GUIDE FOR BUILDING AND CLASSING

VESSELS INTENDED FOR NAVIGATION IN POLAR WATERS

MARCH 2008 (Updated July 2008 – see next page)

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Updates

July 2008 consolidation includes:

- March 2008 version plus Corrigenda/Editorials

Foreword

This Guide contains requirements obtained from IACS Unified Requirements, UR I1 "Polar Class Descriptions and Application", I2 "Structural Requirements for Polar Class Ships" and I3 "Machinery Requirements for Polar Class Ships". These IACS documents are available from www.iacs.org.uk.

The objective of Section 1 is to specify the application of the structural and machinery requirements for polar vessels, and to provide descriptions of the various Polar Classes used throughout these requirements to convey differences with respect to operational capability and strength.

The scope of Section 2 includes ice load definition, as well as specific strength requirements for plating, framing (including web frames and load-carrying stringers), plated structures (such as decks and bulkheads), and the hull girder. The scope of this Section also includes material requirements, as well as corrosion/abrasion allowances. General strength requirements for hull appendages stem and stern frames, as well as some provisions for local details, direct calculations and welding, are also included. The objective of Section 2 is to provide a unified set of structural requirements to enable Polar Class vessels to withstand the effects of global and local ice loads, as well as temperatures, characteristic of their Polar Class.

The scope of Section 3 includes the design ice thickness and strength index for the purpose of calculating the propeller ice loads, for open and nozzle propellers. Further, the Section provides analytical tools for calculating strength of the propeller blade. Finally, this Section defines accelerations imposed upon machinery due to ice impact/ramming are required in order that the integrity of holding-down arrangements of essential machinery is maintained. The provided method for calculation of these accelerations requires additional information on bow vertical ice force and bow side ice force magnitudes from the Structural Requirements in Section 2.

As one can see from the concise summary of Section 3 above, no requirements for shafting, gears, and flexible couplings are provided. Therefore, based on ABS practices, these requirements are incorporated within 3/13.7. Notably, the propulsion power requirement is presented as a goal criterion, (i.e., a vessel is to be able to maintain a design service speed in ice). This approach of tackling this complex issue is taken considering that a commercial operation in arctic waters may impose navigation requiring a minimum power for maintaining a safe operation of the vessel in re-frozen (brash ice) fairway navigation channel and that a propulsion power requirement depends on vessel/machinery configurations, all of which necessitate attention to details in powers estimation. Subsection 3/9 provides a general guidance how to assess the power of propulsion machinery.

The effective date of this Guide is 1 March 2008 and it is applicable for vessels contracted for construction on or after 1 March 2008.

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SECTION 1 Introduction

1 General

1.1 Application

The requirements for Polar Ships apply to vessels constructed of steel and intended for navigation in ice-infested polar waters, except ice breakers [see 6-1-1/1.3 of the ABS *Rules for Building and Classing Steel Vessels* (*Steel Vessel Rules*)].

Vessels that comply with the requirements of this Guide can be considered for a Polar Class notation as listed Section 1, Table 1. The requirements of this Guide are in addition to the open water 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 classification certificate. Compliance of the hull or machinery with the requirements of a higher Polar Class is also to be indicated in the classification certificate or an appendix thereto.

1.3 Ice Breaker Class

Requirements of this Guide do not cover the requirements for the class notation, **Ice Breaker**. Vessels that are to receive the **Ice Breaker** notation should have additional requirements and are to comply with the requirements of 6-1-1/1.5 of the *Steel Vessel Rules*.

3 Description of Ice Class

3.1 Guide for Selection of Polar Classes

3.1.1

The Polar Class (PC) notations and descriptions are given in Section 1, Table 1. It is the responsibility of the Owner to select an appropriate Polar Class. The descriptions in Section 1, Table 1 are intended to guide owners, designers and administrations in selecting an appropriate Polar Class to match the requirements for the vessel with its intended voyage or service.

3.1.2

The **Polar Class** notation is used throughout this Guide to convey the differences between classes with respect to operational capability and strength.

TABLE 1
Polar Class Descriptions

Polar Class	*Ice Description (based on WMO Sea Ice Nomenclature)*
PC1	Year-round operation in all Polar waters
PC2	Year-round operation in moderate multi-year ice conditions
PC3	Year-round operation in second-year ice which may include multi-year ice inclusions.
PC4	Year-round operation in thick first-year ice which may include old ice inclusions
PC5	Year-round operation in medium first-year ice which may include old ice inclusions
PC6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

5 Definitions

5.1 Upper and Lower Ice Waterlines

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

The lower ice waterline is to be determined with due regard to the vessel's ice-going capability in the ballast loading conditions (e.g., propeller submergence).

SECTION 2 Structural Requirements for Polar Class Vessels

1 Application

These requirements are to be applied to Polar Class vessels according to 1/1.1.

3 Hull Areas

3.1 General

i) The hull of all Polar Class vessels 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 Section 2, Figure 1.

ii) The upper ice waterline (UIWL) and lower ice waterline (LIWL) are as defined in 1/5.1.

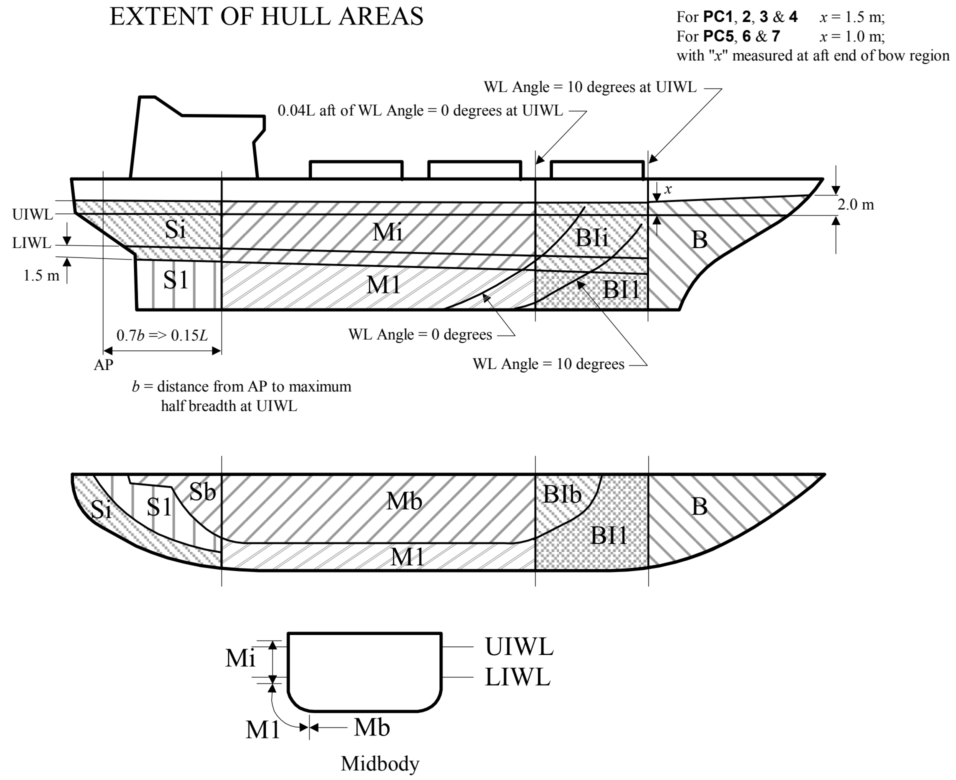
iii) Section 2, Figure 1 notwithstanding, at no time is the boundary between the Bow and Bow Intermediate regions to be forward of the intersection point of the line of the stem and the vessel baseline.

iv) Section 2, Figure 1 notwithstanding, the aft boundary of the Bow region need not be more than $0.45L$ aft of the forward perpendicular (FP).

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

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

FIGURE 1
Hull Area Extents



5 Design Ice Loads

5.1 General

i) For vessels of all Polar Classes, a glancing impact on the bow is the design scenario for determining the scantlings required to resist ice loads.

ii) 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).

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

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

v) Design ice forces calculated according to 2/5.3 are only valid for vessels with icebreaking forms. Design ice forces for any other bow forms are to be specially considered.

vi) Vessel structures that are not directly subjected to ice loads may still experience inertial loads of stowed cargo and equipment resulting from ship/ice interaction. These inertial loads, based on accelerations, are to be considered in the design of these structures.

5.3 Glancing Impact Load Characteristics

The parameters defining the glancing impact load characteristics are reflected in the Class Factors listed in Section 2, Table 1.

TABLE 1
Class Factors

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

5.5 Bow Area

i) 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 (f_a). The hull angles are defined in Section 2, Figure 4.

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

iii) The Bow area load characteristics are determined as follows:

5.5.1 Shape Coefficient

Shape coefficient, fa_i, is to be taken as:

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

where

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

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

$fa_{i,3}$ = 0.60

i = sub-region considered

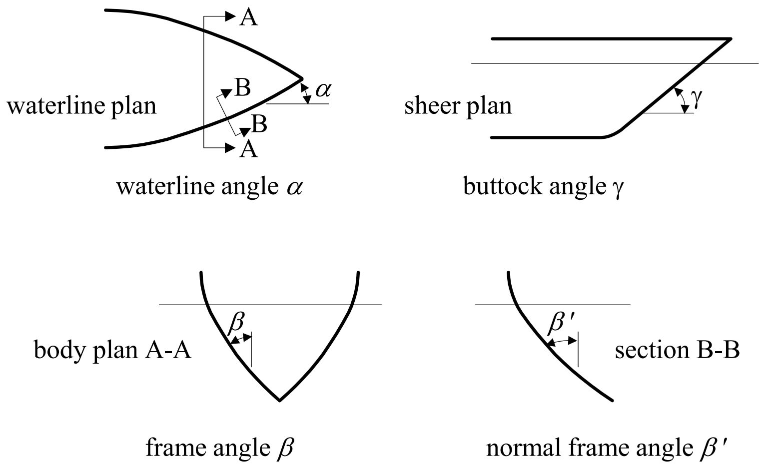
L = vessel length measured at the upper ice waterline (UIWL), in m

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

α = waterline angle, in degrees, see Section 2, Figure. 2

β'	=	normal frame angle, in degrees, see Section 2, Figure 2
D	=	vessel displacement, in kt, not to be taken less than 5 kt
CF_C	=	Crushing Failure Class Factor from Section 2, Table 1
CF_F	=	Flexural Failure Class Factor from Section 2, Table 1

FIGURE 2
Definition of Hull Angles



Note:

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

5.5.2 Force

Force, F, is to be taken as:

$$F_i = fa_i \cdot CF_C \cdot D^{0.64} \quad \text{MN}$$

where

i	=	sub-region considered
fa_i	=	shape coefficient of sub-region i
CF_C	=	Crushing Failure Class Factor from Section 2, Table 1
D	=	vessel displacement, in kt, not to be taken less than 5 kt

5.5.3 Load Patch Aspect Ratio

Load patch aspect ratio, AR, is to be taken as:

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

where

i = sub-region considered

β_i' = normal frame angle of sub-region i, in degrees

5.5.4 Line Load

Line load, Q, is to be taken as:

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

where

i = sub-region considered

F_i = force of sub-region i, in MN

CF_D = Load Patch Dimensions Class Factor from Section 2, Table 1

AR_i = load patch aspect ratio of sub-region i

5.5.5 Pressure

Pressure, P, is to be taken as:

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

where

i = sub-region considered

F_i = force of sub-region i, in MN

CF_D = Load Patch Dimensions Class Factor from Section 2, Table 1

AR_i = load patch aspect ratio of sub-region i

5.7 Hull Areas Other Than the Bow

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

5.7.1 Force

Force, F_{NonBow}, is to be taken as:

$$F_{NonBow} = 0.36 \cdot CF_C \cdot DF \quad \text{MN}$$

where

CF_C = Crushing Force Class Factor from Section 2, Table 1

DF = vessel displacement factor

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

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

D = vessel displacement, in kt, not to be taken less than 10 kt

CF_{DIS} = Displacement Class Factor from Section 2, Table 1

5.7.2 Line Load

Line Load, Q_{NonBow}, is to be taken as:

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

where

F_{NonBow} = force from 2/5.7.1, in MN

CF_D = Load Patch Dimensions Class Factor from Section 2, Table 1

5.9 Design Load Patch

5.9.1 Bow Area

In the Bow area, and the Bow Intermediate Ice belt area for vessels with class notation **PC6** and **PC7**, the design load patch has dimensions of width, w_{Bow}, and height, b_{Bow}, defined as follows:

i) $w_{Bow} = F_{Bow}/Q_{Bow}$ m

ii) $b_{Bow} = Q_{Bow}/P_{Bow}$ m

where

F_{Bow} = maximum F_i in the Bow area, in MN

Q_{Bow} = maximum Q_i in the Bow area, in MN/m

P_{Bow} = maximum P_i in the Bow area, in MPa

5.9.2 Other Hull Areas

In hull areas other than those covered by 2/5.9.1, the design load patch has dimensions of width, w_{NonBow}, and height, b_{NonBow}, defined as follows:

i) $w_{NonBow} = F_{NonBow}/Q_{NonBow}$ m

ii) $b_{NonBow} = w_{NonBow}/3.6$ m

where

F_{NonBow} = force determined using 2/5.7.1, in MN

Q_{NonBow} = line load determined using 2/5.7.2, in MN/m

5.11 Pressure within the Design Load Patch

5.11.1 Average Pressure

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

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

where

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

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

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

5.11.2 Areas of Higher, Concentrated Pressure

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 Section 2, Table 2 are used to account for the pressure concentration on localized structural members.

TABLE 2
Peak Pressure Factors

Structural Member		*Peak Pressure Factor* (PPF_i)
Plating	Transversely Framed	$PPF_p = (1.8 - s) \geq 1.2$
	Longitudinally Framed	$PPF_p = (2.2 - 1.2 \cdot s) \geq 1.5$
Frames in Transverse Framing Systems	With Load Distributing Stringers	$PPF_t = (1.6 - s) \geq 1.0$
	With No Load Distributing Stringers	$PPF_t = (1.8 - s) \geq 1.2$
Load Carrying Stringers Side and Bottom Longitudinals Web Frames		$PPF_s = 1$, if $S_w \geq 0.5 \cdot w$ $PPF_s = 2.0 - 2.0 \cdot S_w/w$, if $S_w < (0.5 \cdot w)$
where s = frame or longitudinal spacing, in m S_w = web frame spacing, in m w = ice load patch width, in m		

5.13 Hull Area Factors

i) 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 Section 2, Table 3.

ii) 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.

iii) Due to their increased maneuverability, vessels 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.

TABLE 3
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 2/5.5i).

** Indicates that strengthening for ice loads is not necessary.

7 Shell Plate Requirements

7.1 Required Minimum Shell Plate Thickness

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

$$t = t_{net} + t_s \quad \text{mm}$$

where

t_{net} = plate thickness required to resist ice loads according to 2/7.3, in mm

t_s = corrosion and abrasion allowance according to Subsection 2/21, in mm

7.3 Shell Plate Thickness to Resist Ice Load

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

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

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

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

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

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

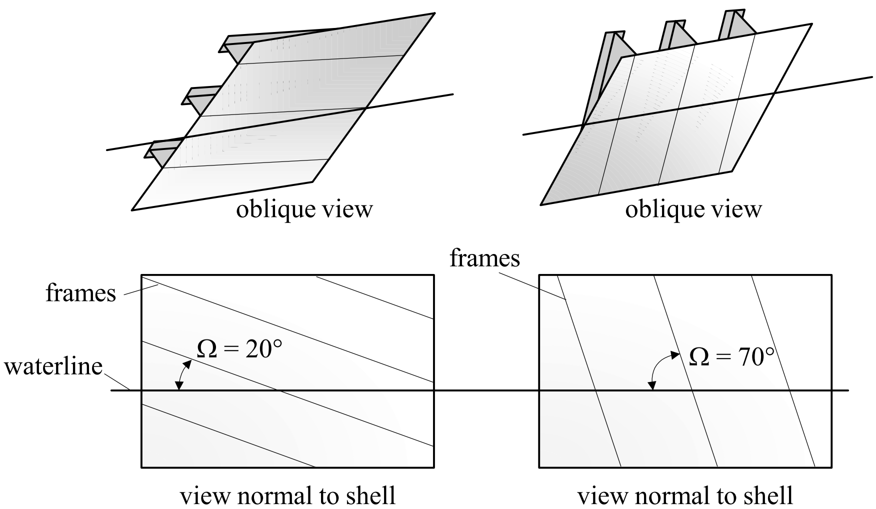
$$t_{net} = 500 \cdot s \cdot [(AF \cdot PPF_p \cdot P_{avg})/\sigma_y]^{0.5} \cdot [2 \cdot b/s - (b/s)^2]^{0.5}/[1 + s/(2 \cdot \ell)] \quad \text{mm}$$

iv) In the case of obliquely-framed plating (70 deg > Ω > 20 degrees), 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 Section 2, Figure 3, in degrees
s	=	transverse frame spacing in transversely-framed vessels or longitudinal frame spacing in longitudinally-framed vessels, in m
AF	=	Hull Area Factor from Section 2, Table 3
PPF_p	=	Peak Pressure Factor from Section 2, Table 2
P_{avg}	=	average patch pressure determined by 2/5.11.1, in MPa
σ_y	=	minimum upper yield stress of the material, in N/mm^2
b	=	height of design load patch, in m, where $b \le (a - s/4)$ in the case 2/7.3i)
ℓ	=	distance between frame supports (i.e., equal to the frame span as given in 2/9.11), but not reduced for any fitted end brackets, in m. When a load-distributing stringer is fitted, the length ℓ need not be taken larger than the distance from the stringer to the most distant frame support.

FIGURE 3
Shell Framing Angle Ω



9 Framing – General

9.1

Framing members of Polar Class vessels are to be designed to withstand the ice loads defined in Subsection 2/5.

9.3

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 Section 2, Figure 1. Where load-distributing stringers have been fitted, the arrangement and scantlings of these are to be in accordance with the requirements of 6-1-1/15.9 of the *Steel Vessel Rules*.

9.5

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.

9.7

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 prepared and submitted for review.

9.9

The design span of a framing member is to be determined on the basis of its moulded length. If brackets are fitted, the design span may be reduced provided the bracket is in accordance with 3-2-9/Table 1 of the *Steel Vessel Rules* and rigidity of the supporting member where the bracket being attached is adequate. Brackets are to be configured to ensure stability in the elastic and post-yield response regions.

9.11

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.

9.13

The actual net effective shear area, A_w, of a framing member is given by:

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

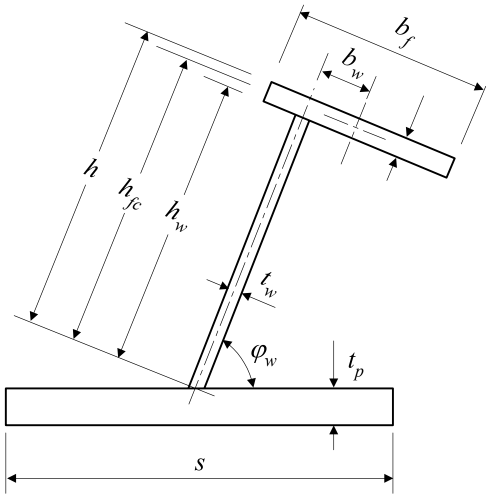
where

h	=	height of stiffener, in mm, see Section 2, Figure 4
t_{wn}	=	net web thickness, in mm
	=	$t_w - t_c$
t_w	=	as-built web thickness, in mm, see Section 2, Figure 4

t_c = corrosion deduction, in mm, to be subtracted from the web and flange thickness (but not less than t_s as required by 2/21.5).

φ_w = smallest angle between shell plate and stiffener web, measured at the midspan of the stiffener, see Section 2, Figure 4. The angle φ_w may be taken as 90 degrees provided the smallest angle is not less than 75 degrees.

FIGURE 4
Stiffener Geometry



9.15

When the cross-sectional area of the attached plate flange exceeds the cross-sectional area of the local frame, the actual net effective plastic section modulus, Z_p, is given by:

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

where

A_{pn} = net cross-sectional area of attached plate, in cm^2, (equal to $t_{pn} \cdot s \cdot 10$, but not to be taken greater than the net cross-sectional area of the local frame)

t_{pn} = fitted net shell plate thickness, in mm, (shall comply with t_{net} as required by 2/7.3)

h_w = height of local frame web, in mm, see Section 2, Figure 4

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

h_{fc} = height of local frame measured to center of the flange area, mm, see Section 2, Figure 4

b_w = distance from mid thickness plane of local frame web to the center of the flange area, in mm, see Section 2, Figure 4

h, t_{wn}, t_c and φ_w are as given in 2/9.13 and s is as given in 2/7.3.

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:

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

and the net effective plastic section modulus, Z_p, is given by:

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

9.17

In the case of oblique framing arrangement (70 degrees > Ω > 20 degrees, where Ω is defined as given in 2/7.3), linear interpolation is to be used.

11 Framing – Transversely-framed Side Structures and Bottom Structures

11.1

The local frames in transversely-framed side structures and in bottom structures (i.e., hull areas BI_b, M_b and S_b) 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.

11.3

The actual net effective shear area of the frame, A_w, as defined in 2/9.13, is to comply with the following condition: $A_w \geq A_t$, where:

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

where

LL = length of loaded portion of span, the lesser of a and b, in m

a = frame span as defined in 2/9.9, in m

b = height of design ice load patch according to 2/5.9.1ii) or 2/5.9.2ii), in m

s = transverse frame spacing, in m

AF = Hull Area Factor from Section 2, Table 3

PPF_t = Peak Pressure Factor from Section 2, Table 2

P_{avg} = average pressure within load patch according to 2/5.11.1, in MPa

σ_y = minimum upper yield stress of the material, in N/mm^2

11.5

The actual net effective plastic section modulus of the plate/stiffener combination, Z_p, as defined in 2/9.15, 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:

i) Ice load acting at the midspan of the transverse frame, and

ii) The ice load acting near a support.

The A_1 parameter, in the equation below, reflects the two conditions:

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

where

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 framing with one simple support outside the ice-strengthened areas
	=	2 for framing without any simple supports
a_1	=	A_t/A_w
A_t	=	minimum shear area of transverse frame as given in 2/11.3, in cm^2
A_w	=	effective net shear area of transverse frame (calculated according to 2/5.13), in cm^2
k_w	=	$1/(1 + 2 \cdot A_{fn}/A_w)$ with A_{fn} as given in 2/9.15
k_z	=	z_p/Z_p in general
	=	0.0 when the frame is arranged with end bracket
z_p	=	sum of individual plastic section modulii of flange and shell plate as fitted, in cm^3
	=	$(b_f \cdot t_{fn}^2/4 + b_{eff} \cdot t_{pn}^2/4)/1000$
b_f	=	flange breadth, in mm, see Section 2, Figure 4
t_{fn}	=	net flange thickness, in mm
	=	$t_f - t_c$ (t_c as given in 2/5.13)
t_f	=	as-built flange thickness, in mm, see Section 2, Figure 4
t_{pn}	=	fitted net shell plate thickness, in mm (not to be less than t_{net} as given in Subsection 2/7)
b_{eff}	=	effective width of shell plate flange, in mm
	=	$500 \cdot s$
Z_p	=	net effective plastic section modulus of transverse frame (calculated according to 2/9.15), in cm^3

AF, PPF_t, P_{avg}, LL, b, s, a and σ_y are as given in 2/11.3.

11.7

The scantlings of the frame are to meet the structural stability requirements of Subsection 2/17.

13 Framing – Side Longitudinals (Longitudinally-framed Vessels)

13.1

Side longitudinals 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.

13.3

The actual net effective shear area of the frame, A_w, as defined in 2/9.13, is to comply with the following condition: $Aw \geq A_L$, where:

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

where

AF	=	Hull Area Factor from Section 2, Table 3
PPF_s	=	Peak Pressure Factor from Section 2, Table 2
P_{avg}	=	average pressure within load patch according to 2/5.11.1, in MPa
b_1	=	$k_o \cdot b_2$, in m
k_o	=	$1 - 0.3/b'$
b'	=	b/s
b	=	height of design ice load patch from 2/5.9.1ii) or 2/5.9.2.ii), in m
s	=	spacing of longitudinal frames, in m
b_2	=	$b(1 - 0.25 \cdot b')$, in m if $b' < 2$
	=	s, in m if $b' \geq 2$
a	=	longitudinal design span as given in 2/9.9, in m
σ_y	=	minimum upper yield stress of the material, in N/mm^2

13.5

The actual net effective plastic section modulus of the plate/stiffener combination, Z_p, as defined in 2/9.15, is to comply with the following condition: $Z_p \geq Z_{pL}$, where:

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

where

A_4	=	$1/(2 + k_{wl} \cdot [(1 - a_4^2)^{0.5} - 1])$
a_4	=	A_L/A_w
A_L	=	minimum shear area for longitudinal as given in 2/13.3, in cm^2
A_w	=	net effective shear area of longitudinal (calculated according to 2/9.13), in cm^2
k_{wl}	=	$1/(1 + 2 \cdot A_{fn}/A_w)$ with A_{fn} as given in 2/9.15

AF, PPF_s, P_{avg}, b_1, a and σ_y are as given in 2/13.3.

13.7

The scantlings of the longitudinals are to meet the structural stability requirements of Subsection 2/17.

15 Framing – Web Frames and Load-carrying Stringers

15.1

Web frames and load-carrying stringers are to be designed to withstand the ice load patch as defined in Subsection 2/5. The load patch is to be applied at locations where the capacity of these members under the combined effects of bending and shear is minimized.

15.3

Web frames and load-carrying stringers are to be dimensioned so that the combined stresses of shear and bending are to be maintained within the acceptable limit (e.g., 95% of the σ_y). Where these members form part of a structural grillage system, appropriate methods of analysis are to be used. Where the structural configuration is such that members do not form part of a grillage system, the appropriate peak pressure factor (PPF) from Section 2, Table 2 is to be used. Special attention is to be paid to the shear capacity in way of lightening holes and cut-outs in way of intersecting members.

15.5

The scantlings of web frames and load-carrying stringers are to meet the structural stability requirements of Subsection 2/17.

17 Framing – Structural Stability

17.1

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

- For flat bar sections: $h_w/t_{wn} \leq 282/(\sigma_y)^{0.5}$
- 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, in N/mm^2

17.3

Framing members for which it is not practicable to meet the requirements of 2/17.1 (e.g., load-carrying stringers or deep web frames) are required to have their webs effectively stiffened. The scantlings of the web stiffeners are to ensure the structural stability of the framing member. The minimum net web thickness for these framing members is given by:

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

where

c_1 = $h_w - 0.8h$ mm

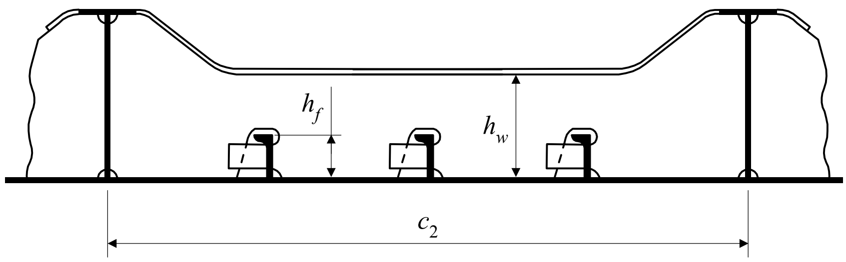
h_w = web height of stringer/web frame , in mm (see Section 2, Figure 5)

h = height of framing member penetrating the member under consideration (0 if no such framing member), in mm (see Section 2, Figure 5)

c_2 = spacing between supporting structure oriented perpendicular to the member under consideration, in mm (see Section 2, Figure 5)

σ_y = minimum upper yield stress of the material, in N/mm^2

FIGURE 5
Parameter Definition for Web Stiffening



17.5

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 material, in N/mm^2

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

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

17.7

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

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

ii) The flange outstand, b_{out}, in mm, shall meet the following requirement:

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

where

t_{fn} = net thickness of flange, in mm

σ_y = minimum upper yield stress of the material, in N/mm^2

19 Plated Structures

19.1

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

19.3

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.

19.5

The stability of the plated structure is to adequately withstand the ice loads defined in Subsection 2/5.

21 Corrosion/Abrasion Additions and Steel Renewal

21.1

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

21.3

The values of corrosion/abrasion additions, t_s, to be used in determining the shell plate thickness for each Polar Class are listed in Section 2, Table 4.

21.5

Polar Class vessels 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 4
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
Other Areas	2.0	2.0	2.0	3.5	2.5	2.0

21.7

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

23 Materials

23.1

Plating materials for hull structures are to be not less than those given in Section 2, Tables 6 and 7 based on the as-built thickness of the material, the Polar Ice Class notation assigned to the vessel and the Material Class of structural members given in Section 2, Table 5.

23.3

Material classes specified in 3-1-2/Table 2 of the *Steel Vessel Rules* are applicable to Polar Class vessels regardless of the vessel's length. In addition, material classes for weather and sea exposed structural members and for members attached to the weather and sea exposed shell plating of polar vessels are given in Section 2, Table 5. Where the material classes in Section 2, Table 5 and those in 3-1-2/Table 2 of the *Steel Vessel Rules* differ, the higher material class is to be applied.

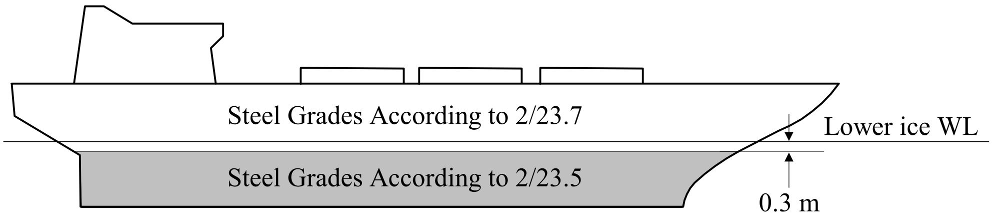
TABLE 5
Material Classes for Structural Members of Polar Class Vessels

Structural Members	*Material Class*
Shell plating within the bow and bow intermediate icebelt hull areas (B, BI_i)	II
All weather and sea exposed SECONDARY and PRIMARY, as defined in 3-1-2/Table 2 of the *Steel Vessel Rules*, structural members outside 0.4*L* amidships	I
Plating materials for stem and stern frames, rudder horn, rudder, propeller nozzle, shaft brackets, ice skeg, ice knife and other appendages subject to ice impact loads	II
All inboard framing members attached to the weather and sea-exposed plating including any contiguous inboard member within 600 mm of the shell plating	I
Weather-exposed plating and attached framing in cargo holds of vessels 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 3-1-2/Table 2 of the *Steel Vessel Rules*, structural members within 0.2*L* from FP	II

23.5

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 Section 2, Figure 6, are to be obtained from 3-1-2/Table 1 of the *Steel Vessel Rules* based on the Material Class for Structural Members in Section 2, Table 5 above, regardless of Polar Class.

FIGURE 6
Steel Grade Requirements for Submerged and Weather Exposed Shell Plating



23.7

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 Section 2, Figure 6, are to be not less than given in Section 2, Table 6.

TABLE 6
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
$t \le 10$	B	AH	B	AH	B	AH	B	AH	E	EH	E	EH	B	AH
$10 < t \le 15$	B	AH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
$15 < t \le 20$	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
$20 < t \le 25$	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
$25 < t \le 30$	D	DH	B	AH	E	EH2	D	DH	E	EH	E	EH	E	EH
$30 < t \le 35$	D	DH	B	AH	E	EH	D	DH	E	EH	E	EH	E	EH
$35 < t \le 40$	D	DH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
$40 < t \le 45$	E	EH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
$45 < t \le 50$	E	EH	D	DH	E	EH	D	DH	F	FH	F	FH	E	EH

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.

23.9

Steel grades for all inboard framing members attached to weather exposed plating are to be not less than given in Section 2, Table 7. This applies to all inboard framing members as well as to other contiguous inboard members (e.g., bulkheads, decks) within 600 mm of the exposed plating.

TABLE 7
Steel Grades for Inboard Framing Members Attached to Weather Exposed Plating

Thickness, t mm	PC1 - PC5		PC6 & PC7	
	MS	*HT*	*MS*	*HT*
$t \leq 20$	B	AH	B	AH
$20 < t \leq 35$	D	DH	B	AH
$35 < t \leq 45$	D	DH	D	DH
$45 < t \leq 50$	E	EH	D	DH

23.11

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

25 Longitudinal Strength

25.1 Application

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

25.3 Design Vertical Ice Force at the Bow

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

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

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

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 = $0.01A_{wp}$ MN/m

CF_L = Longitudinal Strength Class Factor from Section 2, Table 1

e_b	=	bow shape exponent which best describes the waterplane (see Section 2, Figures 7 and 8)	
	=	1.0	for a simple wedge bow form
	=	0.4 to 0.6	for a spoon bow form
	=	0	for a landing craft bow form
		An approximate e_b determined by a simple fit is acceptable	
γ_{stem}	=	stem angle to be measured between the horizontal axis and the stem tangent at the upper ice waterline , in degrees (buttock angle as per Section 2, Figure 2 measured on the centerline)	
C	=	$1/[2 \cdot (L_B/B)^{e_b}]$	
B	=	vessel molded breadth, in m	
L_B	=	bow length used in the equation $y = B/2 \cdot (x/L_B)^{e_b}$, in m (see Section 2, Figures 7 and 8)	
D	=	vessel displacement, in kt, not to be taken less than 10 kts	
A_{wp}	=	vessel waterplane area, in m^2	
CF_F	=	Flexural Failure Class Factor from Section 2, Table 1	

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

FIGURE 7
Bow Shape Definition

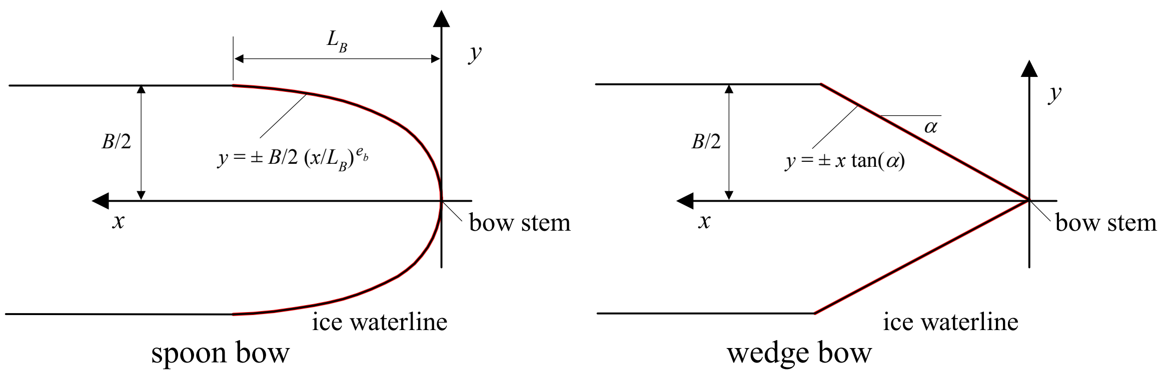
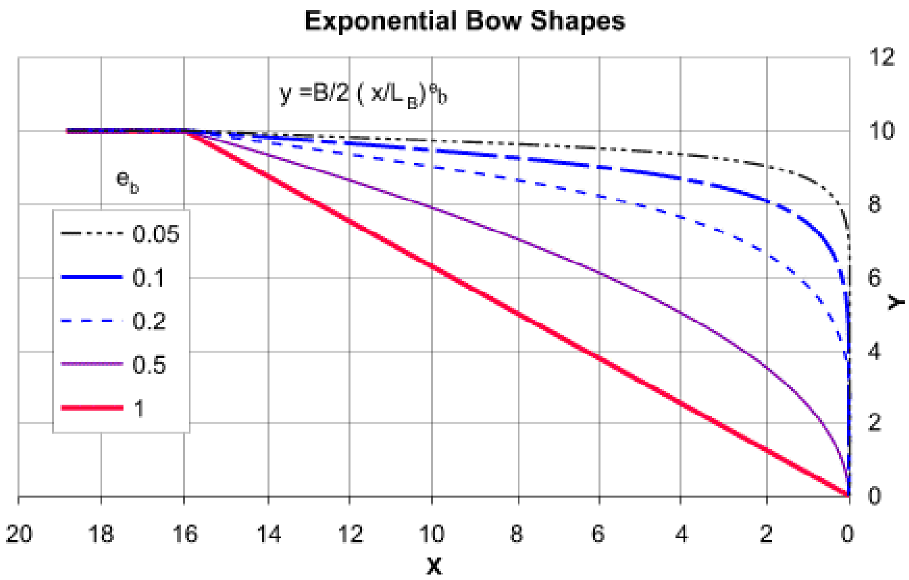


FIGURE 8
Illustration of e_b Effect on the Bow Shape for B = 20 and L_B =16



25.5 Design Vertical Shear Force

25.5.1

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

$$F_I = C_f \cdot F_{IB} \quad \text{MN}$$

where

C_f = longitudinal distribution factor to be taken as follows:

i) *Positive shear force*

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

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

ii) *Negative shear force*

C_f = 0.0 at the aft end of L

= -0.5 between 0.2L and 0.6L from aft

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

Intermediate values are to be determined by linear interpolation

25.5.2

The applied vertical shear stress, τ_a, is to be determined along the hull girder in a similar manner as in 3-2-1/3.9 of the *Steel Vessel Rules* by substituting the design vertical ice shear force for the design vertical wave shear force.

25.7 Design Vertical Ice Bending Moment

25.7.1

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

$$M_I = 0.1 \cdot C_m \cdot L \cdot \sin^{-0.2}(\gamma_{stem}) \cdot F_{IB} \quad \text{MN-m}$$

where

L	=	vessel length (Rule Length as defined in 3-1-1/3.1 of the *Steel Vessel Rules*), in m	
γ_{stem}	=	as given in 2/25.3	
F_{IB}	=	design vertical ice force at the bow, in MN	
C_m	=	longitudinal distribution factor for design vertical ice bending moment to be taken as follows:	
	=	0.0	at the aft end of L
	=	1.0	between $0.5L$ and $0.7L$ from aft
	=	0.3	at $0.95L$ from aft
	=	0.0	at the forward end of L
		Intermediate values are to be determined by linear interpolation	

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

25.7.2

The applied vertical bending stress, σ_a, is to be determined along the hull girder in a similar manner as in 3-2-1/3.7of the *Steel Vessel Rules* by substituting the design vertical ice bending moment for the design vertical wave bending moment. The vessel still water bending moment is to be taken as the maximum sagging moment.

25.9 Longitudinal Strength Criteria

The strength criteria provided in Section 2, Table 8 are to be satisfied. The design stress is not to exceed the permissible stress.

TABLE 8
Longitudinal Strength Criteria

Failure Mode	*Applied Stress*	*Permissible Stress when* $\sigma_y/\sigma_u \le 0.7$	*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	

TABLE 8 (continued)
Longitudinal Strength Criteria

where

σ_a	=	applied vertical bending stress, in N/mm^2
τ_a	=	applied vertical shear stress, in N/mm^2
σ_y	=	minimum upper yield stress of the material, in N/mm^2
σ_u	=	ultimate tensile strength of material, in N/mm^2
σ_c	=	critical buckling stress in compression, according to Appendix 3-2-A4 of the *Steel Vessel Rules*, in N/mm^2
τ_c	=	critical buckling stress in shear, according to Appendix 3-2-A4 of the *Steel Vessel Rules*, in N/mm^2
η	=	0.8

27 Stem and Stern Frames

The stem and stern frame are to be designed according to the requirements of 6-1-1/29 of the *Steel Vessel Rules*. For Polar Class **PC6** and **PC7** vessels requiring Ice Class **1AA**/**1A** Baltic Ice Class of Section 6-1-2 of the *Steel Vessel Rules* equivalency, the stem and stern requirements of the Finnish-Swedish Ice Class Rules may need to be additionally considered.

29 Appendages

29.1

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.

29.3

Load definition and response criteria are to be determined on a case-by-case basis.

31 Local Details

31.1

For the purpose of transferring ice-induced loads to supporting structure (bending moments and shear forces), local design details are to prepared and submitted for review.

31.3

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

33 Direct Calculations

33.1

Direct calculations are not to be utilized as an alternative to the analytical procedures prescribed in this unified requirement.

33.3

Where direct calculation is used to check the strength of structural systems, the load patch specified in Subsection 2/5 is to be applied.

35 Welding

35.1

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

35.3

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

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SECTION 3 Machinery Requirements for Polar Class Vessels

1 Application

The contents of Section 3 apply to main propulsion, steering gear, emergency and essential auxiliary systems essential for the safety of the vessel and the survivability of the crew

3 Drawings and Particulars to be Submitted

3.1 Environmental Conditions

Details of the environmental conditions and the required ice class for the machinery, if different from vessel's ice class.

3.3 Drawings

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.

3.5 Description Detailing

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.

3.7 Calculations and Documentation

Calculations and documentation indicating compliance with the requirements of Section 3.

5 System Design

5.1 Machinery and Supporting Auxiliary

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

5.3 Damage by Freezing

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

5.5 Propeller Damage

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

7 Materials

7.1 Materials Exposed to Sea Water

Materials exposed to sea water, such as propeller blades, propeller hub and blade bolts are to 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°C.

7.3 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°C.

7.5 Materials 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°C below the lowest design temperature,

9 Power of Propulsion Machinery

For Polar Classes **P7** through **P1**, the total ahead power delivered to the propellers, is to be sufficient for the vessel to maintain a design service speed under the ice conditions described in Section 3, Table 1, as related to the appropriate vessel notation.

An appropriate analytical approach or ice model testing results, are to be submitted for review. Where the design is in an early stage or ice model testing is not planned, the requirement for minimum power/astern power as specified in 6-1-1/31 of the *Steel Vessel Rules* may be used for an assessment of power of propulsion machinery, unless otherwise any specific methodology is provided by the cognizant authorities having jurisdiction over the water in which the vessel is intended to operate.

11 Ice Interaction Load

11.1 Propeller-Ice Interaction

This Guide covers 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 vessel's 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. This Guide applies 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 this Guide.

The loads given in Subsection 3/11 are total loads (unless otherwise stated) during ice interaction and are to be applied separately (unless otherwise stated) and are intended for component strength calculations only. The different loads given here are to be applied separately.

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

11.3 Ice Class Factors

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

TABLE 1
Design Ice Thickness and 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

where

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

11.5 Design Ice Loads for Open Propeller

11.5.1 Maximum Backward Blade Force

The maximum backward blade force, F_b, is to be taken as:

- when $D < D_{limit}$:

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

- when $D \geq D_{limit}$:

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

where

D_{limit} = $0.85 \cdot (H_{ice})^{1.4}$ m

n = nominal rotational speed (at MCR free running condition) for CP-propeller and 85% of the nominal rotational speed (at MCR free running condition) for 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

- *Load Case 1:* From 0.6*R* to the tip and from the blade leading edge to a value of 0.2 chord length.
- *Load Case 2:* A load equal to 50% of the F_b is to be applied on the propeller tip area outside of 0.9*R*.
- *Load Case 5:* For reversible propellers, a load equal to 60% of the F_b is to be applied from 0.6*R* 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 Section 3, Table 2.

11.5.2 Maximum Forward Blade Force

The maximum forward blade force, F_f, is to be taken as:

- when $D < D_{limit}$:

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

- when $D \geq D_{limit}$:

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

where

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

d = propeller hub diameter, in m

D = propeller diameter, in m

EAR = expanded blade area ratio

Z = number of propeller blades

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

- *Load Case 3:* From 0.6*R* to the tip and from the blade leading edge to a value of 0.2 chord length.
- *Load Case 4:* A load equal to 50 % of the F_f is to be applied on the propeller tip area outside of 0.9*R*.
- *Load Case 5:* For reversible propellers, a load equal to 60% of F_f is to be applied from 0.6*R* 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 Section 3, Table 2.

11.5.3 Maximum Blade Spindle Torque

Spindle torque Q_{smax} around the spindle axis of the blade fitting shall be calculated both for the load cases described in 3/11.5.1 and 3/11.5.2 for F_b and F_f. If these spindle torque values are less than the default value given below, the default minimum value to be used.

Default Value: $Q_{smax} = 0.25 \cdot F \cdot c_{0.7}$ kN-m

where

$c_{0.7}$ = length of the blade chord at 0.7R radius, in m

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

11.5.4 Maximum Propeller Ice Torque Applied to the Propeller

The maximum propeller ice torque applied to the propeller is to be taken as:

- when $D < D_{limit}$:

$$Q_{max} = 105 \cdot [1 - (d/D)] \cdot S_{qice} \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot \left[\frac{t_{0.7}}{D}\right]^{0.6} \cdot [nD]^{0.17} \cdot D^3 \quad \text{kN-m}$$

- when $D \geq D_{limit}$:

$$Q_{max} = 202 \cdot [1 - (d/D)] \cdot S_{qice} \cdot H_{ice}^{1.1} \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot \left[\frac{t_{0.7}}{D}\right]^{0.6} \cdot [nD]^{0.17} \cdot D^{1.9} \quad \text{kN-m}$$

where

D_{limit} = $1.81H_{ice}$ m

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

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

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

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

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

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

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

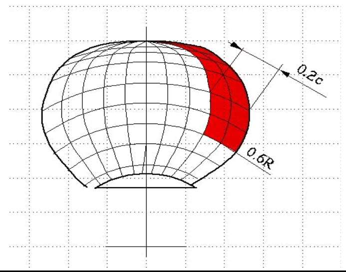
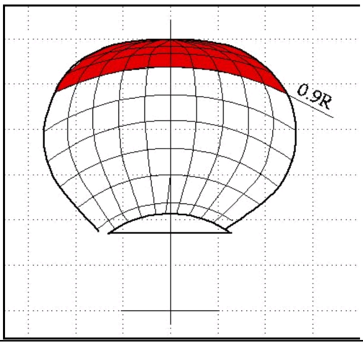
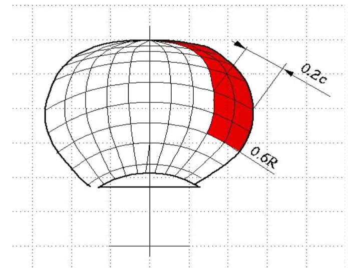
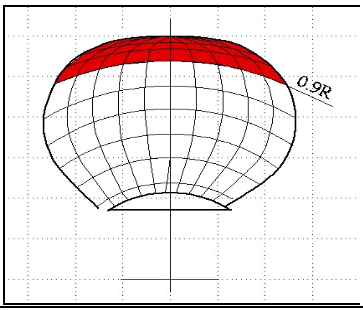
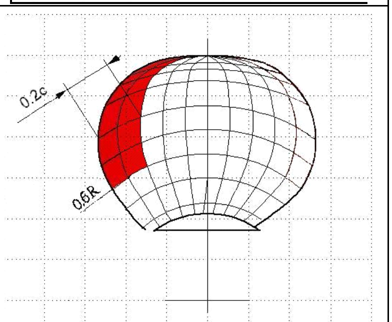
11.5.5 Maximum Propeller Ice Thrust Applied to the Shaft

The maximum propeller ice thrust applied to the shaft is to be taken as:

$T_f = 1.1 \cdot F_f$ kN

$T_b = 1.1 \cdot F_b$ kN

TABLE 2
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 whichever is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0.6R to the tip and from the trailing edge to 0.2 times the chord length	

11.7 Design Ice Loads for Ducted Propeller

11.7.1 Maximum Backward Blade Force

The maximum backward blade force, F_b, is to be taken as:

- when $D < D_{limit}$:

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

- when $D \geq D_{limit}$:

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

where

$$D_{limit} = 4H_{ice} \quad \text{m}$$

n is to be taken as in 3/11.5.1.

F_b is to be applied as a uniform pressure distribution to an area on the back side for the following load cases (see Section 3, Table 3):

- *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.
- *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.

11.7.2 Maximum Forward Blade Force

The maximum forward blade force, F_f, is to be taken as:

- when $D \leq D_{limit}$:

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

- when $D > D_{limit}$:

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

where

$$D_{limit} = \frac{2}{1-(d/D)} \cdot H_{ice} \quad \text{m}$$

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 Section 3, Table 3):

- *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.
- *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.

11.7.3 Maximum Propeller Ice Torque Applied to the Propeller

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

- when $D \le D_{limit}$:

$$Q_{\max} = 74 \cdot [1-(d/D)] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot \left[\frac{t_{0.7}}{D}\right]^{0.6} \cdot [nD]^{0.17} \cdot S_{qice} \cdot D^3 \quad \text{kN-m}$$

- when $D > D_{limit}$:

$$Q_{\max} = 141 \cdot [1-(d/D)] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot \left[\frac{t_{0.7}}{D}\right]^{0.6} \cdot [nD]^{0.17} \cdot S_{qice} \cdot D^{1.9} \cdot H_{ice}^{1.1} \quad \text{kN-m}$$

where

D_{limit} = $1.8H_{ice}$ m

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

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

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

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

11.7.4 Maximum Blade Spindle Torque for CP-mechanism Design

Spindle torque $Q_{s\max}$ around the spindle axis of the blade fitting is to be calculated for the load case described in 3/11.1. If these spindle torque values are less than the default value given below, the default value is to be used.

Default Value: $Q_{s\max} = 0.25 \cdot F \cdot c_{0.7}$ kN-m

where

$c_{0.7}$ = length of the blade chord at $0.7R$ radius, in m

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

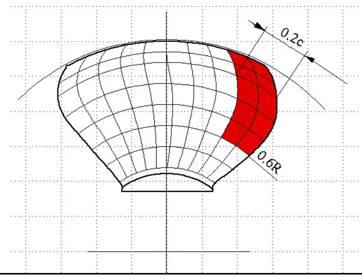
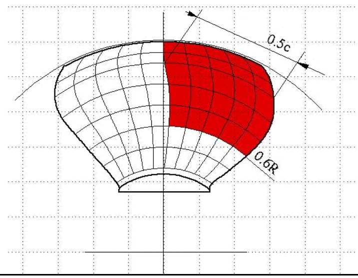
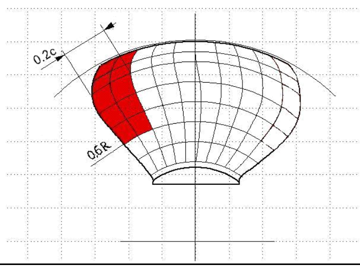
11.7.5 Maximum Propeller Ice Thrust (applied to the shaft at the location of the propeller)

The maximum propeller ice thrust (applied to the shaft at the location of the propeller) is:

$T_f = 1.1 \cdot F_f$

$T_b = 1.1 \cdot F_b$

TABLE 3
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 whichever is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0.6R to the tip and from the trailing edge to 0.2 times the chord length	

11.9 Design Loads on Propulsion Line

11.9.1 Torque

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

$$Q(\varphi) = C_q \cdot Q_{\max} \cdot \sin[\varphi(180/\alpha_i)] \qquad \text{when } \varphi = 0 \ldots \alpha_i$$

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

where C_q and α_i are parameters given in Section 3, Table 4 below.

TABLE 4
Parameters C_q and α_i

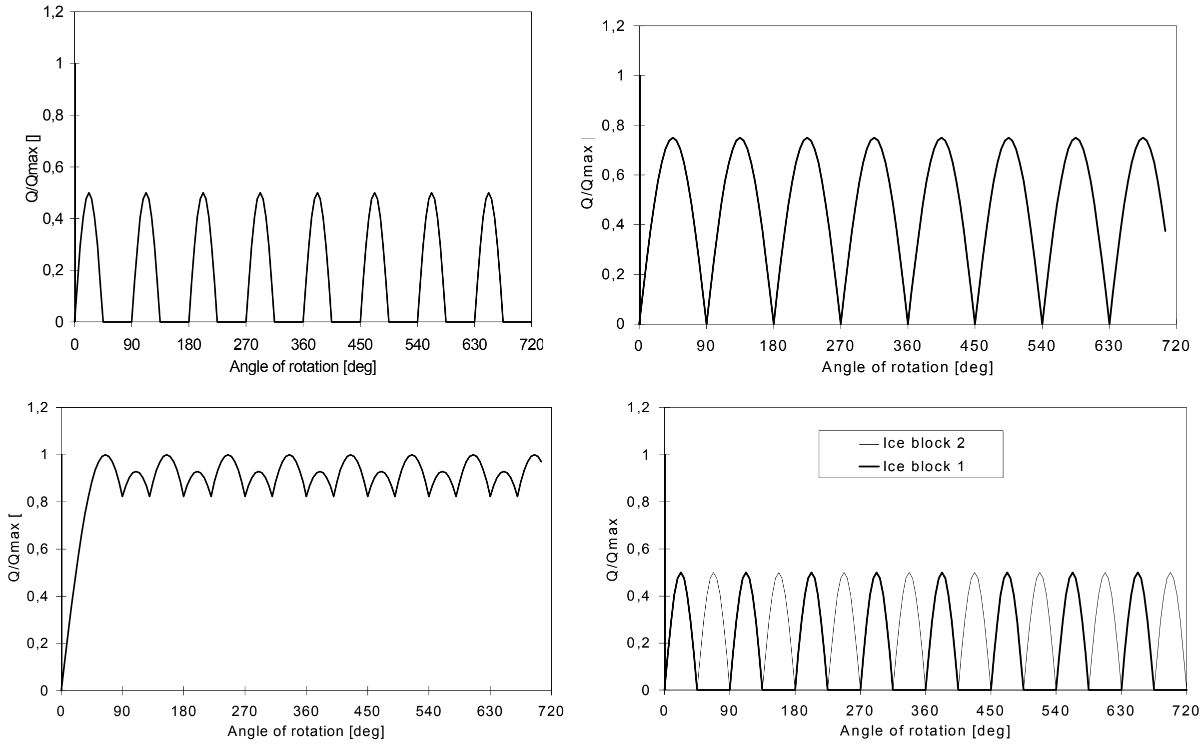
Torque Excitation	*Propeller-Ice Interaction*	C_q	α_i
Case1	Single ice block	0.5	45
Case2	Single ice block	0.75	90
Case 3	Single ice block	1.0	135
Case 4	Two ice blocks with 45 degree phase in rotation angle	0.5	45

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

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

The number of impacts is $Z \cdot N_Q$. See Section 3, Figure 1.

FIGURE 1
Shape of the Propeller Ice Torque Excitation for 45°, 90°, 135° Single Blade Impact Sequences and 45° Double Blade Impact Sequence(Two Ice Pieces) on a Four Bladed Propeller



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

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

Q_e = actual maximum engine torque at considered speed

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

11.9.2 Maximum Response Thrust

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

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

Maximum Shaft Thrust Backwards: $T_r = 1.5 \cdot T_b$ kN

where

T_n = propeller bollard thrust, in kN

T_f = maximum forward propeller ice thrust, in kN

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

TABLE 5
Propeller Bollard Thrust

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

where T is the nominal propeller thrust at MCR at free running open water conditions

11.9.3 Blade Failure Load for both Open and Nozzle Propellers

The force is acting at $0.8R$ in the weakest direction of the blade and at a spindle arm of $^2/_3$ of the distance of axis of blade rotation of leading and trailing edge which ever is the greatest.

The blade failure load is:

$$F_{ex} = \frac{0.3 \cdot c \cdot t^2 \cdot \sigma_{ref}}{0.8 \cdot D - 2 \cdot r} 10^3 \quad \text{kN}$$

where

σ_{ref} = $0.6\sigma_{0.2} + 0.4\sigma_u$

σ_u, $\sigma_{0.2}$ = representative values for the blade material

c = actual chord length

t = thickness of the cylindrical root section of the blade at the weakest section outside root fillet, typically at the termination of the fillet into the blade profile

r = radius of the cylindrical root section of the blade at the weakest section outside root fillet, typically at the termination of the fillet into the blade profile

13 Design

13.1 Design Principle

The strength of the propulsion line shall be designed

i) For maximum loads in Subsection 3/11

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

iii) With sufficient fatigue strength

13.3 Azimuthing Main Propulsors

In addition to the above requirements special consideration is to 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 vessel and the thrusters. In this respect, for example, the loads caused by impacts of ice blocks on the propeller hub of a pulling propeller must be considered. Also loads due to thrusters operating in an oblique angle to the flow must be considered. The steering mechanism, the fitting of the unit and the body of the thruster shall be designed to withstand the loss of a blade without damage. The plastic bending of a blade shall be considered in the propeller blade position, which causes the maximum load on the studied component.

Azimuth thrusters shall also be designed for estimated loads due to thruster body / ice interaction as per Subsection 2/29.

13.5 Blade Design

13.5.1 Maximum Blade Stresses

Blade stresses are to be calculated using the backward and forward loads given in 3/11.5 and 3/11.7. The stresses shall be calculated with recognized and well documented FE-analysis or other acceptable alternative method. The stress on the blade is not to exceed the allowable stresses σ_{all} for the blade material given below.

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

$$\sigma_{calc} < \sigma_{all} = \sigma_{ref}/S$$

where

S = 1.5

σ_{ref} = reference stress, defined as:

= $0.7\sigma_u$ or

= $0.6\sigma_{0.2} + 0.4\sigma_u$, whichever is less

σ_u, $\sigma_{0.2}$ = representative values for the blade material

13.5.2 Blade Edge Thickness

The blade edge thicknesses, t_{ed}, and tip thickness, t_{tip}, are to be greater than t_{edge} given by the following formula:

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

where

x = distance from the blade edge measured along the cylindrical sections from the edge and shall be 2.5% of chord length, however not to be taken greater than 45 mm. In the tip area (above 0.975R radius) x shall be taken as 2.5% of 0.975R section length and is to be measured perpendicularly to the edge, however not to be taken greater than 45 mm.

S = safety factor

= 2.5 for trailing edges

= 3.5 for leading edges

= 5 for tip

S_{ice} = according to 3/11.7.2

p_{ice} = ice pressure

= 16 Mpa for leading edge and tip thickness

σ_{ref} = according 3/13.5.1

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

13.7 Design Torque along Propeller Shaft Line

The design torque of the shaft component (e.g., shafts, gears, couplings), is to be determined by means of torsional vibration analysis of the propulsion line. Calculations are to be carried out for all excitation cases given above and the response has to be applied on top of the mean hydrodynamic torque in bollard condition at considered propeller rotational speed.

13.7.1 Propulsion Shafting Diameters

The diameters of the propulsion shafts are to be not less than that obtained from the following equation:

$$d = k_o \cdot k_1 \cdot \left(W \cdot T^2 \cdot \frac{U}{Y}\right)^{1/3} \quad \text{cm}$$

where

d = diameter of the shaft being considered, measured at its aft bearing, in cm

k_o = 1.05

k_1 = as given in Section 3, Table 6 below

W = expanded width of a cylindrical section measured at the blade section at the 0.25 radius for solid propellers with the propeller hub not larger than 0.25D and at the 0.35 radius otherwise, in cm

T = maximum thickness taken from the propeller drawing measured at the blade section at the 0.25 radius for solid propellers with the propeller hub not larger than 0.25D and at the 0.35 radius otherwise, in cm

U = tensile strength of the propeller material, in N/mm^2

Y = yield strength of the shaft steel, N/mm^2

TABLE 6
Propulsion Shaft Diameter Factor k_1

	Solid Propellers with Hubs	
	Not Larger than 0.25D	*Larger than 0.25D and CPP's*
Tail shaft	1.08	1.15
Tube shaft	1.03	1.10
Intermediate shaft(s)	0.87	0.95
Thrust shaft	0.95	1.01

Torsional vibration stresses in the propulsion shafting are to be evaluated based on criteria provided in 4-3-2/7.5 of the *Steel Vessel Rules.*

13.7.2 Reduction Gears

Pinions, gears and gear shafts are to be designed to withstand an increase in torque over that normally required for ice-free service. The following corrected ice torque (Q_i) is to be utilized in Section 4-3-1 of the *Steel Vessel Rules*.

$$Q_i = Q + C \cdot \left[\frac{Q_{max} \cdot I_H \cdot R^2}{I_L + I_H \cdot R^2} \right]$$

where

Q_i = ice corrected torque, in N-m

Q = torque corresponding to maximum continuous power, in N-m

Q_{max} = ice torque, as defined in 3/11.7.3 and 3/11.5.4, in kN-m

I_H = sum of mass moment of inertia of machinery components rotating at higher rpm (drive side), in kg-m^2

R = gear ratio (pinion rpm/gear wheel rpm)

I_L = sum of mass moment of inertia of machinery components rotating at lower rpm (driven side) including propeller with an addition of 30% for water, in kg-m^2

C = 1000

Where applicable, a vibratory torque, as resulting from the torsional vibration analysis, is to be accounted for in the gear strength evaluation.

13.7.3 Flexible Couplings

Torsionally flexible couplings are to be selected so that the ice-corrected torque, as determined in 3/13.7.2, does not exceed the coupling manufacturer's recommended rating for continuous operation. When the rotating speed of the coupling differs from that of the propeller, the ice-corrected torque is to be suitably adjusted for the gear ratio. If a torque-limiting device is installed between the propeller and the flexible coupling, the maximum input torque to the torque-limiting device may be taken as the basis for selecting the coupling, in lieu of the ice-corrected torque. Flexible couplings which may be subject to damage from overheating are to be provided with temperature-monitoring devices or equivalent means of overload protection with alarms at each engine control station.

Where applicable, a vibratory torque as resulting from the torsional vibration analysis should be accounted for in the coupling's power loss (heat generation) evaluation.

13.9 Prime Movers

13.9.1 Starting Capabilities

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

13.9.2 Heating Arrangements

Provisions are to 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 vessel.

13.9.3 Starting Devices and Energy

Emergency power units are to be equipped with starting devices with a stored energy capability of at least three consecutive starts at the design temperature in 3/13.9.2 above 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 is to be provided for an additional three starts within 30 min., unless manual starting can be demonstrated to be effective.

15 Machinery Fastening Loading Accelerations

15.1 Essential Equipment and Main Propulsion Machinery

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

15.3 Longitudinal Impact Accelerations

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

$$a_\ell = (F_{IB}/\Delta) \cdot \left\{ \left[1.1 \cdot \tan(\gamma + \varphi)\right] + \left[7 \cdot \left(\frac{H}{L}\right)\right] \right\} \quad \text{m/s}^2$$

15.5 Vertical Acceleration

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

$$a_v = 2.5 \cdot (F_{IB}/\Delta) \cdot F_X \quad \text{m/s}^2$$

where

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	

15.7 Transverse Impact Acceleration

Combined transverse impact acceleration, a_t, at any point along hull girder:

$$A_t = 3 \cdot F_i \cdot \frac{F_X}{\Delta} \quad \text{m/s}^2$$

where

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	
ϕ	=	maximum friction angle between steel and ice, normally taken as 10, in degrees	
γ	=	bow stem angle at waterline, in degrees	
Δ	=	displacement	
L	=	length between perpendiculars, in m	
H	=	distance from the water line to the point being considered, in m	
F_{IB}	=	vertical impact force, defined in 2/25.3	
F_i	=	total force normal to shell plating in the bow area due to oblique ice impact, defined in 2/5.5	

17 Auxiliary Systems

17.1 Machinery Protection

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.

17.3 Freezing

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

17.5 Vent and Discharge Pipes

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

19 Sea Inlets and Cooling Water Systems

19.1 Cooling Water Systems for Machinery

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

19.3 Sea Chests

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

19.5 Ice Boxes

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

19.7 Sea Inlet Valves

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

19.9 Vent Pipes

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

19.11 Sea Bays Freezing Prevention

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

19.13 Cooling Seawater Re-circulation

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.

19.15 Ice Boxes Access

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.

19.17 Openings in Vessel Sides

Openings in vessel 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 les 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.

21 Ballast Tanks

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.

23 Ventilation System

23.1 Air Intakes Location

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

23.3 Air Intakes Heating

Accommodation and ventilation air intakes are to be provided with means of heating.

23.5 Machinery Air Intakes

The temperature of inlets air provided to machinery from the air intakes is to be suitable for the safe operation of the machinery

25 Alternative Designs

As an alternative to Section 3, a comprehensive design study may be submitted and may be requested to be validated by an agreed test program.

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