voyage duration

Guidance: The PWOM should provide information on any limitations on ship endurance such as fuel tankage, fresh water capacity, provision stores, etc. This will normally only be a significant consideration for smaller ships, or for ships planning to spend extended periods in ice.

Division 2 – Ship operations

Chapter 1 Strategic planning

Assumptions used in conducting the analyses referred to below should be included in the Manual.

1.1 Avoidance of hazardous ice

Guidance: For ships operating frequently in polar waters, the PWOM should provide information with respect to periods during which the ship should be able to operate for intended areas of operation. Areas that pose particular problems, e.g. chokepoints, ridging, as well as worst recorded ice conditions should be noted. Where the available information is limited or of uncertain quality, this should be recognized and noted as a risk for voyage planning.

1.2 Avoidance of hazardous temperatures

Guidance: For ships operating frequently in polar waters, the PWOM should provide information with respect to, the daily mean daily low temperature as well as the minimum recorded temperature for each of the days during the intended operating period. Where the available information is limited or of uncertain quality, this should be recognized as a risk for voyage planning.

1.3 Voyage duration and endurance

Guidance: Procedures to establish requirements for supplies should be established, and appropriate safety levels for safety margins determined taking into account various scenarios, e.g. slower than expected steaming, course alterations, adverse ice conditions, places of refuge and access to provisions. Sources for and availability of fuel types should be established, taking into account long lead times required for deliveries.

1.4 Human resources management

Guidance: The PWOM should provide guidance for the human resources management, taking into account the anticipated ice conditions and requirements for ice navigation, increased levels of watch keeping, hours of rest, fatigue and a process that ensures that these requirements will be met.

Chapter 2 Arrangements for receiving forecasts of environmental conditions

Guidance: The PWOM should set out the means and frequency for provision of ice and weather information. Where a ship is intended to operate in or in the presence of ice, the manual should set out when weather and ice information is required and the format for the information.

When available, the information should include both global and localized forecasts that will identify weather and ice patterns/regimes that could expose the ship to adverse conditions.

The frequency of updates should provide enough advance notice that the ship can take refuge or use other methods of avoiding the hazard if the conditions are forecast to exceed its capabilities.

The PWOM may include use of a land-based support information provider an effective method of sorting through available information, thereby providing the ship only with information that is relevant, reducing demands on the ship's communications systems. The manual may also indicate instances in which additional images should be obtained and analysed, as well as where such additional information may be obtained.

2.1 Ice information

Guidance: The PWOM should include or refer to guidance on how radar should be used to identify ice floes, how to tune the radar to be most effective, instructions on how to interpret radar images, etc. If other technologies are to be used to provide ice information, their use should also be described.

2.2 Meteorological information

Chapter 3 Verification of hydrographic, meteorological and navigational information

Guidance: The PWOM should provide guidance on the use of hydrographic information as further described in the additional guidance to chapter 10.

Chapter 4 Operation of Special Equipment

4.1 Navigation systems

4.2 Communications systems

Chapter 5 Procedures to maintain equipment and system functionality

5.1 Icing prevention and de-icing

Guidance: The PWOM should provide guidance on how to prevent or mitigate icing by operational means, how to monitor and assess ice accretion, how to conduct de-icing using equipment available on the ship, and how to maintain the safety of the ship and its crew during all of these aspects of the operation.

5.2 Operation of seawater systems

Guidance: The PWOM should provide guidance on how to monitor, prevent or mitigate ice ingestion by seawater systems when operating in ice or in low water temperatures. This may include recirculation, use of low rather than high suctions, etc.

5.3 Procedures for low temperature operations

Guidance: The PWOM should provide guidance on maintaining and monitoring any systems and equipment that are required to be kept active in order to ensure functionality; e.g. by trace heating or continuous working fluid circulation.

Division 3 – Risk management

Chapter 1 Risk mitigation in limiting environmental condition

1.1 Measures to be considered in adverse ice conditions

Guidance: The PWOM should contain guidance for the use of low speeds in the presence of hazardous ice. Procedures should also be set for enhanced watchkeeping and lookout manning in situations with high risks from ice, e.g. in proximity to icebergs, operation at night, and other situations of low visibility. When possibilities for contact with hazardous ice exist, procedures should address regular monitoring, e.g. soundings/inspections of compartments and tanks below the waterline.

1.2 Measures to be considered in adverse temperature conditions

Guidance: The PWOM should contain guidance on operational restrictions in the event that temperatures below the ships polar service temperature are encountered or forecast. These may include delaying the ship, postponing the conduct of certain types of operation, using temporary heating, and other risk mitigation measures.

Chapter 2 Emergency response

Guidance: In general, where the possibility of encountering low air temperatures, sea ice, and other hazards is present, the PWOM should provide guidance on procedures that will increase the effectiveness of emergency response measures.

2.1 Damage control

Guidance: the PWOM should consider damage control measures arrangements for emergency transfer of liquids and access to tanks and spaces during salvage operations.

2.2 Firefighting

2.3 Escape and evacuation

Guidance: Where supplementary or specialized lifesaving equipment is carried to address the possibilities of prolonged durations prior to rescue, abandonment onto ice or adjacent land, or other aspects specific to polar operations, the PWOM should contain guidance on the use of the equipment and provision for appropriate training and drills.

Chapter 3 Coordination with emergency response services

3.1 Ship emergency response

Guidance: The PWOM should include procedures to be followed in preparing for a voyage and in the event of an incident arising.

3.2 Salvage

Guidance: The PWOM should include procedures to be followed in preparing for a voyage and in the event of an incident arising.

3.3 Search and rescue

Guidance: The PWOM should contain information on identifying relevant Rescue Coordination Centres for any intended routes, and should require that contact information and procedures be verified and updated as required as part of any voyage plan.

Chapter 4 Procedures for maintaining life support and ship integrity in the event of prolonged entrapment by ice.

Guidance: Where any ship incorporates special features to mitigate safety or environmental risks due to prolonged entrapment by ice, the PWOM should provide information on how these are to be set up and operated. This may include, for example, adding additional equipment to be run from emergency switchboards, draining systems at risk of damage through freezing, isolating parts of HVAC systems, etc.

4.1 System configuration

4.2 System operation

Division 4 – Joint operations

Chapter 1 Escorted operations

Guidance: The PWOM should contain or reference information on the rules and procedures set out by coastal States who require or offer icebreaking escort services. The manual should also emphasize the need for the master to take account of the ship's limitations in agreeing on the conduct of escort operations.

Chapter 2 Convoy operations

APPENDIX 2

Table 1 - Load cases for open propeller

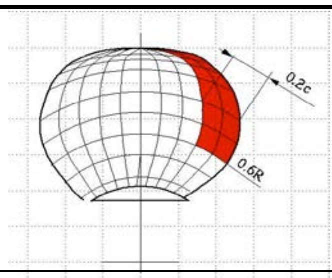
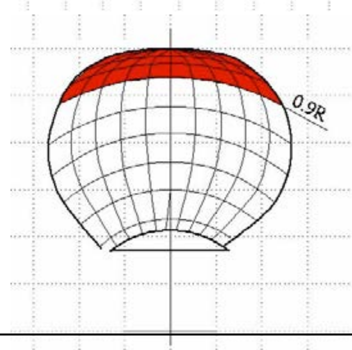
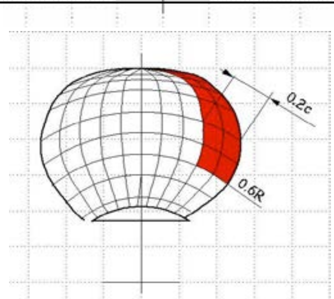
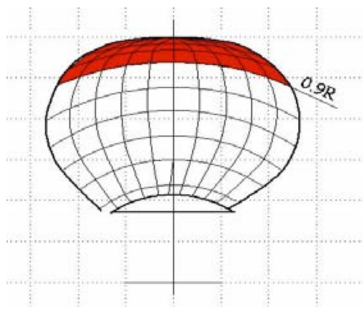
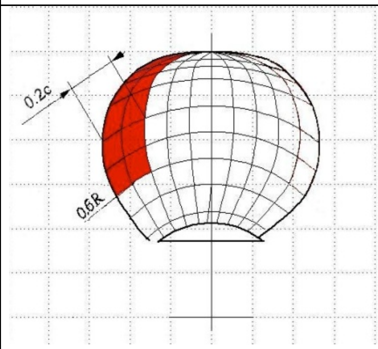
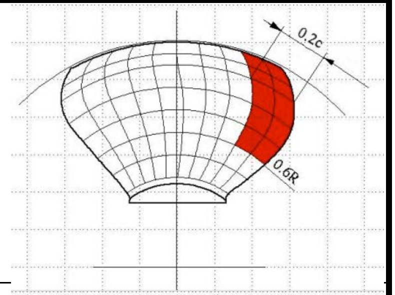
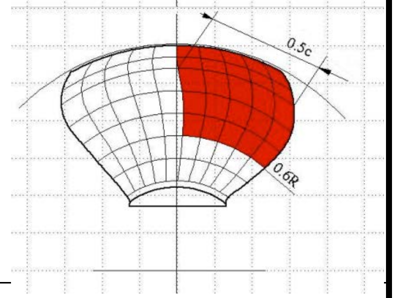
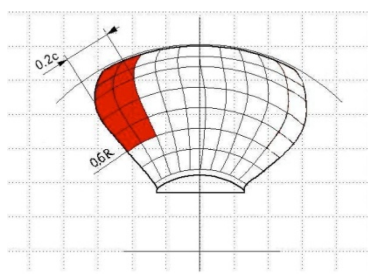
	Force	Loaded area	Right handed propeller blade seen from back
Load case 1	F_b	Uniform pressure applied on the back of the blade (suction side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length.	
Load case 2	50 % of F_b	Uniform pressure applied on the back of the blade (suction side) on the propeller tip area outside of 0.9R radius.	
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_f or F_b which one 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.	

Table 2 - Load cases for ducted propeller

	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.	
Load case 5	60 % of F_f or F_b which one 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.	

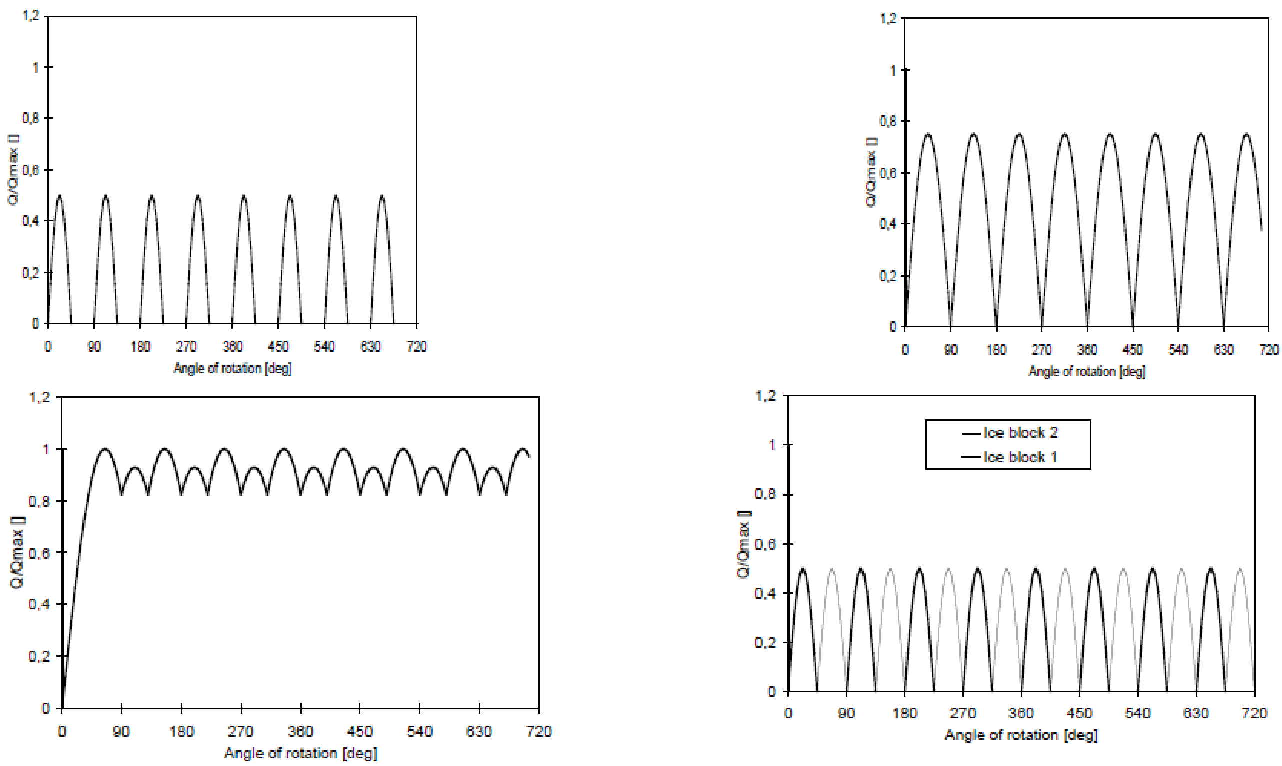


Figure 1 - The shape of the propeller ice torque excitation for 45, 90, 135 degrees single blade impact sequences and 45 degrees double blade impact sequence (two ice pieces) on a four bladed propeller